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Pollutant Removal Efficiency and Seasonal Variation of a Storm Water Wetland BMP

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POLLUTANT REMOVAL EFFICIENCY AND SEASONAL VARIATION OF A STORM WATER WETLAND BMP

By

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Abstract

An existing dry detention basin on the campus of Villanova University was retrofitted to create a storm water wetland best management practice in 1998 (BMP). The site is designed to improve the water quality of water flowing through it as well as maintaining the original storm water detention controls. Grab samples were taken at four locations within the wetland during baseflow over the course of one year and analyzed for various pollutants. The sampled pollutants included reactive phosphorous, total phosphorous, total nitrogen, total suspended solids, total dissolved solids, dissolved zinc, lead, copper, and *Escherichia coli (E. coli)* bacteria.

The data was separated into seasonal groups and removal efficiencies were calculated in order to determine the effectiveness of the storm water wetland in removing the various pollutants during baseflow. Pollutant removal parameters for storm water BMPs are established for storm events, but baseflow comprises between approximately 40% and 60% of the total discharge at this wetland.

All of the nutrient parameters showed annual average removal efficiencies in excess of 50% removal. Reactive phosphorous (60%), total phosphorous (55%), and total nitrogen (70%) may not have met some of the targets established for storm event removals in a storm water wetland, but do prove that there is continued functionality from this type of BMP outside of its design parameters. Additionally, total suspended solids (TSS) displayed an annual average removal efficiency of 20%, well below the target for storm events, but lower inlet concentrations of TSS make it harder to see higher removal

efficiencies. Total dissolved solids do not show any removal during baseflow. Encouragingly, *E. coli* bacteria also showed a positive removal efficiency of 30%. All of these results further prove the usefulness of storm water wetlands where possible because of their additional functionality during low flow events.

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Figure 1.1 A view of the storm water wetland from the upstream (inlet) end looking downstream toward the outlet.

1.1 Introduction

The purpose of this study is to analyze the pollutant removal efficiency of a storm water wetland best management practice on the campus of Villanova University during times of baseflow. These pollutants include nutrients, solids, metals, and coliform bacteria. Specifically, this study will examine the removal efficiency for three parameters of nutrients, total nitrogen, total phosphorous, and orthophosphate, total and dissolved solids, three metals, zinc, lead, and copper, and coliform bacteria. Nutrients, solids, and metals are considered some of the most harmful pollutants to streams and aquatic life. Bacterial pollution is typically seen as a greater risk to human health when water is consumed. Previous research has evaluated many of these parameters during storm events, but not extensively during baseflow.

Villanova University is host to the Villanova Urban Storm water Partnership (VUSP), whose stated mission is to advance the evolving comprehensive storm water management field and to foster the development of public and private partnerships through research on innovative storm water management best management practices (bmps), directed studies, technology transfer and education. The unique role of the VUSP allows it to manage research on a variety of storm water management bmps on and around Villanova University's campus in Villanova, Pennsylvania.

One of the largest bmps on Villanova University's campus is the storm water wetland. The site was formerly managed as a dry detention pond and was retrofitted as a storm water wetland in October 1999 with funding from a Section 319 NPS Grant through the Pennsylvania Department of Environmental Protection. The site maintained its previous ability to mitigate peak flow reductions for the 2 – 100 year storms, while also gaining the ability to improve the water quality leaving the site. The project was selected as a US Environmental Protection Agency Section 319 Success Story, Volume III (US EPA 2002).

Previous studies have been conducted on Villanova University's storm water wetland (Rea 2004). However, those studies focused primarily on the wetland's efficiency in removing nutrients and solids during storm events, specifically addressing the "first flush" phenomenon of storm water runoff. It is significant to note that a large percentage of the discharge from this wetland comes from baseflow rather than storm water runoff.

1.2 Site Location

The project site is located on the campus of Villanova University. Villanova is located on the western edge of the city of Philadelphia. On Villanova's campus, the site is located east of the current law school buildings, which is located on the corner of County Line Road and Spring Mill Road (Figure 1.2.)

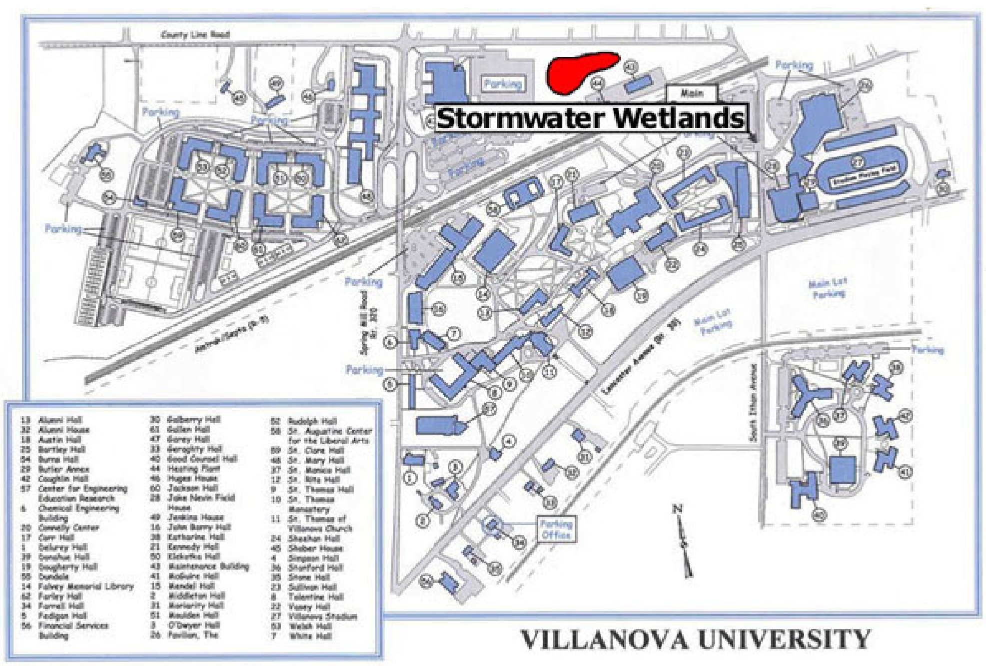

Figure 1.2 Campus map showing the location of the storm water wetland.

The project site is located in the headwaters of the Mill Creek watershed (Figure 1.3). Mill Creek is a tributary of the Schuylkill River and therefore ultimately the Delaware

River. Mill Creek is classified by the Pennsylvania Department of Environmental Protection's Chapter 93 Water Quality Classification as a Trout Stocked Fishery (TSF) (Commonwealth of Pennsylvania 2005). Mill Creek is also listed on the Pennsylvania Department of Environmental Protection's 303d List of Impaired Streams for not meeting one or more of its designated uses (Pennsylvania DEP 2004).

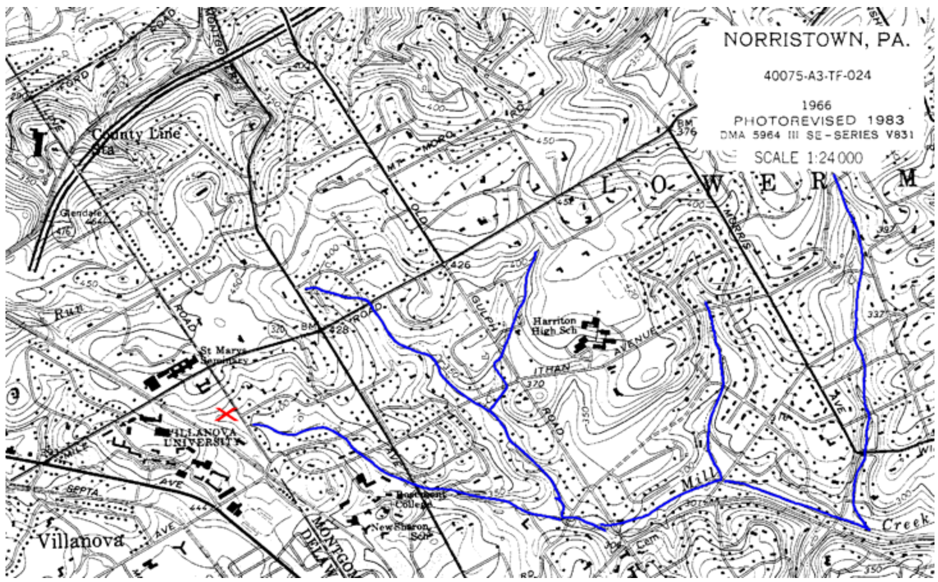

Figure 1.3 Topographic map depicting the location of Villanova University, the wetland site, and the rest of the Mill Creek watershed (streams outlined in blue.)

1.3 Site Description

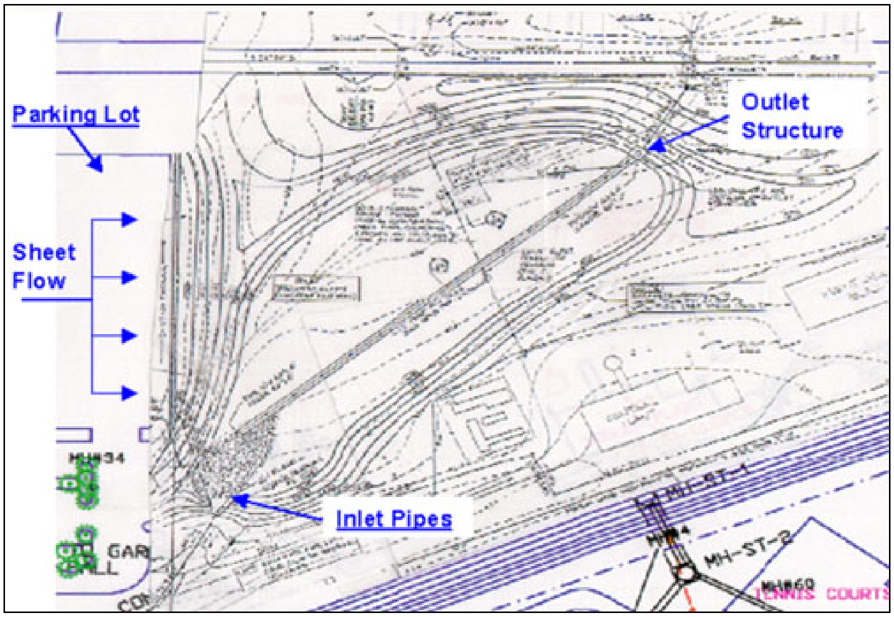

Figure 1.4 Plan view of the original dry detention basin on the campus of Villanova University.

The project site's original purpose was as a more traditional detention pond (Figure 1.4) for the treatment of storm water flows from Villanova University's main and west campuses, totaling approximately 40-acres of drainage area. In order to accomplish this objective, a dry detention pond was constructed at the site with an underdrain and three outlet structures designed to pass the 25, 50 and 100-year storms. Later inspection of the project site revealed that the underdrain contained flow throughout the year, leading to the conclusion that the detention pond must have been constructed on top of a number of small natural springs. The springs created a component of baseflow on the project site. Like most detention ponds, the site was maintained as mowed lawn by Villanova University's facilities management staff (Traver 2000).

In 1998, Villanova University redesigned the site as part of a Section 319 NPS Grant through the Pennsylvania Department of Environmental Protection. The redesign purpose was to remove the underdrain and make the baseflow an active portion of the wetland's function in order to create a storm water wetland. Villanova University followed design criteria outlined in "A Handbook of Constructed Wetlands, Storm water" during the redesign of the detention pond into the current storm water wetland (Davis 1995).

Detention ponds are designed to mitigate the impacts of increased peak flow rate resulting from storm water runoff. However, because of their design criteria, they are extremely ineffective in mitigating the water quality effects associated with storm water runoff. Villanova University believed the retrofitted storm water wetland would be able to achieve water quality improvements while not losing the site's overall ability to control peak flow rate. To achieve these objectives, many new features were designed to change the site's function from its original detention pond design to the desired storm water wetland including a sediment forebay, a meandering channel, and a reconstructed outlet structure.

1.3.1 Inlet Structures

The project site's original inlet structures were not altered during the redesign of the site into the current storm water wetland. There are two main inlet structures for the site. One inlet structure services approximately 25-acres of main campus and is 48-inches in diameter. The second inlet structure services approximately 15-acres of west campus and is 36-inches in diameter.

Each of these pipes, like the other locations discussed, is instrumented with samplers and probes, which are described below in the Materials and Methods Section, to provide the option of continuous and automated data collection. Data is collected at both of these locations for a number of water quality parameters to accurately assess the quality of water as it enters the storm water wetland. Because of the developed nature of Villanova University's campus, there are a large number of underground pipes throughout the area. Other issues may have been discovered regarding those pipes and are discussed in the conclusions section of this report.

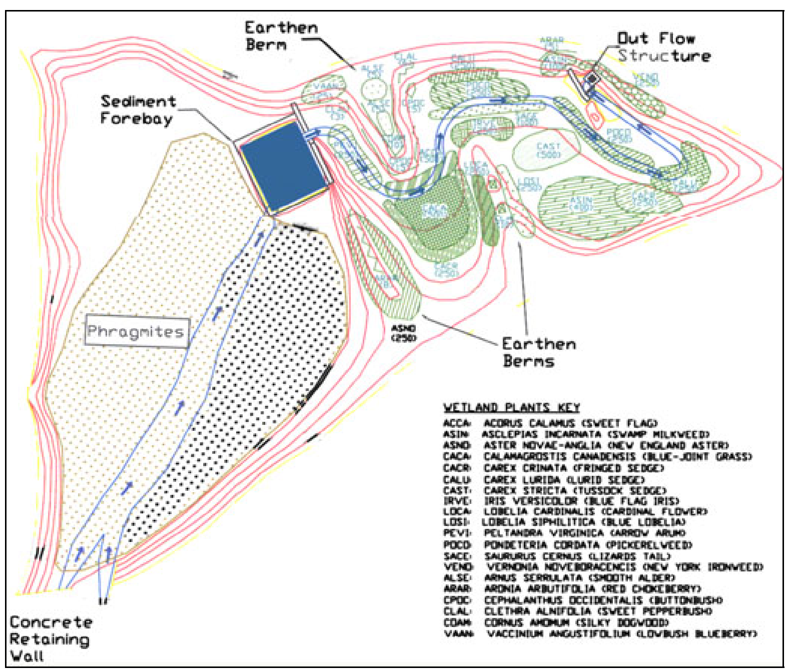

Figure 1.5 Plan view look at the design for the storm water wetland at Villanova University.

1.3.2 Sediment Forebay

As seen in Figure 1.5, once runoff leaves the inlet structures it flows as sheet flow in the general direction of the sediment forebay. Extreme storm event flows would likely not follow this path and instead would bypass the sediment forebay. The sediment forebay was constructed as part of the redesign of the dry detention pond into the storm water wetland. A sediment forebay is a pool of water whose purpose is to allow suspended particles to settle out of the water column as they are slowed within its structure.

The sediment forebay, as can be noted in Figure 1.5, was not placed directly in front of the inlet structures for the wetland. The design intention for offsetting the sediment forebay was to avoid constant turbulence in the sediment forebay and re-suspension of particles in the water column. To combat this concern, the sediment forebay was offset so that low-flows would be directed into it, but high (velocity) flows would move directly through the wetland, bypassing the sediment forebay. The sediment forebay is designed to hold 0.1-inches of runoff from the impervious surfaces of the watershed or roughly 0.05-inches of runoff over the entire watershed.

The sediment forebay was constructed using earthen material to form the sides, a concrete pad to form the base, and gabion baskets to form the downstream weir structure. The earthen material was taken from the excavation material created during the sediment forebay’s construction. The concrete pad was poured to form the base of the sediment forebay so that maintenance vehicles would be able to go into it in the future and remove excess sediment as necessary. The downstream side of the sediment forebay was constructed with gabion baskets and geotextile in a weir construction to regulate flow into the next portion of the storm water wetland. There are two steps to the gabion weir structure. The lower step passes up to the 2-year storm. The higher step passes the 10-year storm.

1.3.3 Meandering Channel

A wetland's ability to remove pollutants is directly proportional to the water's retention time in the wetland. As a result, Villanova University designed a length of meandering channel immediately downstream from the sediment forebay. Earthen material within the former dry detention pond was relocated to create a series of earthen finger-like berms to redirect flow. The design objective was to lengthen the flow path, maximize roughness, and maintain as flat a bottom as possible within the channel.

A longer flow path obviously increases retention time within the storm water wetland. Increased roughness, from the plants, along the flow channel serves a number of purposes. First, increased roughness promotes friction along the water-land surface interface, slowing the flow of water. Second, the water course more directly mimics natural conditions for plant growth and micro-habitat formation. The minimal channel slope was intended to promote lowered velocities.

1.3.4 Outlet Structure

The original dry detention pond's outlet structure contained numerous openings. First, there was an underdrain connected to the bottom of the outlet structure. Second, there was a rectangular weir, roughly midway up the overall outlet structure, designed to control the 25 and 50-year storms. Lastly, there was a final grated structure on the top of the overall outlet structure designed to discharge the 100-year storm.

Because the redesign of the dry detention pond was intended to improve the quality of the water leaving the site, but not its ability to alter the quantity of water leaving the site, the outlet structure was not removed. However, because the baseflow of the site was needed to create the storm water wetland, the outlet structure had to be altered to pond water, thus creating the wetland.

The redesign called for the underdrain to be removed, the water daylighted, which allowed the water to be ponded up within the storm water wetland. To achieve this objective, a berm was constructed in front of the outlet structure with gabion baskets and geotextile. The end of the berm was then finished with wooden 6-inch-by-6-inch timbers to create a smooth weir over which water flows into the outlet structure. The berm immediately in front of the outlet structure was placed at an elevation to pass the approximate 10-year storm.

1.3.5 Wetland Plantings

Because of the hydrologic profile of wetlands, only specific plant species are suited to survive within them. Wetland plants must be able to grow and thrive in low-flow, partial inundation, and complete flood conditions. A wetland's overall ability to remove pollutants from the water column is closely linked with the plant community's ability to either take up nutrients themselves or foster microbiological communities that can convert the pollutant to other forms.

Because of the plant community's importance to the overall function of the storm water wetland, a significant amount of time was spent developing a planting list and scheme for the site. Chuck Leeds, Villanova University's Chief Horticulturist, developed the planting list and overall scheme.

A great deal of concern was placed in using wetland plants that were not only appropriate for the hydrologic conditions at the site, but also their appropriateness in this region of the country. Native plant material is desirable for a number of reasons. First, plants that are native to an area are more likely to thrive there under the various conditions that they might encounter. In addition, there is less chance that these plants will be predisposed to out-compete other plant species because they have already evolved in conjunction with the other species of the area. However, as is the case when planting any site, the ultimate makeup of the plant community is heavily dependent on the community structure of the site's existing seed bank, airborne dispersion of seeds, and the local animal community's dispersion of seeds. This site was no different and has encountered significant intrusion of Phragmites and Cattails within the storm water wetland. While these plant species may not be as desirable aesthetically, they do seem to be hearty species capable of withstanding the rigors of a storm water wetland.

1.4 Baseflow Significance

To determine the significance of baseflow in the hydrologic makeup of the storm water wetland, flow data was studied from the flow meters located at the site (Table 1.1.) As can be seen in the table, data for the summer months had to be utilized from data recorded in the summer of 2003 because of equipment malfunctions in the summer of 2004 due to a lightning strike at the site. In all four calculation methods, the results are presented in terms of the percentage of baseflow in comparison with direct runoff (DRO) and baseflow as a percentage of the total discharge (Q) from the site. Direct runoff (DRO) is overland flow caused by excess precipitation that is not stored in depressions in the land, intercepted by overhead cover, evaporated into the air, transpired by plants, or infiltrated into the ground.

Month	Precipitation (in)	# Days	Total Area (acres)	Impervious Area (acres)	Baseflow Outlet Discharge (cfs)	Baseflow (acre feet)	Mean Outlet Discharge (cfs)
Jun-03	9.64	30	40	16	0.15	9.00	0.23
Jul-03	2.50	31	40	16	0.08	4.96	0.20
Aug-03	6.66	31	40	16	0.28	17.36	0.40
Sep-04	12.52	30	40	16	0.20	12.00	0.61
Oct-04	3.34	31	40	16	0.08	4.65	0.22
Nov-04	6.23	30	40	16	0.12	7.20	0.44
Dec-04	4.31	31	40	16	0.13	7.75	0.42
Jan-05	4.84	31	40	16	0.12	7.44	0.44
Feb-05	1.76	15	40	16	0.12	3.60	0.34
Mar-05	3.59	31	40	16	0.13	8.06	0.44
Apr-05	2.78	24	40	16	0.13	6.24	0.44
May-05	1.17	31	40	16	0.13	8.06	0.22
Avg.	4.95				0.14	8.03	0.37

Table 1.1 Detail of Data Used for Baseflow Calculations.

The first method employed utilized data obtained from the flow meters employed at the storm water wetland. Utilizing the calculated monthly mean flow at the outlet in comparison with the observed baseflow discharge at the wetland, it was possible to determine the percentage of direct runoff and total discharge that baseflow comprises (Table 1.2). The observed baseflow discharge was considered the monthly baseline discharge that existed frequently at a steady state type condition.

	Baseflow / Stormflow Comparison				
Month	Precipitation (in.)	**Baseflow (acre feet)**	**Stormflow-DRO (acre feet)**	**Baseflow % of DRO**	**Baseflow % of Total Q**
Jun-03	**9.64**	9.00	4.80	188%	65%
Jul-03	**2.50**	4.96	7.44	67%	40%
Aug-03	**6.66**	17.36	7.44	233%	70%
Sep-04	12.52	12.00	24.84	48%	33%
Oct-04	3.34	4.65	8.68	54%	35%
Nov-04	6.23	7.20	19.32	37%	27%
Dec-04	4.31	7.75	18.17	43%	30%
Jan-05	4.84	7.44	19.65	38%	27%
Feb-05	1.76	3.60	6.51	55%	36%
Mar-05	3.59	8.06	19.16	42%	30%
Apr-05	2.78	6.24	14.83	42%	30%
May-05	1.17	8.06	5.70	141%	59%
Avg.			13.05	82%	40%

Table 1.2 Baseflow Calculation Method 1.

The second method made use of regional evapotranspiration data simply divided by 12 months evenly to obtain a monthly evapotranspiration value. The regional evapotranspiration rate for southeastern Pennsylvania that was utilized was twenty-eight inches (Ehlke and Reed 1999.) Utilizing that data created a precipitation excess value that could be applied over the entire 40-acre watershed to generate a direct runoff value. The direct runoff value could then be used in comparisons between the baseflow discharge and total discharge values (Table 1.3.)

	ET Monthly Avg. (ET = 28"/12months)				
Month	Precipitation (in.)	**Precip Excess**	**Direct Runoff (acre feet)**	**Baseflow % of DRO**	**Baseflow % of Q**
Jun-03	**9.64**	7.31	24.36	37%	27%
Jul-03	**2.50**	0.17	0.56	893%	90%
Aug-03	**6.66**	4.33	14.42	120%	55%
Sep-04	12.52	10.19	33.96	35%	26%
Oct-04	3.34	1.01	3.36	139%	58%
Nov-04	6.23	3.90	12.99	55%	36%
Dec-04	4.31	1.98	6.59	118%	54%
Jan-05	4.84	2.51	8.36	89%	47%
Feb-05	1.76	0.59	1.98	182%	65%
Mar-05	3.59	1.26	4.19	192%	66%
Apr-05	2.78	0.45	1.49	419%	81%
May-05	1.17	0.00	0.00	NA	100%
Avg.			9.35	190%	59%

Table 1.3 Baseflow Calculation Method 2.

The third method utilized to calculate the significance of baseflow within the storm water wetland system utilized evaporation data, but rather than using a regional annual evapotranspiration, data was obtained from the Pennsylvania State University Climatological Center as to calculated evaporation rates for southeastern Pennsylvania. Utilizing the calculated evaporation rates, precipitation excess values were again calculated and applied over the entire watershed to obtain direct runoff values (Table 1.4).

	Calculated ET (Data from PSU Meteoroligical Data)				
Month	Precipitation **(in.)**	**Precip Excess**	**Direct Runoff (acre feet)**	**Baseflow % of DRO**	**Baseflow % of Q**
Jun-03	**9.64**	2.87	9.57	94%	48%
Jul-03	**2.50**	0.00	0.00	NA	100%
Aug-03	**6.66**	1.02	3.40	511%	84%
Sep-04	12.52	8.54	28.47	42%	30%
Oct-04	3.34	0.52	1.73	268%	73%
Nov-04	6.23	6.23	20.77	35%	26%
Dec-04	4.31	4.31	14.37	54%	35%
Jan-05	4.84	4.84	16.13	46%	32%
Feb-05	1.76	1.76	5.87	61%	38%
Mar-05	3.59	3.59	11.97	67%	40%
Apr-05	2.78	2.78	9.27	67%	40%
May-05	1.17	0.00	0.00	NA	100%
Avg.			10.13	104%	54%

Table 1.4 Baseflow Calculation Method 3.

The fourth method utilized for calculating the significance of baseflow did not use evaporation or evapotranspiration data at all. Instead, this method assumed that all monthly precipitation fell only on the estimated impervious area within the watershed in order to calculate direct runoff. Utilizing this calculation, comparisons could be made to the calculated baseflow discharge value used in all four methods (Table 1.5).

Month	No ET (Precip on Impervious Only) Precipitation (in.)	Direct Runoff (acre feet)	Baseflow % of DRO	Baseflow % of Q
Jun-03	**9.64**	12.85	70%	41%
Jul-03	**2.5**	3.33	149%	60%
Aug-03	**6.66**	8.88	195%	66%
Sep-04	12.52	16.69	72%	42%
Oct-04	3.34	4.45	104%	51%
Nov-04	6.23	8.31	87%	46%
Dec-04	4.31	5.75	135%	57%
Jan-05	4.84	6.45	115%	54%
Feb-05	1.76	2.35	153%	61%
Mar-05	3.59	4.79	168%	63%
Apr-05	2.78	3.71	168%	63%
May-05	1.17	1.56	517%	84%
Avg.		6.59	161%	57%

Table 1.5. Baseflow Calculation Method 4.

The goal in performing all four methods of calculation was to assess the importance of baseflow in storm water wetland systems. Interestingly, while none of the methods yield the exact same calculated percentages, all of the methods do depict the significance of baseflow when compared to the direct runoff (storm flows) and total discharge leaving the wetland. All four calculation methods show an annual average of baseflow of between 40% and 59% of the total wetland discharge. While stormwater wetlands are designed to mitigate many of the effects associated with the non-point source pollution generated by storm events, there is an additional benefit that can be observed from the baseflow component that constantly flows through these devices. Pollutants also exist in the influent of storm water wetland bmps during baseflow as well as storm events.

The significance of the baseflow discharge is even greater after an analysis of various pollutant inputs. The sources and consequences of non-point source pollution associated with storm water runoff have been well documented, but an equally significant water quality improvement can be associated with pollutant removal during baseflow. This study attempted to quantify this effect by regularly sampling the influent and effluent of the storm water wetland to determine the wetland's efficiency removing various pollutants: total nitrogen, total phosphorous, orthophosphate, total suspended solids, total dissolved solids, coliform bacteria, and metals.

1.5 Research Objective

The purpose of this study is to analyze the functional efficiency of a storm water wetland best management practice on the campus of Villanova University during times of baseflow. Research on storm water bmps typically focuses on the storm event itself as it passes through the device. However, a storm water wetland should contain some component of baseflow or extended flow. The periods of baseflow usually form a significant percentage of the wetland's total discharge. This research intends to characterize the efficiency of the storm water wetland to process various pollutants during baseflow events. Questions to be answered include: are nutrients reduced through the storm water wetland during baseflow?, are solids removed during baseflow or are they simply passed directly through wetland?, what is the rate of metals uptake throughout a wetland during baseflow? This research also explores a storm water wetland's role in microbiological contamination. Are storm water wetlands a source of microbiological contamination or can they help in reducing such pollution? These are but a few of the questions that this research will attempt to answer or at least provide a baseline set of observations on which future research can attempt to answer them.

Chapter 2 – Literature Review

2.1 Background

In the United States, the legislative birth of water pollution control began with the passage of the 1972 Water Pollution Control Act and the 1977 and 1983 amendments to the Clean Water Act (CWA). By the mid-1980's, these legislative efforts had lead to a sharp decline in the impact of point sources of pollution on water quality (Tsihrintzis and Hamid 1997). The decline of point sources of pollution such as municipal wastewater treatment plants and industrial water treatment facilities lead to a glaring source of pollution to receiving waters, non-point source pollution (NPS pollution). In 1984, the United States Environmental Protection Agency (US EPA) completed a report to Congress in which they declared that NPS pollution was a leading cause of remaining water quality impairment problems in the United States (US EPA 1984).

Later, in a 1988 report to Congress, the US EPA concluded that urban storm water runoff was the fourth most extensive cause of water quality impairment of rivers, and the third most extensive source of water quality impairment for lakes (US EPA 1990). Other studies also came to very similar conclusions over the next few years (Novotny 1991, Novotny and Olem 1994, and Lee and Jones-Lee 1994). Based on these widespread conclusions of the harmful impact of urban storm water runoff on the water quality of the United States' rivers and lakes, the US EPA issued in 1990 stringent regulations as part of the National Pollution Discharge Elimination System (NPDES) Storm Water Permit Program Regulations (Tsihrintzis and Hamid 1997).

Specific amendments to the Clean Water Act were actually made in 1987 creating a two phase program that created a comprehensive national program to address storm water discharges. Phase I of this program was officially publicized in November, 1990 (US EPA 2000). Phase I required NPDES permits for storm water discharges for priority sources such as medium and large municipal separate storm water sewer systems (MS4s). Medium and large municipal systems were classified as those servicing populations of approximately 100,000 people or more. The priority source category also included several categories of industrial activity and construction activity that disturbed five acres of land or more (US EPA 2000). Phase II of the program, announced in 1998, encompassed the smaller MS4 systems and construction activity between 1 and 5 acres of disturbed area.

Both Phase I and Phase II of the NPDES Storm Water Permit Program require the completion of a Storm Water Pollution Prevention Plan (SWPPP). In addition to a site description, the applying entity has been required as per this program to submit a site description as well as a description of the Best Management Practices (Bmps) designed for the site to mitigate erosion and sedimentation impacts, post-construction storm water management, and other controls (US EPA 2000).

Another main focus of the NPDES Storm Water Permit Program is illicit discharges. In addition to the pollutants associated with normal storm water runoff flows, many storm water discharges can contain additional pollutants from non-storm water sources, which are referred to as illicit discharges. The term illicit is used because MS4 systems are not designed to process or discharge wastes from such sources as sanitary sewer pipe systems, improperly functioning septic tanks, car washes, or industrial water treatment systems (US EPA 2000).

2.2 Best Management Practices

The development and implementation of the NPDES program has spurred many engineers, designers, planners, and other professionals to begin developing techniques and designs to mitigate the negative impacts of urban storm water runoff. A wide variety of different techniques have been developed over the years with varied effectiveness. These various techniques have been given the name Best Management Practices (Bmps) and are typically defined as control measures for slowing, retaining, and absorbing pollutants produced by surface runoff associated with non-point sources (Mandelker 1989). It has been proposed that an effective BMP design must contain six basic components of consideration for design (Schueler et al. 1992):

1) Runoff attenuation – focuses on the reduction of pollutants by minimizing the total volume of runoff.

2) Runoff conveyance – provides safe and effective transport of storm water to the BMP device with minimum disruption to the existing network.

3) Runoff pre-treatment – captures or traps large sediments before entering the BMP device to prevent excess sedimentation and therefore decreased storage volume.

4) Runoff treatment – the main purpose of the BMP device, to lower the pollutant levels of the storm water runoff.

5) System maintenance – realistic plan to maintain the long-term performance of the system.

6) Secondary impact mitigation – the unintended negative impact to surrounding or downstream areas such as groundwater contamination due to infiltration of pollutants or the discharge of thermal pollution from pond systems.

One effective BMP device design that has been developed is called a constructed wetland or storm water wetland. These structures have generally been described as large retention-based systems dominated by large shallow-depth water areas ideally suited for the establishment and natural growth of wetland species plants (Tsihrintzis and Hamid 1997). The design of these systems are intended to maximize pollutant removal through the settling, dilution, filtration, and biological uptake associated with a naturally occurring wetland complex (Metropolitan Washington Council of Governments 1992). Another added advantage to mimicking the natural characteristics of wetland complexes is the associated long-term sustainability of the wetland complex, both hydrologically and biologically.

Natural wetland systems, no matter what their specific type, have been described as nature's most effective flood-control and water-filtering device (Nebel and Wright 1998).

The ability of natural wetlands to improve water quality is a function of several chemical, biological, and physical mechanisms including sedimentation, filtration, adsorption, precipitation, decomposition, bacterial and plant metabolism, and natural die-off (Smith et al. 1993). Vegetation within a natural wetland physically slows flows and allows suspended particles to fall out of the water column. In addition, vegetation can take up nutrients and metals, which are sources of pollution within the system. Natural wetlands do encounter periods of increased and decreased efficiency, based on a number of factors such as precipitation, seasonal temperatures, and plant growth potential due to seasonal growth rates (Smith et al. 1993).

Specifically, Smith et al. (1993) noted that nutrient retention in natural wetlands fluctuates seasonally with the retention capacity greatest during the growing season. It was further noted that some time periods may result in a net export or release of nutrients. Dissolved constituents may experience their own trends in natural wetlands. Chlorides are often observed to pass through natural wetlands unaltered. Heavy metals on the other hand, often become immobilized in soils by adsorptive processes (Smith et al. 1993).

Because constructed wetlands are built with the intention of mimicking natural wetlands, many characteristics of constructed wetlands are taken from the observed conditions of natural wetlands. Storm water wetlands are not all alike though. Many different varieties of constructed wetland have been designed, especially as BMP devices to treat storm water runoff. For example, the New Jersey Department of Environmental Protection's storm water BMP manual specifically discusses two main types of constructed storm water wetland, pond wetlands and marsh wetlands. The descriptive term dictates which feature of the wetland is the dominant one. The manual outlines that the allocation of storm water runoff volume for a pond wetland should be 70% pool and 30% marsh. Conversely, a marsh wetland should have a storm water runoff volume allocation of 30% pool and 70% marsh (NJ DEP 2004). These percentages are approximations developed by the Center for Watershed Protection from research and are only intended as approximate guidelines for design purposes.

2.3 Dry Basins vs. Storm Water Wetlands

One of the primary bmps implemented since the mid-1970's has been dry storm water detention basins. These structures are constructed of earthen material in either an existing natural depression in the land or an excavated depression. The main function of dry detention basins has been to attenuate storm water runoff peaks (NJ DEP 2004). With the development of new designs for storm water wetlandes, there are significant differences between dry storm water detention basins and storm water wetlandes that must be discussed.

The Pennsylvania Department of Environmental Protection (PA DEP) BMP Manual (Draft 2005) does not even discuss dry storm water detention basin design any longer. Rather, the design parameters have been changed so that the basins are considered dry extended detention basins. The original design of dry detention basins was to mitigate peak discharge, as mentioned above. However, according the PA DEP BMP Manual, dry extended basins should be designed to drastically extend the holding time of water in the device, which should accomplish two additional functions. First, with an extended detention time, total volumes of infiltration and evapotranspiration will increase. Total volume lost to these two hydrologic components means that in addition to mitigating peak discharge, overall volume being released to the receiving water body is reduced, although potentially only minimally based on infiltration rates of soils, antecedent moisture content of the soil and regional evapotranspiration rates. The second additional benefit achieved with extended dry basins is also associated with the detention time. Additional residence time for the water within the basin leads to additional opportunities for water quality improvement as the water has a longer contact time with vegetation within the basin and the overall soil complex. A third benefit is greatly reduced small storm peak flows. According to the design parameters for dry extended basins listed in the PA DEP BMP Manual, the overall design should include a forebay to encourage sediment removal, a micropool downstream of the forebay to promote water quality improvements through contact with vegetation, and no low flow channels. Again, these design parameters are simply guidelines developed by the Center for Watershed Protection and are not specific design requirements.

Storm water wetlands, as they will be discussed here, are actually the hybridization of two independent storm water bmps listed in the PA DEP BMP Manual: wet pond/retention basin and a constructed wetland. The PA DEP BMP Manual defines a wet pond/retention basin as a storm water basin that includes a permanent pool for water quality treatment, additional storage capacity above the permanent pool, and one or more forebays. The distinctive feature of a wet pond is that the permanent pool is usually a large standing pool of water downstream of from a forebay and surrounded by vegetation. Because of the standing pool of water, wet pond/retention basins can be considered aesthetic attributes of a site and may provide some wildlife habitat benefits. The second part of our hybridized BMP is what the PA DEP BMP Manual terms a constructed wetland, and defines as a shallow marsh system planted with vegetation that are designed to treat storm water runoff. The distinguishing feature of constructed wetlands is the creation of a meandering channel throughout the system to increase retention time for pollutant removal as well as peak flow and total volume mitigation. Because the meandering channel design of constructed wetlands more closely mimics natural wetlands, wildlife habitat benefits are also much greater as well as the overall natural aesthetic value of the site.

The advantage of storm water wetland systems (the combination of a forebay, permanent pool, meandering channel design) in comparison with typical dry detention or even dry extended detention basins lies in three main attributes. First, storm water wetland systems can reduce peak flows and total volume of discharge with efficiency comparable to dry basins. Second, storm water wetlands have a greater capacity to remove pollutants and improve water quality because of drastically increased retention time and the integration of a more complete aquatic ecosystem, which is able to process more pollutants within the system. The third major benefit, and one that should not be overlooked in any discussion, is the improvement to overall site aesthetics and wildlife habitat that is possible with storm water wetland systems in comparison with dry detention basins. Dry detention basins have historically been constructed using turf grass, making them often appear as unkempt sewer collection sites as years pass and maintenance is ignored. The only requirement for a storm water wetland that may serve as an impediment to its installation is the need for a water source to create the permanent water surface required for the system's survival. Dry detention basins can easily be designed to function in dry weather conditions because they are typically planted with woody vegetation rather than emergent aquatic species.

2.4 Pollutants

As part of its requirements to the United States Environmental Protection Agency, each state's environmental protection body is responsible to assess all of its receiving waters and assign a designation based on the approximate quality of the surface water system. This assessment can be done either in smaller sections or for the entire watershed. The designation is built upon approximate levels of pollutants consistently seen in the water body. As such, most states also then establish standard levels of pollutants that must be met by each water quality designation. In most states, as is the case in Pennsylvania, the designation status of a water body can also influence the land use decisions made within that watershed.

The receiving stream immediately downstream from the storm water wetland discussed here is Mill Creek. Mill Creek has been designated by the Pennsylvania Department of Environmental Protection's Chapter 93 Water Quality Standards as a Trout Stocking

Fishery (TSF) (Commonwealth of Pennsylvania 2005). The PA DEP Chapter 93 Water Quality Standards set maximum levels of various pollutants that are permissible to meet the existing water quality designation.

2.4.1 Nitrogen and Phosphorous

Nitrogen comes in many forms in nature because the nitrogen cycle is one of the more complex natural systems. Many of the reactions in the nitrogen cycle are performed through microbially catalyzed oxidation-reduction reactions. For example, the most common reaction for nitrogen in an aerobic environment such as a wetland is for NH_4^+ to be oxidized by microorganisms to NO_3^- and for NO_3^- to then be ultimately reduced by microorganisms to N_2 , which is elemental nitrogen gas. This process is typically referred to as denitrification (Madigan 2003). The nitrogen gas is then released to the atmosphere, thus completing the nitrogen cycle by returning it to its atmospheric form (Snoeyink 1980).

Phosphorous is completely different from nitrogen because the large stores of phosphorous in nature are not located in the atmosphere, but rather in various rock and soil minerals (Nebel and Wright 1998). Phosphorous ions are only released when the rock and soil minerals are broken down and dissolved in water. Phosphorous ions are then adsorbed onto soil particles and can only be turned into usable, organic phosphate, through plant uptake (Nebel and Wright 1998). Phosphorous removal from a water body can only take place through adsorption to soil particles, precipitation out of a dissolved form into a solid form and the biological uptake through plants, and creation of organic phosphate (Shatwell and Cordery 1999). Because phosphorous does not have a gaseous stage, it then only completes its cycle when the organic phosphorous is returned to the soil when the plant dies.

Nitrogen and phosphorous are two pollutants that are also nutrients. Nutrients can pollute water bodies when they exist in abundance. Abundant levels of nitrogen, as well as phosphorous, can lead to higher than normal levels of algae growth in the water system, a well-documented condition called eutrophication (Boesch 2001). Then, as seasons change and the plant material settles to the bottom layers, decomposition takes place, which uses up valuable dissolved oxygen within the water body (Boesch 2001). The depressed dissolved oxygen levels then place stress on populations of fish and aquatic macro-invertebrates.

Specific studies have been conducted to track the nitrogen removal efficiencies of various wetland complexes. For example, Prior and Johnes (2002) tracked the removal efficiency of a natural wetland that sits immediately adjacent to a stream channel, in England, to determine whether nutrients were being removed by the wetland complex or the stream channel itself. They found that approximately 85% of total nitrogen and approximately 70% of total phosphorous was removed from the water flowing through the wetland under baseflow conditions. The study concluded that the wetland was the primary factor removing nutrients from the system and regulating the surface water quality at the site (Prior and Johnes 2002). The study also discusses its findings of seasonal variation for removal efficiency due to varied growth rates. At the storm water wetland at Villanova University, this is most likely tied to the varied vegetation growth rates during the different seasons experienced in the somewhat harsh southeastern Pennsylvania climate. In terms of phosphorous, the PA DEP BMP Manual estimates that wet ponds/retention basins remove approximately 60% of total phosphorous. It also estimates that constructed wetlands remove approximately 85% of total phosphorous (PA DEP 2005). This would result in a range of 60% - 85% removal of total phosphorous for our hybridized storm water wetland. All of the PA DEP BMP Manual estimates were based on independent research conducted on wet detention ponds and constructed wetlands (Mallin et. al 2002).

2.4.2 Suspended and Dissolved Solids

Suspended solids are typically considered dust and dirt that are either eroded from the land surface or are washed from impervious surfaces during precipitation events. Technically, suspended solids are classified as those particles in the water column that are 1.5 microns or larger. There are some pollutants such as metals in particular, that are associated with suspended solids,. The metals are adsorbed to the large particles and may settle along with the particle. Dissolved solids are typically smaller particles of soil that become dissolved in the water column once they have been either eroded off of the land surface, washed off of it during precipitation events, or simply erode from channel sides during baseflow. Because suspended solids are classified as those particles that are larger than 1.5 microns, dissolved solids are those particles that are smaller than 1.5 microns. Nutrients, nitrogen and phosphorous, typically adsorb to solids.

A number of studies have been conducted linking vegetation and increased sedimentation within wetlands. The studies have highlighted a number of factors that allow vegetation to increase the rate at which solid material falls out of the water column. The main basic influences of vegetation are reduced overall turbulence and reduced velocities within the wetland (Braskerud 2001). In addition, specific mechanisms associated with vegetation can aid in the removal of solid material. Vegetation can remove sediment in a number of ways: 1) particles flowing into stems and leaves, losing velocity and settling, 2) particles sticking to bio-film layers created by microorganisms on plant roots and stems, 3) sheltering particles from re-suspension, 4) microorganisms on plant roots producing organic matter that is sticky and promotes flocculation (Braskerud 2001).

The PA DEP BMP Manual estimates that wet ponds/retention basins remove approximately 70% of total suspended solids from incoming flows. It estimates that constructed wetlands remove approximately 85% of total suspended solids, but is based on removal efficiency during storm events (PA DEP 2005). This would presumably lead to an approximate range of solids removal of 70% - 85% for our hybridized storm water wetland. A study conducted on a wetland treating wastewater found similar ranges for the removal rates of solid materials (Mashauri *et al*. 2000).

2.4.3 Dissolved Metals

Samples for this research study were analyzed for the concentration of three metals in solution: zinc, Lead, and Copper. A search of previous studies did not uncover other studies that have analyzed metals concentrations in solution for a storm water wetland specifically. As such, the guiding parameters that will be used for the sake of comparison and analysis are the US EPA's federal drinking water standards for metals concentrations in solution. According to the US EPA's latest guidelines, there are primary drinking water standards for two of the metals measured in this study, Lead (0 ppb with an action level of 0.015 ppb) and Copper (action level of 1.3 ppb). Primary drinking water standards are enforceable levels that if not followed could pose serious health risks to human populations. According to the latest US EPA document, there is a secondary drinking water standard for the third metal sampled through this study, Zinc (5 ppm). Secondary drinking water standards are non-enforceable recommendations that are made based on deleterious impacts to human cosmetic conditions such as skin or tooth discoloration or aesthetic impacts to drinking water characteristics like taste, odor, and color (US EPA 2003).

The storm water wetland at Villanova University contains two predominant species of vegetation, Cattails (*Typha latifolia*) and Phragmites (*Phragmites australis*). This fact is relevant because another aspect of the research conducted on the storm water wetland at Villanova University is to measure the removal efficiency for the three metals mentioned earlier. Wetlands are believed to be natural sinks for metals. Metals retention is possible both through deposition and plant uptake (Goulet and Pick 2001). As such, it is important to analyze the studied relative removal efficiency of the two dominant vegetation types at the site.

Goulet and Pick (2001) studied the significance of cattails on the removal efficiency for metals within a wetland system. This study was conducted on four different constructed wetlands in Ontario, Canada to determine if cattails increased metals removal. The study concluded that the presence of cattails did not affect the concentration of metals in surface sediments (Goulet and Pick 2001). This is because the dominant method for metals retention in wetlands is through the deposition of particulate metals onto surface sediments (Goulet and Pick 2001).

Windham *et al*. (2004) studied the metals removal efficiency of Phragmites in comparison with a more native species, Spartina grass (*Spartina alterniflora*), in a Hackensack, New Jersey natural wetland. In metal contaminated wetlands, live as well as dead plant tissue can serve as sink for metals. For the most part, metals are stored in the roots of wetland plants, but a small amount can be translocated to the tissue of the leaves of the plant (Windham *et al.* 2004). Then, as dead plant material falls onto the surface of the wetland and decomposes, the metals in the resulting detritus can enter the food web. Over time, as more and more plant material decays, it can serve as a greater source of metals (Windham *et al.* 2004). Windham *et al.* concluded that Phragmites did not contribute any additional metals to the detritus it created than did the more native Spartina grass. As a result, it would seem that Phragmites offers similar metals uptake capacity to some native wetland species. The wetland studied in the Windham et al. research is a tidal wetland. Thus, the water conditions within the wetland would experience elevated salinity levels. The storm water wetland at Villanova University is not a tidal wetland, but does treat storm water runoff in a mid-Atlantic climate. This means snow and ice melting products are applied to the watershed, which elevate chloride levels within the wetland during most of the year (Rea 2004).

2.5 Coliform Bacteria

Another form of pollution that must be considered in surface water bodies is biological pollution. Biological pollution is a major concern because of the potential effect on humans through drinking water consumption or exposure to contaminated water through recreational activities in streams and other water bodies. The storm water wetland at Villanova University is no different. As mentioned, the wetland complex drains to a receiving stream that travels through highly suburbanized areas, creating a risk of recreational exposure to pollutant sources for humans.

Microbiological pathogens cause a variety of illnesses in humans, some more severe than others. Human exposure can take place in large quantities through drinking water consumption or in smaller quantities when the exposure occurs during recreational activities. Unfortunately, illness can be caused in humans through a minimum amount of exposure (Leclerc 2001). Microbial growth occurs when contaminated water is consumed and the organisms grow in the intestines of the host. The organisms are then discharged into the waste stream in fecal matter, which can then continue to infect hosts without detection or disinfection (Madigan 2003).

The most intensive monitoring has occured where the largest potential source of exposure can occur place, drinking water supplies. As such, water providers have been required to monitor and attempt to prevent microbiological contamination in drinking water supplies for a long time. However, as drinking water supplies have become adequately monitored, society has had the opportunity to begin exploring effective applications of microbiological sampling to ambient water quality conditions.

While developing microbiological sampling techniques, scientists began to realize there were a number of limitations to sampling every microorganism. Because of that, specific organisms needed to be found that showed distinct correlations to the incidence of pollution and illness in humans (Leclerc 2001). A number of different organisms have been used as indicators of water quality. Conventional science has seemed to settle on one specific group of organisms as indicators of pathogenic organisms, coliform bacteria. Coliform bacteria are defined as all aerobic and facultative aerobic, gram-negative, nonspore-forming lactose-fermenting bacteria. " Coliforms are used as indicators of water contamination because they commonly inhabit the intestinal tract of humans and other animals in large numbers. In general, we assume that the presence of coliform organisms in a water sample indicates fecal contamination and makes the water unsafe for human consumption" (Madigan 2001).

Within the group of coliform bacteria, there are a number of specific organisms that have been purported to be useful indicators of water quality. However, studies have indicated that there is no coliform that can function as a reliable indicator of all enteric pathogens (Leclerc 2001). Numerous studies have been conducted to determine the most wide ranging and effective indicator of water quality. Results have been varied, but the Environmental Protection Agency does offer recommended guidelines for sampling.

2.5.1 *E. coli* and Enterococcus

Escherichia coli (*E. coli*) has long served as an indicator of fecal pollution for a number of reasons. First, it is not normally pathogenic to humans, which limits exposure to those performing the sampling. In addition, it is present in water at much higher concentrations than the concentrations of the pathogens whose presence it is intended to predict. Like all indicator organisms, however, *E. coli* are of limited use in some particular situations. For example, recent studies have indicated that *E. coli* is not a reliable indicator organism in tropical and subtropical environments because it possesses the ability to reproduce in contaminated soils at temperatures usually found in these climates (Scott 2002). In addition, *E. coli* is not suitable as an indicator organism in marine environments because of its increased breakdown rate with increased exposure to sunlight (Noble 2003).

The enterococcus group of coliform bacteria is a subgroup of fecal streptococci and is made up of a total of five species. Enterococci have been successfully used as indicators of fecal pollution. In particular, as will be discussed later, they are specifically reliable in marine environments and recreational waters, both fresh and marine. However, one potential limitation does exist in the use of enterococcus as an indicator organism. It is known that reservoirs of the bacteria exist in the environment and that they can readily reproduce once they are introduced into an environment (Scott 2002).

2.5.2 Ambient Water Quality

Before beginning any further discussion about biological sampling to ensure the ambient water quality of surface water systems, it seems necessary to outline the US EPA's current guidelines. First, the US EPA only requires states and Native American Indian tribes to monitor biological indicators of water quality when the surface water is used for some sort of human recreational activity. Drinking water monitoring is the responsibility of the water provider. Similarly, monitoring biological indicator organism concentrations in industrial or municipal discharges is the responsibility of the discharging entity.

As part of its 2002 draft document entitled *Implementation Guidance for Ambient Water Quality Criteria for Bacteria*, the US EPA has encouraged states and Native American tribes to separate the monitoring of surface water recreational sites into two different categories, fresh recreational waters and coastal recreational waters. The US EPA has recommended the use of *E. coli* or enterococci as the basis of their water quality criteria for fresh recreational waters. However, for coastal (marine) recreational waters, the US EPA only recommends the use of enterococci as the basis for water quality criteria for bacteria (US EPA 2002).

The first recommendations for the use of indicator organisms to indicate water quality (in an ambient setting) came from the United States Department of the Interior in the form of the 1968 Federal Water Pollution Control Administration report. Within that report, a recommendation was made to use fecal coliforms as the indicator of water quality because limited research indicated a correlation between instances of fecal coliform presence and acute gastrointestinal illness in humans exposed to those waters. However, subsequent US EPA research was conducted to confirm these results (US EPA 2002).

The US EPA updated the 1968 Federal Water Pollution Control Administration recommendations with its detailed water quality criteria for bacteria in 1986. Within those recommendations, the US EPA cited a series of epidemiological studies that explored the relationship between acute gastrointestinal illness and the microbiological quality of waters used recreationally by swimmers. The results of those studies indicated that the presence of fecal coliforms does not have as strong a correlation to cases of gastrointestinal illness as some other possible organisms. Two indicator organisms, *E. coli* and enterococci, did exhibit strong correlations to the incidence of gastrointestinal illness in humans exposed to the water. As a result of these conclusions, the US EPA issued its *Ambient Water Quality Criteria for Bacteria – 1986* under Section 304(a) of the Clean Water Act recommending that *E. coli* and enterococci be used as indicator organisms rather than fecal coliforms (US EPA 2002). The recommended indicator organisms have not changed in the 2002 update from the original 1986 report.

As part of the 2002 updated report, the US EPA included documentation of the current states' ambient water quality parameters for indicator organisms within sampling programs. The purpose of the tables was to illustrate the variability of current practices from state to state throughout the country. However, for the purpose of this study, the quantitative parameter data can serve as a benchmark for the levels of *E. coli* observed at the storm water wetland. The closest geographic state following the US EPA recommendation of *E. coli* as the indicator of ambient fresh water quality is Ohio. Ohio has adopted the US EPA recommended standard of 126 colony forming units per 100 milliliters of sample (CFU/100 mL). This standard applies only to secondary human contact during recreation activities, which applies to activities such as boating, fishing, and swimming (US EPA 2002). Of interest is the fact that the state of Pennsylvania currently is still utilizing fecal coliform and total coliform levels as its standards for surface water quality through the Pennsylvania Code's Chapter 93 Water Quality Standards (2005 Pennsylvania Code). Hopefully, in the future the state of Pennsylvania will also adopt the US EPA's recommendation of utilizing *E. coli* as the recommended indicator organism for fresh water quality and enterococcus for marine water quality.

2.5.3 Alternative Indicator Organisms

Many studies have focused on the development of other indicator organisms to determine fresh surface water system quality, but with little success. For example, some studies have attempted to utilize *Giardia* spp. and *Cryptosporidium* spp. as indicators of fresh surface water quality. However, there has been extensive variation found between studies, seasonally, and based on the source of the pollution. The presence of sewage plants as opposed to agricultural activities within the sampled watershed impacted the observed incidence of pathogens (Horman 2004).

However, studies have shown distinct correlations between *E. coli* counts in a given watershed and the incidence of pathogens. The specific counts of *E. coli* seem to be less important to predicting the presence of pathogens than simply the presence or absence of *E. coli* (Horman 2004). The question remains then as to what other indicator organisms are being utilized in fresh water recreation systems and what their effectiveness has been in determining the presence of pathogenic microorganisms.

Researchers have noted outbreaks of waterborne illness in fresh water recreation systems where the mandated levels of fecal and total coliform, other popular indicator organisms, concentrations have been met. This has led to a widespread belief that measuring total coliforms and fecal coliforms are not reliable methods for determining the likelihood of the presence of pathogenic microorganisms (Scott 2002). Obviously, useful indicator organisms need to mimic the environmental persistence of the pathogens that they are intended to indicate. The exact survival rate of the indicator organism in the fresh water system does not have to exactly match that of its correlative pathogen, but it must at least survive in some concentration for a similar length of time as its related pathogen (Long 2003). *E. coli* have shown distinct positive correlation as an indicator of waterborne disease. In addition, enterococci have also shown strong correlation as an indicator of pathogen presence (Scott 2002).

Chapter 3 - Methods

3.1 Introduction

The purpose of this section is to describe the methods and setup involved in the collection and analysis of samples. The frequency of sampling and schedule within that sampling timeframe will be outlined and described. The instrumentation of the site and test procedures utilized to analyze the water quality of the site will be discussed in detail. In addition, the timing and method of data collection will be outlined for potential repetition in future studies. Data collection for this study was conducted for baseflow sampling from June 1, 2004 through May 30, 2005.

3.2 Sampling Schedule

For the purpose of this study, baseflow was defined as flows within the storm water wetland at least 12 hours after a precipitation event occurred. This determination was based on an average time required for storm water wetland hydrographs to return to stable flows at the inlets. Due to the extended detention time for water within the storm water wetland, increased flows at the outlet are not seen for approximately 2 - 3 hours after the peak flows are seen at the inlet, depending on the size and intensity of the storm.

Generally, sampling occurred twice a month on Wednesday mornings, but exceptions had to be made on a few select occasions due to storm events. As the study's purpose is to draw conclusions about the functionality of the storm water wetland from a seasonal perspective, the sample data has been divided into four periods: summer (June 1, 2004 – August 31, 2004), fall (September 1, 2004 – November 30, 2004), winter (December 1, 2004 – February 28, 2005), and spring (March 1, 2005 – May 30, 2005). Analysis has been conducted on data from each “season” and compared to each other as well as other experimental data to determine the storm water wetland’s relative efficiency to remove all of the pollutant parameters discussed.

3.3 Instrumentation and Setup

For the purposes of describing the sampling locations within this report, the Villanova storm water wetland site is divided into four separate areas: the main campus inlet, the west campus inlet, the sediment forebay, and the outlet. Each location is described in great detail as to its relevant instrumentation and sample collection procedures. For brevity, all parameters discussed were programmed to record data in 5-minute intervals.

3.3.1 Main Campus Inlet

The main campus inlet is a 42” pipe that conveys flows from the main campus of Villanova University. Its watershed consists of areas around Mendel Hall, Falvey Library, John Barry Hall, and Tolentine Hall. Of the 41 acres in the total watershed, approximately 25-27 come from the main campus pipe. In order to measure multiple variables at constant intervals, an American Sigma 950 Flow Meter has been installed for the main campus inlet pipe. It is housed in a waterproof lock box located above the inlet structure. The American Sigma 950 for the main campus inlet is programmed and outfitted to record data from an area / velocity bubbler probe and a rain gage (Figure 3.1.) It has also been equipped with an external modem. The lockboxes are wired to provide constant A/C power to all instrumentation, so that battery power is only required during power loss.

Figure 3.1 American Sigma 950 flow meter.

The rain gage attached to the main campus Sigma 950 is an American Sigma Model 2149 tipping bucket rain gage. It has been placed and leveled on a poured concrete surface at the headwaters of the wetland. The rain gage has been modified with external bird-wire placed along the edges to keep birds from perching and possibly clogging the spout.

In order to measure velocity and depth of flow in this pipe, it has been outfitted with an American Sigma area / velocity bubbler probe. The area / velocity probe uses two different forms of technology in order to measure both depth and velocity. A small air line is located within the probe's cable and is attached to the American Sigma 950. The 950 pumps air bubbles through this tube and into the flowing water of the pipe. The 950 then measures the pressure of the air bubble at the release point, and calculates the depth of the water from a calibration standard. Each area / velocity probe is calibrated at 6 month intervals. In order to measure velocity of the flowing pipe, the probe uses the Doppler Effect. By releasing a sound wave from one end of the probe, the Sigma 950 can measure the shift in its frequency as it moves away with the flow. Based on this shift, the 950 can calculate a velocity of the flowing water. The minimum default velocity is 0.05 feet per second for baseflow sampling purposes.

The external modem on the Sigma 950 is connected to phone lines that have been installed inside the lockboxes at the site. Each Sigma 950 has a unique phone number that can be called and programmed or downloaded from a remote location. American Sigma Insight v.5.01 software is used to connect and download data from each Sigma 950 unit. Data is stored in text form and is easily converted to Microsoft Excel spreadsheets for analysis.

3.3.2 West Campus Inlet

The second location setup for sampling and data recording is the west campus inlet. Villanova University's west campus consists of the law school, the law school parking lot, the nursing college, and the west campus apartments. The area of this watershed draining to the storm water wetland is approximately 14-16 acres. A 48" inch pipe conveys storm water from west campus into the wetland system. The west campus inlet has also been outfitted with its own American Sigma 950 Flow Meter. It has also been equipped with an area/velocity probe and an external modem. Details of these can be found above in the main campus section. Unlike the main campus inlet, however, the west campus pipe is equipped with probes to measure temperature, conductivity, and pH.

To measure conductivity, an American Sigma conductivity probe model number 3328 was installed. The probe measures the conductivity of the water by measuring the ability of a solution to conduct current. In solution, current flows by ion transport, therefore, an increase in ions means an increase in conductivity. The conductivity probe applies a potential difference between two probe electrodes of a known distance. The resulting current is proportional to the conductivity of the solution. The American Sigma probe more accurately measures conductance, the reciprocal of resistance, and is converted into conductivity by knowing the distance between the electrodes and the electrode surface area.

To measure pH, an American Sigma pH probe, catalog number 3328-89, was installed. This sensor operates in principle as if it contained two 'batteries' whose voltages are measured and transmitted by electronic amplifiers. One battery is formed by the ground electrode and the glass process electrode. The voltage of this battery is a function of the solution pH. The other battery is formed by the same ground electrode and the standard electrode which contains a pH electrode in a chemical standard of fixed pH value. The voltage of the second battery is subtracted from the voltage of the first battery. The result is a differential pH measurement, the final signal being that of a pH electrode in the process compared to a pH electrode in a chemical standard solution. A temperature sensitive resistor inside of the sensor automatically compensates the pH measurement for temperature variations by adjusting the output of the sensor.

3.3.3 Sediment Forebay

The third sampling site is referred to as the sediment forebay, which is discussed in the introduction section. The sediment forebay's Sigma 950 Flow Meter was removed from the sediment forebay prior to the beginning of this study because of a number of factors. First, the data obtained from the sediment forebay is less important for the overall determination of the storm water wetland's efficiency because it is located in the middle of the system and efficiency is based solely on influent versus effluent. Second, a number of problems with the Sigma 950 Flow Meters needed to be remedied since their original installation at the site. In order to troubleshoot those needs, non-functional

Sigma 950 Flow Meters often had to be swapped with functional units. As a result, a decision was made to remove the Sigma 950 Flow Meter from the sediment forebay so that a functional unit could be constantly maintained for immediate installation at the wetland site.

3.3.4 Outlet

The final sampling location is the outlet structure. Like all the other sites, the outlet is outfitted with an American Sigma 950 Flow Meter. This flow meter is located within a lockbox behind the outlet structure. The outlet 950 is equipped with an area / velocity bubbler probe, an external modem, a pH probe, a conductivity probe, and a dissolved oxygen probe. A special structure was built to house all the probes and the sampler tube (Figure 3.2).

Figure 3.2 Outlet outfitted with pH, conductivity, dissolved oxygen, and sampler.

3.4 Sample Collection Protocol

All samples collected for this study were grab samples collected at the four sites described earlier: main campus inlet (IM), west campus inlet (IW), sediment forebay (SF), and the outlet (O). The grab samples were collected immediately downstream from each inlet pipe at the main campus inlet and west campus inlet sites. The grab sample for the sediment forebay was collected at the gabion weir at the downstream end of the sediment forebay to characterize the flow leaving the sediment forebay. The outlet flow was characterized by taking a grab sample immediately upstream from the water flowing into the concrete outlet structure.

All grab samples were taken in 1-liter High Density PolyEthylene (HDPE) containers that were washed in a 10% HCl solution as per EPA recommendations. The samples were then taken to Villanova University's Civil and Environmental Engineering Water Resources Laboratory for analysis. Because of the location of the storm water wetland site on campus, the time from sample collection to the beginning of analysis was never more than 30 minutes. Analysis was typically completed within 24 hours of sample collection. Any samples that were not analyzed within 24 hours were preserved according to appropriate protocols. In the laboratory, a number of parameters were tested: total nitrogen, total phosphorous, orthophosphate, total suspended solids, total dissolved solids, and metals (zinc, lead, and copper). Separate samples were collected once a week for the coliform bacteria analysis. Weekly coliform samples collected during storm events were discounted from the analysis.

3.4.1 Analytical Methods - Nutrients Testing

Upon arrival in the laboratory, the samples were analyzed for the concentration of three parameters of nutrients: total phosphorous, orthophosphate, and total nitrogen. The total phosphorous test (Hach Method No. 8190) and the total nitrogen test (Hach Method No. 10071) are EPA approved. The nutrient analysis was conducted utilizing a Hach DR 4000 Spectophotometer unit.

A TenSette Pipette as well as serological pipettes were used to make accurate measurements when performing tests using this apparatus. For quality assurance purposes, the tips and serological pipettes were replaced between uses to prevent cross-contamination between samples.

The reactive phosphorus 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 after 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 phosphorus 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 a total of 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.

3.4.2 Analytical Methods – Solids Testing

Once the nutrient analysis was finished on each sample taken, the solids analysis was initiated. The first step was the total suspended solids (TSS) test. After the completion of the TSS test, 15 mL of sample was removed from the filtered sample for metals analysis. The remaining sample volume was then utilized for the total dissolved solids (TDS) test.

The Standard Methods procedure 2540D was followed for TSS analysis. Predetermined volumes of sample were filtered through 1.5 micron pore size filters. These filter papers were then transferred to pre-weighed tins and were dried at 105 degrees Celsius according to procedures outlined in the standard methods. Once completely heated and dessicated the tins were reweighed and the resultant difference of weight per unit volume gave the total suspended solids in units of mg/L. In areas of particularly clear water, such as the outlet structure, or during baseflow conditions, large volume of sample was needed. Maximum sample volume for our study was 1000 mL (1 L) because of sample container size. Early samples utilized volumes that were less than this maximum because of sample protocol development, but the majority of sample volumes were 1 L.

The Standard Methods (APHA, 1995) 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 ceramic evaporating dishes. The sample volume for the TDS test was typically 985 mL. The volume of the evaporation dishes for the TDS test is approximately 125 mL. Because of these facts, numerous refills of the evaporating dishes were necessary for the completion of the TDS test. The TDS test was typically completed within 72 hours of its initiation.

3.4.3 Analytical Methods – Dissolved Metals

As described, approximately 15 mL of sample was taken from the total sample volume following its filtration through the 1.5 micron filter paper for the TSS test prior to the TDS test for the purpose of conducting the dissolved metals analysis. The metals test sample was placed in a 50 mL HDPE container. As per EPA Method 7010, all metals sample containers were washed with 1:1 nitric acid (HNO_3). Metals samples were preserved with 70% HNO_3 and analyzed on a Perkin-Elmer 2380 Atomic Absorption Spectophotometer with its Graphite Furnace equipment. An auto-sampler unit was used in conjunction with the Graphite Furnace equipment to perform the sample analysis. A number of standard concentrations were run in conjunction with each sample set run in order to calculate the concentration of metals in solution using the absorbance values determined by the unit for that individual run. This calibration procedure was conducted for each group of samples analyzed.

3.4.4 Analytical Methods – Coliform Bacteria

Coliform bacteria sampling was performed once a week to provide a larger number of samples for analysis. Coliform bacteria sampling followed EPA-approved Method 10029 for Membrane Filtration of Coliforms, *Enterococci*, and Pseudomonas. Coliform samples were collected in autoclaved 125 mL HDPE containers and immediately diluted and analyzed at Villanova University's Civil and Environmental Engineering Water Resources Laboratory. All other equipment used in the dilution and filtration processes were also autoclaved each week prior to sampling and stored in wrapped foil for preservation of a sterile environment. Two dilutions were created (10^{-1} and 10^{-2}) and then filtered through a membrane filter. Once filtered, the samples were placed on a petri dish containing Hach's m-Coli Blue broth and incubated to foster growth. After the prescribed incubation time, the samples were removed from incubation, counted, and calculated in terms of colony forming units (CFU) per 100 mL of sample.

3.5 Statistical Analysis – t-test

For analysis purposes, a basic student's t-test was performed on the inlet and outlet data on a seasonal basis. A t-test assesses the statistical difference between the averaged values of two normally distributed groups. Once the t value is calculated, it can be used to consult a standard statistics t-test table that reports a correlating confidence interval of the significance between the data. In the application of the t-test for this analysis, the averaged inlet and outlet concentrations were calculated on a seasonal basis. The formula used to calculate the t value is shown below (Trochim 2002.) The t values and a complete listing of the confidence intervals can be found in any standard statistics textbook. For the purpose of this study, only confidence intervals greater than 50% will be considered significant. All confidence intervals below 50%, which is typically considered a correlation between the data that is purely chance, will be reported as <50%.

$$t = \frac{X_t - X_c}{(var_t/n_t + var_c/n_c)^{1/2}}$$

X_t = the mean of the treated sample (outlet)
X_c = the mean of the control (averaged inlet)
var_t = the variance of the treated sample (STD^2)
var_c = the variance of the control (STD^2)
n_t = number of treated samples
n_c = number of control samples

Chapter 4 - Results

4.1 Introduction

Results from the monthly sampling are presented on a seasonal basis and are grouped as they were in earlier sections. Results are presented in terms of the averaged inlet concentration (averaging the inlet main and inlet west), outlet concentration, and removal efficiency. Removal efficiency was calculated by dividing the change in the average seasonal concentrations by the average seasonal inlet concentration and is reported as a percentage. Individual removal efficiency data are discussed within each season’s pollutant sections, with summaries listed in the appendix.

An estimated loading calculation was also performed for each pollutant parameter based on the average seasonal concentration of each pollutant parameter and an average outlet baseflow discharge determined for each month based on recorded flow data. The average outlet baseflow discharge was observed using the five minute interval data measured by the Sigma 950 autosamplers located at the storm water wetland, as described earlier. Utilizing the average seasonal averaged inlet pollutant concentration in comparison with the average seasonal outlet pollutant concentration and the average outlet baseflow discharge, the loading calculation was a simple unit conversion in order to obtain total load removed per season. Results in the charts are also presented in terms of average seasonal inlet and outlet concentrations as well as an overall seasonal removal efficiency. The average seasonal removal efficiency is an average of the individual sampling events’ removal efficiencies. Each section will discuss and show the seasonal load removal data for specific pollutants. Refer to the appendix listed at the beginning of each season's section for the complete tables of load removal data.

4.2 Seasonal Data – Summer

There was a total of five sampling events throughout the summer of 2004. Due to supplies shortages, there were two sampling dates that were not tested for some pollutant parameters. The coliform bacteria sampling was conducted on a weekly basis rather than bi-weekly basis due to sampling staff availability, funding, and the desire to build up a large database for coliform bacteria levels within the storm water wetland during baseflow. The removal efficiencies for all pollutants were calculated for each sampling event as well as seasonally (averaged) for each pollutant type (Appendix A.)

4.2.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

Nutrients - Summer					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
Orthophosphate (df=4)	0.069	0.057	18%	-0.2820	<50%
Total Phosphorous (df=2)	0.11	0.09	22%	-0.7365	<50%
Total Nitrogen (df=3)	2.43	0.52	78%	-6.7062	99%

Table 4.1 Summary of Nutrients Data for Summer

There were no removal efficiency standards found for orthophosphate in previous research. There are, however, removal efficiency standards for total phosphorous. Previous research has indicated that total phosphorous should have an approximate removal efficiency of 70% for a storm water wetlands system during storm events. The average total phosphorous removal for the summer sampling period during baseflow events was 22%. As documented by previous research, the allocated target for total nitrogen removal in a storm water wetlands system is 85% for storm events. The average total nitrogen removal efficiency for the summer period of baseflow sampling was 78%.

During the summer period of baseflow sampling, the average orthophosphate and total phosphorous removal efficiencies showed removal of both pollutants. The average removal efficiency for orthophosphate was 42% (n = 5, df = 4, t = 0.2820, STD = 31%.) The average removal efficiency for total phosphorous was 26% (n = 3, df = 2, t = 0.7365, STD = 14%). With one outlying data point discounted in the summer, all of the removal efficiencies for total nitrogen for the summer period were between 71% and 97% (n = 4, df = 3, t = 6.7062, STD = 10% (without outlier).)

The average seasonal averaged inlet concentration for orthophosphate was 0.069 mg/L. The average seasonal outlet concentration for orthophosphate was 0.057 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 1 lbs. of orthophosphate removed in the storm water wetland during the summer sampling period. The average seasonal averaged inlet concentration for total phosphorous was 0.11 mg/L. The average seasonal outlet concentration for total phosphorous was 0.09 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 2 lbs. of phosphorous removed in the storm water wetland during the summer sampling period. The average seasonal averaged inlet concentration for total nitrogen was 2.43 mg/L. The average seasonal outlet concentration for total nitrogen was 0.52 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 123 lbs. of nitrogen removed in the storm water wetland during the baseflow of the summer sampling period.

4.2.2 Solids – TSS and TDS

Solids - Summer					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
TSS (df=2)	10.556	1.889	82%	0.9157	50%
TDS (df=2)	466.22	608.56	-31%	-4.0586	90%

Table 4.2 Summary of Solids Data for Summer

As documented by previous research, the allocated target for suspended solids is 70% - 85% for storm events. The purpose of this paper is to establish whether or not those efficiency standards continue to be met during baseflow conditions. There were no empirically derived target removal efficiencies found in any research for baseflow. In addition, a relationship will be discussed later in Chapter 5 between observed conductivity levels and total dissolved solids due to previous research on this storm water wetland.

During the summer period of baseflow sampling, the average total suspended solids removal was 82%, but there was a great deal of variability between the most efficient removal of 92% and an actual contribution of suspended solids on another sampling date (n = 3, df = 2, t = 0.9157, STD = 69%.) During the summer period of baseflow sampling, the average total dissolved solids removal efficiency did not actually show any removal at all and was a net input of dissolved solids (n = 3, df = 2, t = 4.0586, STD = 21%.)

The average seasonal averaged inlet concentration for total suspended solids was 10.56 mg/L. The average seasonal outlet concentration for total suspended solids was 1.89 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 558 lbs. of suspended solids removed in the storm water wetland during baseflow of the summer sampling period. The total dissolved solids data actually showed a net input of material to the system. The average seasonal averaged inlet concentration for dissolved solids was 466.22 mg/L. The average seasonal outlet concentration for dissolved solids was 608.56 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 9166 lbs. of dissolved solids added to downstream receiving water body from the storm water wetland during the summer sampling period.

4.2.3 Dissolved Metals

There was no dissolved metals analysis conducted during the summer period of baseflow sampling because the equipment used to analyze the metals concentration in solution was purchased during this period and required significant amounts of time to become operational and calibrated. Metals analysis commenced during the fall period of baseflow sampling. For the purposes of this report, dissolved metals analysis will be referred to as metals analysis.

4.2.4 Coliform Bacteria

As was mentioned in the previous literature review, there are no current guidelines for allowable levels of coliform bacteria removal in storm water wetlands. There are, however, recommended levels of coliform bacteria for surface water systems in the state of Pennsylvania under the Pennsylvania Code's Chapter 93 Water Quality Standards. Notably, the Pennsylvania standards have not been adjusted to be in line with the United States Environmental Protection Agency's recommended indicator organism species for coliform bacteria in fresh water systems, *E. coli*. As a result, the research results for this paper will be presented in terms of *E. coli* colony forming units per 100 milliliters of sample (CFU/100 mL). As mentioned in the literature review section, the closest state geographically to Pennsylvania, Ohio, that has adopted the US EPA's recommendation of utilizing *E. coli* as an indicator organism for fresh water bodies has an established standard for secondary human contact during recreation activities of 126 CFU/100mL.

During the summer sampling period, there was a total of 10 sampling events for the abundance of *E. coli* CFU. However, only 8 of those samples were utilized in calculating the seasonal average values because of storm events occurring too recent to the collection of the samples. Scheduling restraints caused all samples to be collected on a specific weekday predominantly. Therefore, throughout the various sampling seasons, sampling events that were too close in proximity to storm events were discounted. The seasonal removal efficiency of *E. coli* during the summer sampling period actually indicates a significant percentage net input of *E. coli* (n = 8, df = 7, t = 0.6622, STD = 221%).

4.3 Seasonal Data – Fall

There was a total of six sampling dates during the fall sampling period. In addition to all of the parameters that were sampled, metals were analyzed during the fall sampling period. Data for the fall sampling period are reported in the same manner as described for the summer sampling period for all parameters (Appendix B.)

4.3.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

Nutrients - Fall					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
Orthophosphate (df=5)	0.089	0.043	52%	-1.4904	80%
Total Phosphorous (df=5)	0.12	0.03	77%	-4.2583	97.50%
Total Nitrogen (df=5)	3.36	0.95	72%	-8.1076	99.90%

Table 4.3 Summary of Nutrients Data for Fall

During the fall period of baseflow sampling, the average orthophosphate and total phosphorous removal efficiencies showed removal of both pollutants. The average removal efficiency for orthophosphate was 52% (n = 6, df = 5, t = 1.4904, STD = 17%.) The average removal efficiency for total phosphorous was 77% (n = 6, df = 5, t = 4.2583, STD = 20%.) The average removal efficiency for total nitrogen during the fall sampling period was 72% (n = 6, df = 5, t =8.1076, STD = 4%.)

The average seasonal averaged inlet concentration for orthophosphate was 0.089 mg/L. The average seasonal outlet concentration for orthophosphate was 0.043 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 3 lbs. of orthophosphate removed in the storm water wetland during the fall sampling period. The average seasonal averaged inlet concentration for total phosphorous was 0.12 mg/L. The average seasonal outlet concentration for total phosphorous was 0.03 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 6 lbs. of phosphorous removed in the storm water wetland during the fall sampling period.The average seasonal averaged inlet concentration for total nitrogen was 3.36 mg/L. The average seasonal outlet concentration for total nitrogen was 0.95 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 153 lbs. of nitrogen removed in the storm water wetland during the fall sampling period.

4.3.2 Solids – TSS and TDS

Solids - Fall					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
TSS (df=5)	5.211	1.533	71%	-1.4598	60%
TDS (df=5)	454.35	457.51	-1%	0.1137	<50%

Table 4.4 Summary of Solids Data for Fall

The average removal efficiency of total suspended solids during the fall sampling period was 71% (n = 6, df = 5, t = 1.4598, STD = 76%.) As can be seen in the statistical analysis of this data, there was a great deal of variation of the data throughout the sampling period. Similar to the variation seen during the summer sampling period, the removal efficiency of total suspended solids ranged from a maximum of complete removal, 100%, to an actual input of suspended material. Overall though on average, the storm water wetland continued to remove suspended solid material during baseflow events. During the fall period of baseflow sampling much like the summer sampling period, the average total dissolved solids removal efficiency did not show any removal, but rather displayed a net input of dissolved solids (n = 6, df = 5, t = 0.1137, STD = 9%.) The net input observed during the fall sampling period was a much less significant percentage of the influent concentration, however.

The average seasonal averaged inlet concentration for total suspended solids was 5.21 mg/L. The average seasonal outlet concentration for total suspended solids was 1.53 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 234 lbs. of suspended solids removed in the storm water wetland during the fall sampling period. The total dissolved solids data showed a net input of material to the system. The average seasonal averaged inlet concentration for dissolved solids was 454.35 mg/L. The average seasonal outlet concentration for dissolved solids was 457.51 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 201 lbs. of dissolved solids added to the downstream receiving water body from the storm water wetland during the fall sampling period.

4.3.3 Dissolved Metals

Metals - Fall					
Pollutant	**Avg. Inlet Conc. (μg/L)**	**Avg. Outlet Conc. (μg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
Zinc (df=2)	73.35	27.16	63%	-1.4172	60%
Lead (df=2)	1.81	0.92	49%	-1.0922	60%
Copper (df=2)	25.07	0.87	97%	-1.6848	80%

Table 4.5 Summary of Dissolved Metals Data for Fall

Metals sampling commenced during the fall sampling period. A total of three samples was analyzed for metals concentration in solution for the fall sampling period. Unfortunately, there are no current guidelines about expected removal efficiencies in storm water wetlands during storm events or baseflow. Therefore, the only basis for analysis will have to be the data mentioned in the literature review section about current drinking water standards.

Among the three samples that were analyzed for metals concentration, the average removal efficiency was 63% for zinc, 49% for lead, and 97% for copper during the fall sampling period. However, the average inlet and outlet concentrations should be noted in addition to the removal efficiency. The average inlet concentrations of each metal were 73.35 ppb, 1.81 ppb, and 25.07 ppb respectively for the fall sampling period. More interestingly, the average outlet concentrations for the fall sampling period were 27.16 ppb, 0.92 ppb, and 0.87 ppb respectively. This means that zinc is well within the EPA's recommended secondary drinking water standard at the outlet of the wetland (although it was below at the inlet as well) during the fall sampling period. In addition, the storm water wetland removed a sufficient amount of copper during the fall sampling period to bring it from non-compliance with drinking water standards to within compliance on average. The only metal sampled that was not brought within compliance was lead. There were no sampling events during the fall sampling period in which the lead concentration at the outlet met drinking water standards.

The average seasonal averaged inlet concentration for zinc was 73.35 ppb. The average seasonal outlet concentration for zinc was 27.16 ppb. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 3 lbs. of zinc removed in the storm water wetland during the fall sampling period. The average seasonal averaged inlet concentration for lead was 1.81 ppb. The average seasonal outlet concentration for lead was 0.92 ppb. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded no calculable pounded total load of lead removed in the storm water wetland during the fall sampling period. The average seasonal averaged inlet concentration for copper was 25.07 ppb. The average seasonal outlet concentration for copper was 0.87 ppb. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 2 lbs. of copper removed in the storm water wetland during the fall sampling period.

4.3.4 Coliform Bacteria

During the fall sampling period, there was a total of 11 sampling events for the abundance of *E. coli* CFU. However, only 10 of those samples were utilized in calculating the seasonal average values because of one storm event occurring too recent to the collection of the samples. Unlike the seasonal removal efficiency of *E. coli* during the summer sampling period, the fall sampling period indicated a significant removal of *E. coli* from the storm water wetland system with an average removal efficiency of 91% (n = 10, df = 9, t = 1.9223, STD = 52%). There were only 2 sampling events that indicated a net input of *E. coli* bacteria out of the total of 10 collected and utilized for statistical analysis. There was also a much lower standard deviation value as a result of the more consistent results observed during the fall sampling period in comparison with the summer sampling period.

4.4 Seasonal Data – Winter

There was a total of five sampling dates during the winter sampling period. Data for the winter sampling period is reported in the same manner as described for the fall sampling period for all parameters, including metals (Appendix C.)

4.4.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

Nutrients - Winter					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
Orthophosphate (df=4)	0.154	0.032	79%	-1.3609	60%
Total Phosphorous (df=4)	0.24	0.13	46%	-2.1493	90%
Total Nitrogen (df=4)	2.97	1.12	62%	-4.6945	99%

Table 4.6 Summary of Nutrients Data for Winter

During the winter period of baseflow sampling, the average orthophosphate and total phosphorous removal efficiencies showed removal of both pollutants. The average removal efficiency for orthophosphate was 79% (n = 5, df = 4, t = 1.3609, STD = 30%.) The average removal efficiency for total phosphorous was 46% (n = 5, df = 4, t = 2.1493, STD = 23%.) The average removal efficiency for total nitrogen during the winter sampling period was 62% (n = 5, df = 4, t = 4.6945, STD = 24%.)

The average seasonal averaged inlet concentration for orthophosphate was 0.154 mg/L. The average seasonal outlet concentration for orthophosphate was 0.032 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 8 lbs. of orthophosphate removed in the storm water wetland during the winter sampling period. The average seasonal averaged inlet concentration for total phosphorous was 0.24 mg/L. The average seasonal outlet concentration for total phosphorous was 0.13 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 7 lbs. of phosphorous removed in the storm water wetland during the winter sampling period. The average seasonal averaged inlet concentration for total nitrogen was 2.97 mg/L. The average seasonal outlet concentration for total nitrogen was 1.12 mg/L.

Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 117 lbs. of nitrogen removed in the storm water wetland during the winter sampling period.

4.4.2 Solids – TSS and TDS

Solids - Winter					
Pollutant	**Avg. Inlet Conc. (mg/L)**	**Avg. Outlet Conc. (mg/L)**	**Avg. Removal Efficiency**	**t**	**Confidence Interval**
TSS (df=4)	1.805	1.040	42%	-0.9491	60%
TDS (df=4)	813.10	930.02	-14%	0.3138	<50%

Table 4.7 Summary of Solids Data for Winter

The average removal efficiency of total suspended solids during the winter sampling period was 42% (n = 5, df = 4, t = 0.9490, STD = 218%.) As can be seen in the statistical analysis of this data, there was a great deal of variation between the data throughout the sampling period. Similar to the variation seen during the summer and fall sampling periods, the removal efficiency of total suspended solids ranged from a maximum of complete removal, 100%, to a significant input of suspended material. It is noteworthy that there was only one sampling event that showed a net input of suspended material, but it was such a significant net input that it skewed the standard deviation for the seasonal sampling period. During the winter period of baseflow sampling much like the summer and fall sampling periods, the average total dissolved solids removal efficiency did not show any removal at all and rather displayed a net input of the influent dissolved solids (n = 5, df = 4, t = 0.3138, STD = 77%.)

The average seasonal averaged inlet concentration for total suspended solids was 1.80 mg/L. The average seasonal outlet concentration for total suspended solids was 1.04 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 48 lbs. of suspended solids removed in the storm water wetland during the winter sampling period. The total dissolved solids data again showed a net input of material to the system. The average seasonal averaged inlet concentration for total dissolved solids was 813.10 mg/L. The average seasonal outlet concentration for total dissolved solids was 930.02 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 7366 lbs. of total dissolved solids added to downstream receiving water body from the storm water wetland during the winter sampling period.

4.4.3 Dissolved Metals

Metals - Fall

Pollutant	Avg. Inlet Conc. (µg/L)	Avg. Outlet Conc. (µg/L)	Avg. Removal Efficiency	t	Confidence Interval
Zinc (df=4)	160.58	158.80	1%	-0.0157	<50%
Lead (df=4)	11.57	16.38	-42%	0.7407	50%
Copper (df=4)	18.71	7.24	61%	-1.3455	60%

Table 4.8 Summary of Dissolved Metals Data for Winter

A total of five samples were analyzed for metals concentration during the winter sampling period. The average removal efficiency was 61% for copper during the winter sampling period. Zinc and Lead each showed basically a net input during the winter sampling period, or at least the metals being passed through the wetland. The average inlet concentrations of each metal were 160.58 ppb Zn, 11.57 ppb Pb, and 18.71 ppb Cu respectively for the winter sampling period. The average outlet concentrations for metals during the winter sampling period were 158.80 ppb, 16.38 ppb, and 7.24 ppb respectively. This means that zinc is again well within the EPA's recommended secondary drinking water standard at the outlet of the wetland (although it was below at the inlet as well) during the winter sampling period. Neither lead nor copper were within EPA drinking water standards at the outlet of the storm water wetland on average.

The storm water wetland system did not remove any load of either zinc or lead and not a significant enough concentration was added to even register a one pound addition of either metal. However, the storm water wetland system did remove one pound of copper after comparing the inlet and outlet average concentrations, multiplying the difference by the average outlet baseflow discharge and converting units.

4.4.4 Coliform Bacteria

During the winter sampling period, there was a total of 9 sampling events for the abundance of *E. coli* CFU. However, only 8 of those samples were utilized in calculating the seasonal average values because of one storm event occurring too recent to the collection of the samples. Similar to the fall sampling period, the winter sampling period also showed an average net removal of *E. coli* from the storm water wetland system, a 57% ($n = 8$, $df = 7$, $t = 1.9882$, STD = 67%). There was only 1 sampling event that indicated a net input of *E. coli* bacteria out of the total of 8 collected and utilized for statistical analysis. The deviation value for the winter sampling period was higher than that for the fall sampling period, but the data showed consistent removal efficiencies throughout the sampling period.

4.5 Seasonal Data – Spring

There was a total of six sampling dates during the spring sampling period. Data for the spring sampling period are reported in the same manner as described for the fall and winter sampling periods for all parameters, including metals. Complete data tables containing summarized removal efficiencies, detailed removal data, and load removal data for the spring sampling period are listed in Appendix D.

4.5.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

Nutrients - Spring

Pollutant	Avg. Inlet Conc. (mg/L)	Avg. Outlet Conc. (mg/L)	Avg. Removal Efficiency	t	Confidence Interval
Orthophosphate (df=5)	0.061	0.017	72%	-6.9826	99.90%
Total Phosphorous (df=5)	0.23	0.08	68%	-2.7845	95%
Total Nitrogen (df=5)	3.46	1.17	66%	-8.9992	99.90%

Table 4.9 Summary of Nutrients Data for Spring

During the spring sampling period, the average orthophosphate and total phosphorous removal efficiencies showed removal of both pollutants. The average removal efficiency for orthophosphate was 72% ($n = 6$, $df = 5$, $t = 6.9826$, $STD = 10\%$.) The average removal efficiency for total phosphorous was 68% ($n = 6$, $df = 5$, $t = 2.7845$, $STD = 29\%$.) The average removal efficiency for total nitrogen during the spring sampling period was 66% (n = 6, df = 5, t = 8.2151, STD = 15%.) The total nitrogen removal data was very consistent in its averaged inlet concentration, outlet concentration, and removal efficiencies throughout the entire sampling period.

The average seasonal averaged inlet concentration for orthophosphate was 0.061 mg/L. The average seasonal outlet concentration for orthophosphate was 0.017 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 3 lbs. of orthophosphate removed in the storm water wetland during the spring sampling period. The average seasonal averaged inlet concentration for total phosphorous was 0.24 mg/L. The average seasonal outlet concentration for total phosphorous was 0.08 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 10 lbs. of phosphorous removed in the storm water wetland during the spring sampling period. The average seasonal averaged inlet concentration for total nitrogen was 3.46 mg/L. The average seasonal outlet concentration for total nitrogen was 1.17 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 148 lbs. of nitrogen removed in the storm water wetland during the winter sampling period.

4.5.2 Solids – TSS and TDS

Solids - Spring

Pollutant	Avg. Inlet Conc. (mg/L)	Avg. Outlet Conc. (mg/L)	Avg. Removal Efficiency	t	Confidence Interval
TSS (df=5)	2.600	0.917	65%	-2.6507	95%
TDS (df=5)	792.80	1291.35	-63%	0.7628	50%

Table 4.10 Summary of Solids Data for Spring

The average removal efficiency of total suspended solids during the spring sampling period showed a positive removal average of 72% (n = 6, df = 5, t = 2.6507, STD = 53%.) As can be seen in the statistical analysis of this data, there was much less variation of the data throughout the spring sampling period in comparison with the winter sampling period. Similar to the variation seen during the three previous sampling periods, the removal efficiency of total suspended solids ranged from a maximum of complete removal, 100%, to a significant input of suspended material. It is noteworthy that there was only one sampling event that showed a net input of suspended material. Other than that one event that showed a net contribution of suspended solid material to the system, all other sampling events showed removal efficiencies of 54% or better. During the spring sampling period much like the other three sampling periods, the average total dissolved solids removal efficiency did not show any removal at all and was again a net input of the influent dissolved solids (n = 6, df = 5, t = 0.7628, STD = 63%.)

The average seasonal averaged inlet concentration for total suspended solids was 2.6 mg/L. The average seasonal outlet concentration for total suspended solids was 0.92 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 108 lbs. of suspended solids removed in the storm water wetland during the spring sampling period. The total dissolved solids data showed a net input of material to the system. The average seasonal averaged inlet concentration for dissolved solids was 792.80 mg/L. The average seasonal outlet concentration for dissolved solids was 1291.35 mg/L. Multiplying the difference between the two by the average outlet baseflow discharge and converting units yielded a total load of 32,107 lbs. of dissolved solids added to downstream receiving water body from the storm water wetland during the spring sampling period.

4.5.3 Dissolved Metals

Metals - Fall					
Pollutant	Avg. Inlet Conc. (μg/L)	Avg. Outlet Conc. (μg/L)	Avg. Removal Efficiency	t	Confidence Interval
Zinc (df=5)	110.96	148.59	-34%	0.3236	<50%
Lead (df=5)	11.21	15.64	-40%	0.3512	<50%
Copper (df=5)	15.51	7.14	54%	-1.3925	60%

Table 4.11 Summary of Dissolved Metals Data for Spring

A total of 6 samples were analyzed for metals concentration during the spring sampling period. The average removal efficiency was 54% for copper during the spring sampling period. Zinc and lead both showed a net input during the spring sampling period. However, as during the fall and winter sampling periods, the average inlet and outlet concentrations should be noted in addition to the removal efficiency. The average inlet concentrations of each metal were 110.96 ppb Zn, 11.21 ppb Pb, and 15.51 ppb Cu respectively for the spring sampling period. The inlet concentrations for the spring sampling period were significantly higher than the inlet concentrations for the winter sampling period. The average outlet concentrations for metals during the spring sampling period were 148.59 ppb, 15.64 ppb, and 7.14 ppb respectively. This means that zinc is again well within the EPA's recommended secondary drinking water standard at the outlet of the wetland (although it was below at the inlet as well) during the spring sampling period. However, neither lead nor copper would be within the EPA's recommended drinking water standard at the outlet of the storm water wetland system.

Multiplying the difference between the average inlet and outlet concentration by the average outlet baseflow discharge and converting units yielded a total load of 2 lbs. of zinc added to the system in the storm water wetland during the spring sampling period. Multiplying the difference between the inlet and outlet concentration by the average outlet baseflow discharge and converting units yielded no lead removed in the storm water wetland during the winter sampling period. There was no measurable mass of lead removed in the storm water wetland during the spring sampling period because of the very low concentrations and the fact that the concentration of lead was higher in the outlet than the inlet. Multiplying the difference between the inlet and outlet concentrations of copper by the average outlet baseflow discharge and converting units yielded a total load of 1 lbs. of copper removed in the storm water wetland during the spring sampling period.

4.5.4 Coliform Bacteria

During the spring sampling period, there was a total of 10 sampling events for the abundance of *E. coli* CFU. However, only 8 of those samples were utilized in calculating the seasonal average values because of storm events occurring too recent to the collection of the samples. Unlike the fall and winter sampling periods, the spring sampling period showed an average net input of *E. coli* from the storm water wetland system (n = 8, df = 7, t = 0.5398, STD = 563%). However, there was only 1 sampling event that indicated a net input of *E. coli* bacteria out of the total of 8 collected and utilized for statistical analysis, but that one sample was such a large input of *E. coli* that it altered the average significantly. Discounting that one extreme result would have resulted in an average removal efficiency of 93%. Because of this one outlying piece of data, the deviation value for the spring sampling period was the highest of all three sampling periods.

Chapter 5 – Discussion

5.1 Introduction

This section will draw on data presented in Chapter 4 – Results to present meaningful discussion and analysis about the data that were collected. Because of the seasonal approach to this research, an attempt will be made to highlight trends among seasons as well as within them. The tables list some events as being statistically unreliable (notated as **.) This result refers to the confidence interval determined through the t-test returning a result below the 50% confidence interval, essentially meaning the correlation between the data could be chance.

5.2 Overall Discussion – Yearly Trends

Information about the annual trends observed in the storm water wetland will be presented in two different ways. First, a graph will be shown with the inlet and outlet concentrations of each pollutant parameter for each individual sampling event. This should allow for some realization of possible trends in spikes in inlet and outlet concentrations. The second method for displaying the data is within a table depicting the total load of each pollutant removed from the storm water wetland utilizing the calculation described earlier. Below is a graph depicting the various removal efficiencies for each pollutant parameter for the entire year. This calculation was made in the same manner as it was for each individual season. The annual inlet and outlet concentrations were determined for each pollutant parameter and then utilized to determine the overall annual removal efficiency for the site (Figure 5.1)

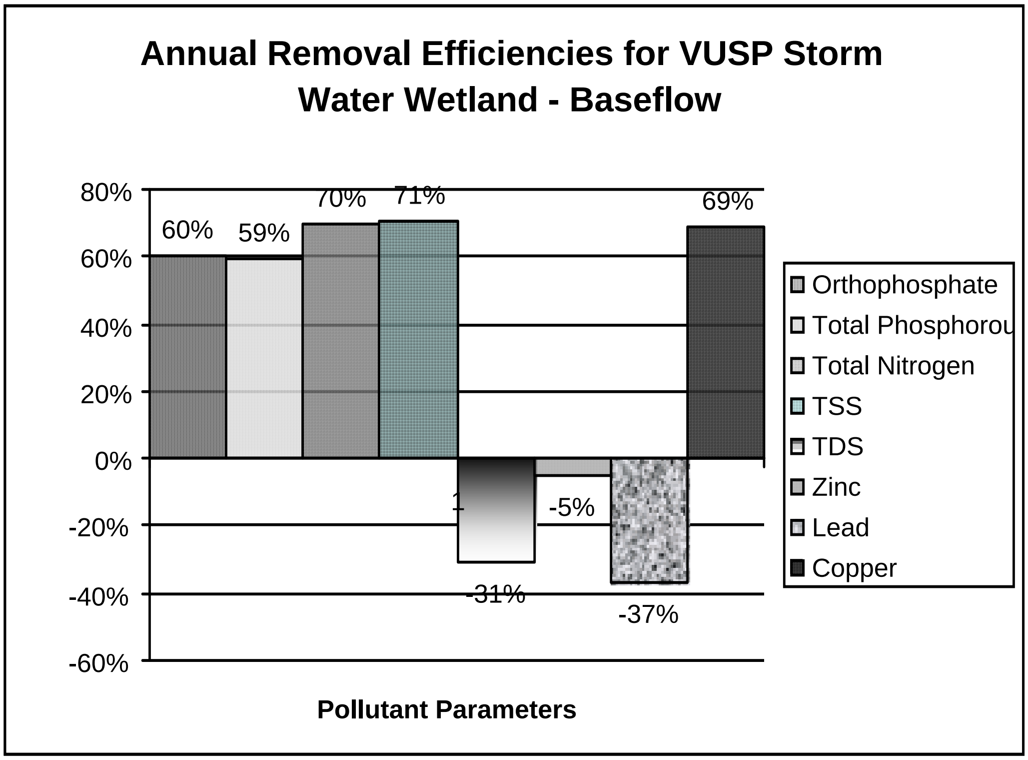

Figure 5.1 Annual Removal Efficiencies

Note**dissolved metals removal efficiencies are based on 9 months of sampling (excludes summer.)

5.2.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

As a general statement for all four sampling seasons, it appears a trend that a significant percentage of the total phosphorous removed in the wetland system is orthophosphate, both in terms of a removal efficiency and load basis. Based on the significant vegetative component of the storm water wetland system, it is logical that phosphorous removal through plant uptake would be significant. The total phosphorous removal efficiencies for the four sampling seasons on average did not meet the target established for storm event functioning of a storm water wetland complex, but did always offer positive removal efficiencies and did not add any phosphorous to the system despite drastically lower inlet concentrations than would be observed during storm events. Total nitrogen removal efficiency did typically meet or exceed the target removal efficiency set for storm events in this type of BMP as per the PA DEP BMP Manual standards. This is most likely due to the fact that the end product for nitrogen removal is the gaseous state of nitrogen resulting from the activity of nitrifying bacteria. Increased retention time allows greater time for this process to take place. The exceptional removal efficiency is more remarkable considering the average influent concentration was well below the Pennsylvania Code's limit of 10 mg/L for a potable water source (PWS) for all four sampling seasons. Typically, it is more difficult to remove a pollutant when influent concentrations are lower as opposed to when they are higher.

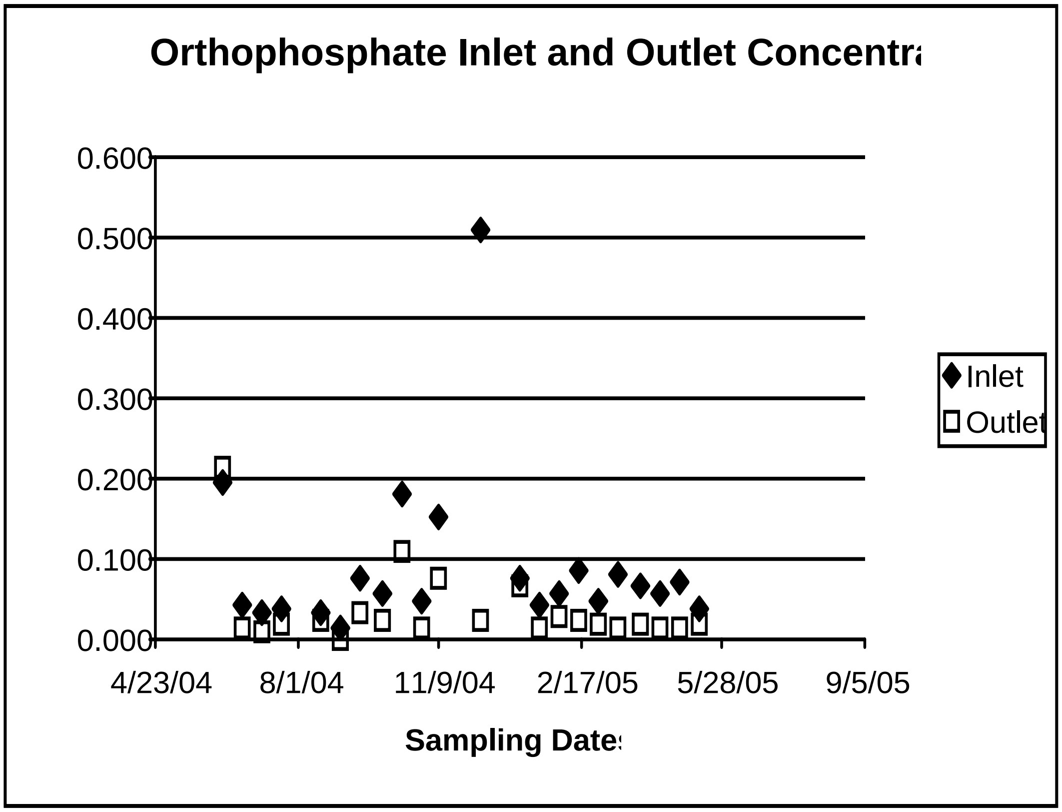

Figure 5.2 Orthophosphate Concentrations

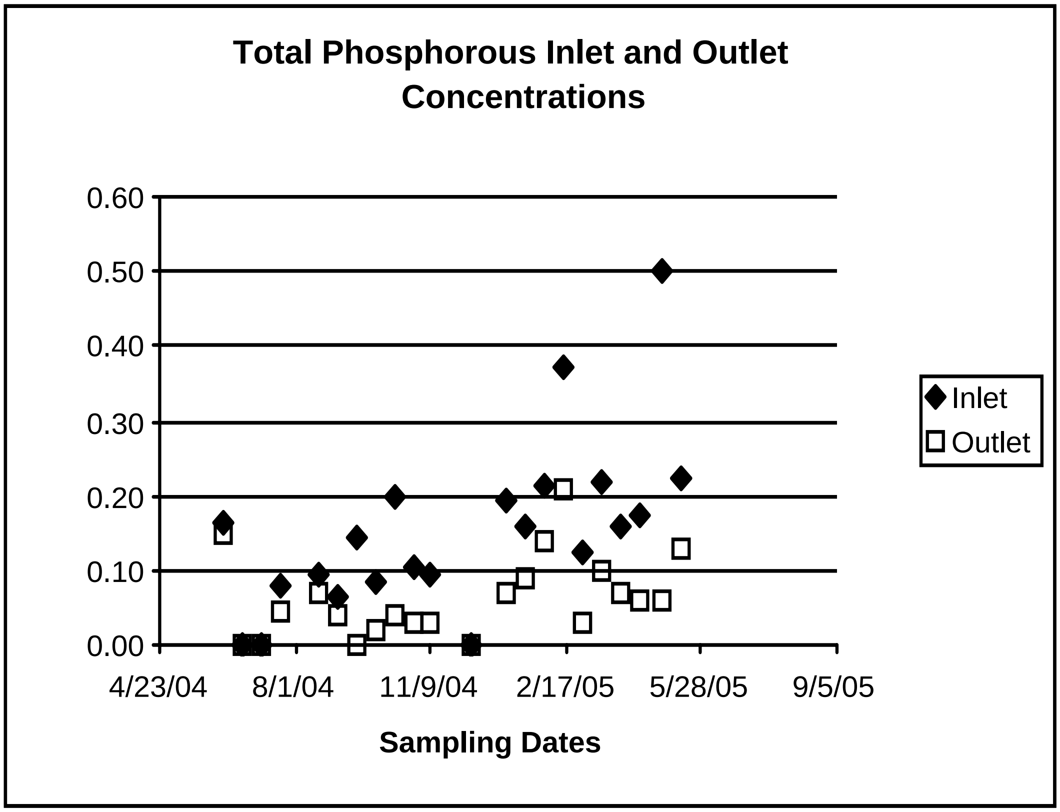

Figure 5.3 Total Phosphorous Concentrations

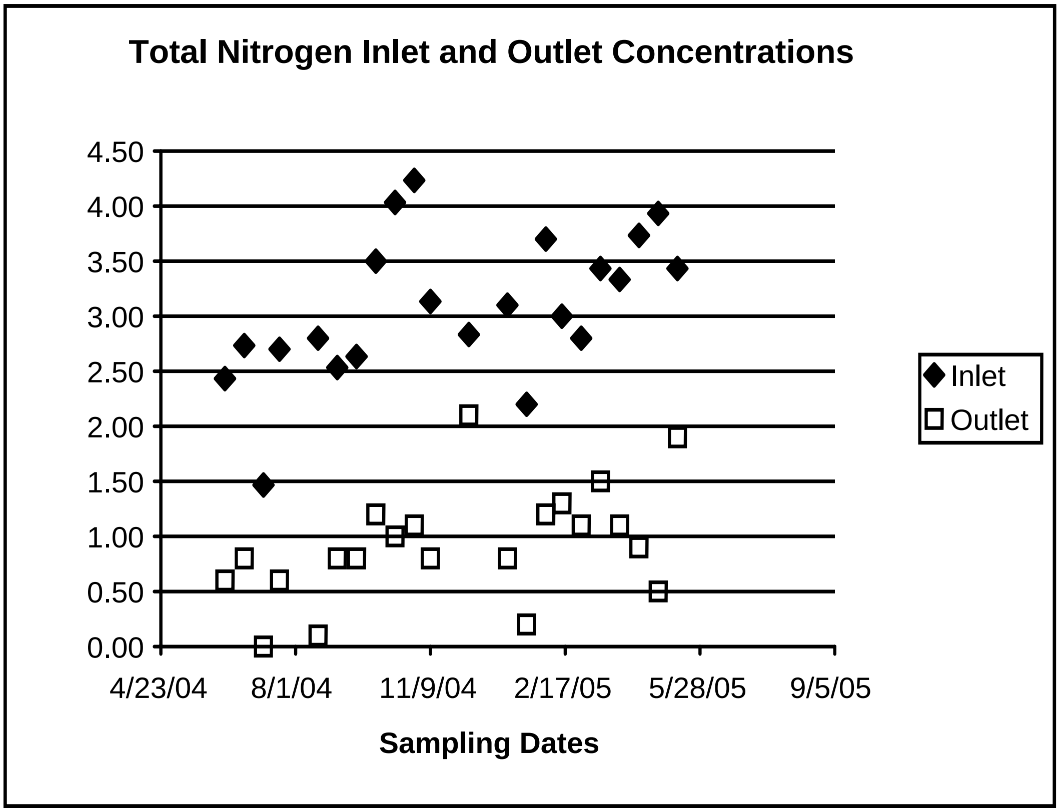

Figure 5.4 Total Nitrogen Concentrations

Table 5.1 Yearlong Nutrients Load Removal Totals

Season	Orthophosphate (lbs P)	Total P (lbs P)	Total N (lbs N)
Summer Total	**	**	123
Fall Total	0	6	153
Winter Total	8	7	117
Spring Total	3	10	148
Overall Total	11	23	540

5.2.2 Solids – TSS and TDS

In all seasons, the TSS removal efficiencies were well below the targets set for storm sampling by the PA DEP BMP Manual. In addition, the TSS removal efficiencies were extremely variable within seasons and among seasons. Overall, it was very difficult to see many trends as they pertain to total suspended solids other than the fact that for all seasons other than winter, positive removal efficiencies were seen.

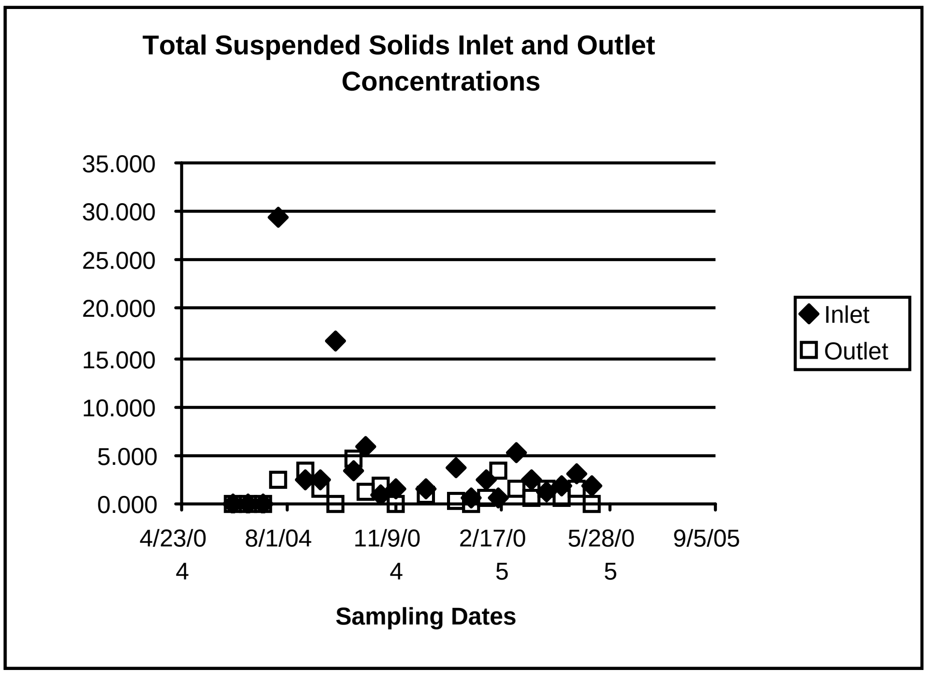

Figure 5.5 Total Suspended Solids Concentrations

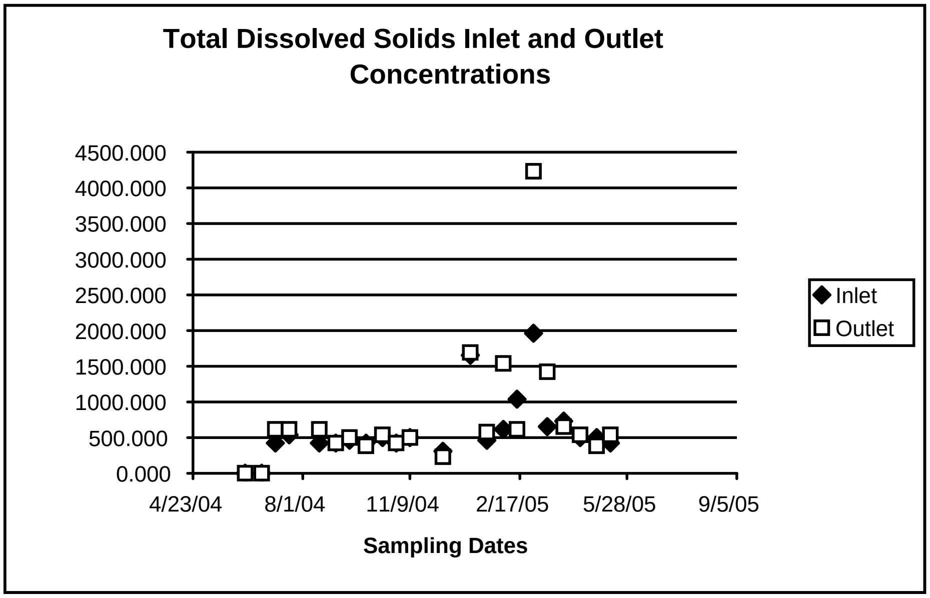

Figure 5.6 Total Dissolved Solids Concentrations

Season	Conductivity	TSS (lbs)	TDS (lbs)
Summer Total	NA	558	-9166
Fall Total	NA	234	**
Winter Total	NA	48	**
Spring Total	NA	108	-32107
Overall Total	NA	949	-41274

Table 5.2 Yearlong Solids Load Removal Totals

All four sampling seasons showed an overall net input of TDS into the system. However, it appears as if the addition of TDS is mostly due to the release of de-icing material stored in the storm water wetland system from winter storm events. As evidence of this hypothesis, there is a correlation between increased conductivity levels at the outlet in comparison with the inlet and the same addition of TDS. In addition, a thick, white, flaky residue was observed on most dissolved solids weighing / evaporating dishes at the conclusion of the test. When re-dissolved within the dish, the residue had a distinct odor of chlorine.

5.2.3 Dissolved Metals

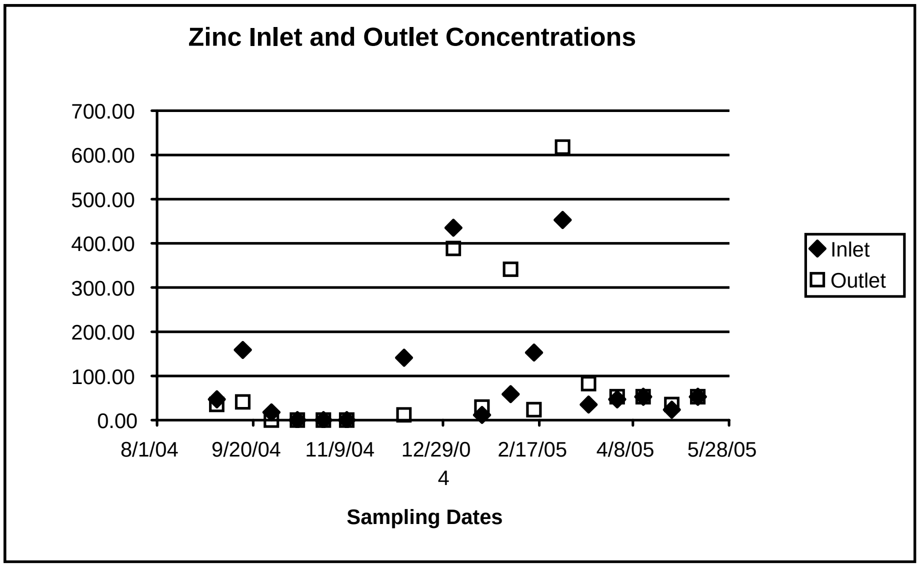

Figure 5.7 Zinc Concentrations

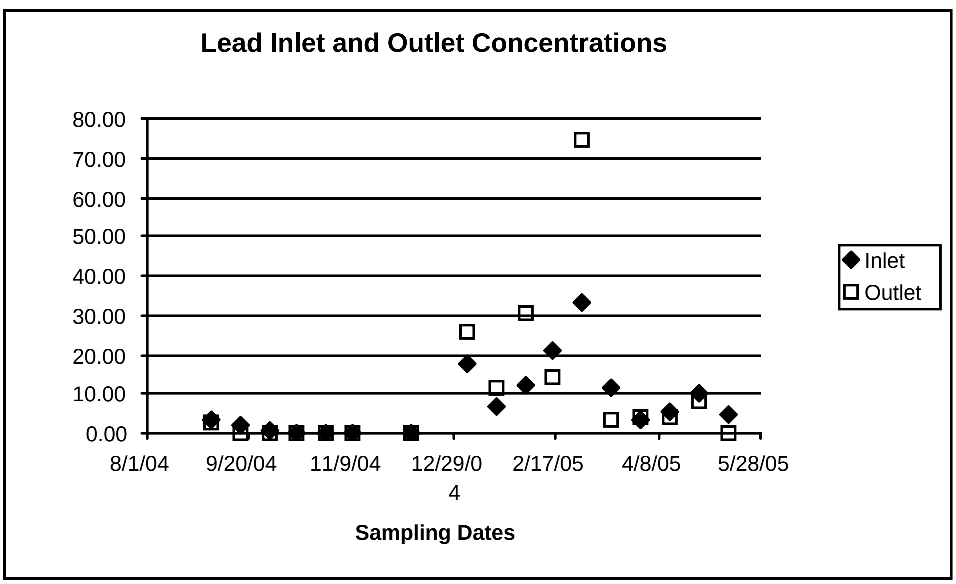

Figure 5.8 Lead Concentrations

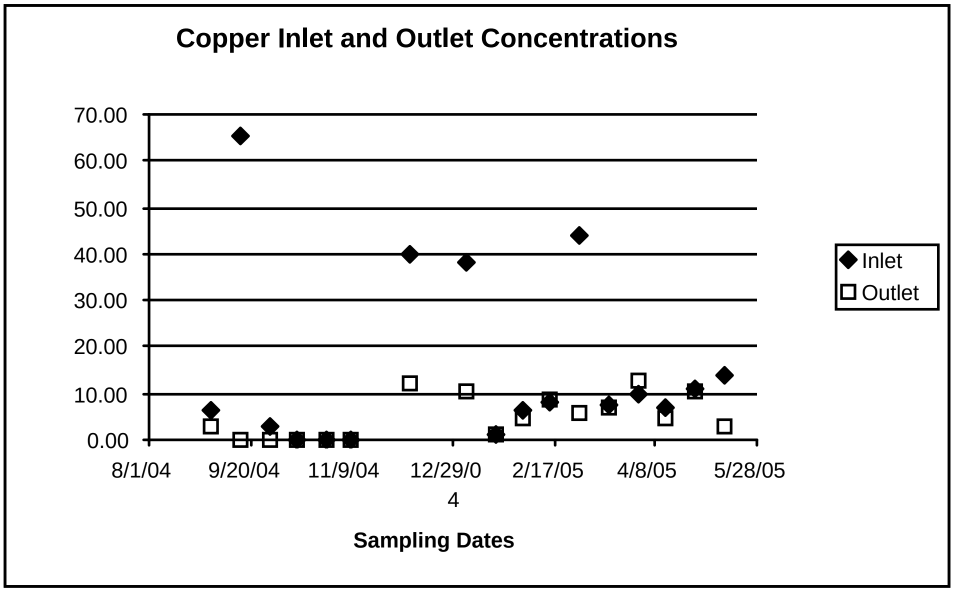

Figure 5.9 Copper Concentrations

Season	Zinc (lbs Zn)	Lead (lbs Pb)	Copper (lbs Cu)
Summer Total	NA	NA	NA
Fall Total	3	0	2
Winter Total	**	0	1
Spring Total	**	**	1
Overall Total	3	0	4

Table 5.3 Yearlong Metals Load Removal Totals (9 Months of Data)

In all seasons, as has been mentioned, the only standards to compare the concentrations of metals in solution is the EPA's Drinking Water Standards. For all three sampling seasons in which metals were analyzed, the Zinc levels observed at the outlet were well below the secondary drinking water standard by an order of magnitude. However, the influent concentrations of Zinc were an order of magnitude less than this standard already. Neither Lead nor Copper showed average outlet concentrations below the action levels for the EPA's Drinking Water Standards, but were still on the order of parts per billion, which is the same units as the drinking water standards. This results in insignificant loads of Lead and Copper added to the system when net inputs were observed. There were still a significant number of sampling events, however, in which net removals of Lead and Copper were observed, indicating that the overall effect on Lead and Copper by a storm water wetland system during baseflow is negligible in terms of significant addition or removal.

5.2.4 Coliform Bacteria

Coliform Bacteria - Summary
E. coli

Seasonal Average	Inlet *E. coli* (CFU/100mL)	Outlet *E. coli* (CFU/100mL)	Removal Efficiency (%)	t	Confidence Interval
Summer (df=7)	225	450	-94%	0.6622	<50%
Fall (df=9)	9185	430	65%	-1.9223	90%
Winter (df=8)	617	67	50%	-1.9882	90%
Spring (df=6)	519	325	93%	-0.5049	<50%
Total Average	2636	318	29%		

Table 5.4 Yearlong *E. coli* Removal Efficiency Averages

The only sampling season that showed a net input of *E. coli* was the summer sampling period, assuming the elimination of one extreme outlying piece of data during the spring sampling period. In fact, assuming the elimination of that piece of data, the fall, winter and spring sampling seasons all displayed removal efficiencies in excess of 50% and even as high as 93%. The summer sampling season may have observed a net input of *E. coli* into the system because of the relatively ideal environmental growing conditions during that season. Warmer daily temperatures, including evening and night temperatures would foster near 24-hour reproductive capability for *E. coli* colonies already present in the water column. The temperatures observed during evening and throughout the night of the other three sampling seasons (fall, winter, and spring) would repress if not stop *E. coli* reproduction and metabolic activities. This observation would indicate that in terms of the abundance of *E. coli* CFU, temperature is as significant to removal as the wetland's design characteristics.

5.3 Discussion – Summer

5.3.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

In addition to the generally observed trends for orthophosphate and total phosphorous, there were a few specific trends observed within the summer sampling period for these two pollutants. A large percentage of the total phosphorous removed was comprised of orthophosphate. As a matter of fact, there was a total of two pounds of total phosphorous removed and one pound of orthophosphate. This is logical, however, because orthophosphate is the form usable by plant material. Thus, at the height of the growing season, the summer, it makes sense that vegetation would efficiently remove orthophosphate.

5.3.2 Solids – TSS and TDS

The summer sampling period showed great variability among the TSS data collected. However, it is reasonable to assume that more consistent removal efficiencies would have been obtained if more samples had been collected. A limited number of TSS samples were collected during the summer sampling period due to the need to perfect sampling protocols for solids material. In addition to the variability that may have been created during the summer sampling period due to small sample size, it is possible that typical larger summer thunderstorms may have stirred up sediments within the sediment forebay, thus pushing them through the system at a higher rate due to the increased intensity of rain storms typically seen in the summer as opposed to at other times of the year.

5.3.3 Dissolved Metals

There were no metals samples collected during the summer sampling period for this study.

5.3.4 Coliform Bacteria

The *E. coli* data showed the greatest fluctuation in removal efficiency of all of the parameters sampled during the summer sampling period ranging from a 500% input to a total 100% removal. This variation is likely due to the fact that growing conditions are ideal during summer months, but *E. coli* colonies may also be flushed from the storm water wetland system by summer storm events. Interestingly, the average outlet concentration during the summer sampling period was well in excess of the level recommended by the US EPA and outlined by the state of Ohio for secondary recreational contact. However, this average outlet concentration was elevated by one high data point. Excluding that one data point, half of the sampling dates had outlet concentrations below the US EPA recommended level for *E. coli* CFU/100mL of sample.

5.4 Discussion – Fall

5.4.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

The total loads removed of both orthophosphate and total phosphorous rose from the summer sampling period to the fall sampling period. It is reasonable to assume that this increase of both pollutants is due to the increased leaf litter and other organic matter falling in the wetland and being decomposed during the typical fall plant die-off. However, the removal efficiencies for both orthophosphate and total phosphorous were higher during the fall sampling period than the summer sampling period. This increased removal efficiency was accomplished with similar inlet concentrations during the fall sampling period in comparison with the summer sampling period.

5.4.2 Solids – TSS and TDS

For the fall sampling period, there was a lack of correlation between the TSS removal efficiency and the total nitrogen removal efficiency results. This may indicate that at this site during baseflow conditions, a great deal of the nitrogen particles may not actually be contained on suspended particles. In addition, there does not seem to be a reduction in the removal efficiency of TSS during the fall sampling period in comparison with the summer sampling period. One might expect that with increased plant die-off during the fall season, the storm water wetland system would experience less efficient removal due to increased concentrations. However, the opposite occurred and efficiency increased. In fact, the average influent TSS concentration was lower in the fall than during the summer sampling period. Possibly, plant die-off may occur in fall and the release of forms of phosphorous happens quickly, but the physical break down of leaf and stalk material of the vegetation is a more lengthy process. Thus, increased levels of TSS in the system would be seen well after the plant die-off has taken place.

5.4.3 Dissolved Metals

The fall sampling period showed the highest removal efficiency for all three metals analyzed. In addition, the fall sampling period exhibited the lowest outlet concentrations for both Lead and Copper. During no other sampling period were the levels of Lead and Copper closer to being in compliance with the EPA's Drinking Water Standards.

5.4.4 Coliform Bacteria

The fall sampling period saw an increased removal efficiency of *E. coli* as well as an increased number of events with an outlet concentration of 200 CFU or lower. The ratio remained the same during the fall sampling period in comparison with the summer sampling period. The fall sampling period had 5 of 10 sampling events showing 200 CFU or lower and the summer sampling period had 4 of 8 events with 200 CFU or lower.

Interestingly though, the average seasonal outlet *E. coli* concentration was actually higher during the fall sampling period than the summer sampling period.

5.5 Discussion – Winter

5.5.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

The total load of orthophosphate and total phosphorous removed increased again from the fall sampling period to the winter sampling period as it did from the summer sampling period to the fall sampling period. This fact is interesting considering one would hypothesize that a decreased amount of living vegetation in the wetland (during colder winter months) would indicate a correlative decreased need of orthophosphate for growth. To increase the level of confusion on this matter, the average inlet concentration for both orthophosphate and total phosphorous nearly doubled from the fall sampling period to the winter sampling period, but the outlet concentration for orthophosphate stayed the same and total phosphorous was only slightly more. This may indicate that the mechanism in the wetland that is actually removing phosphorous is not actually seasonally dependent and can only achieve a certain concentration at the outlet due to natural environmental conditions. As was observed in other sampling periods, the load of orthophosphate that was removed comprises a significant portion of the total load of total phosphorous removed from the system. The concentrations of total nitrogen at the inlet and outlet for the winter sampling period are extremely consistent with the summer and fall sampling periods, furthering supporting the observation that total nitrogen is the most consistent pollutant in terms of removal efficiency, inlet concentration, and outlet concentration for all four seasons sampled.

5.5.2 Solids – TSS and TDS

While the winter sampling period displayed a net input of suspended solids material to the system, when one extreme sampling event at the end of the sampling period is removed from the calculation, the resulting removal efficiency is 54%, which is much more in-line with the averages that were seen throughout the rest of the year. Also of note, the average inlet concentration of TSS during the winter sampling period was much lower than the average inlet concentration of TSS during the summer or fall sampling periods, including the outlying piece of data at the end of the sampling period. The lack of suspended solids material in the influent to the storm water wetland system is logical due to the decreased frequency of erosion inducing rainstorms during winter months in comparison with other seasons during the year.

5.5.3 Dissolved Metals

Both Zinc and Lead showed net inputs into the system for the winter sampling period, which could be due to the fact that most of the metals removal in the wetland system is actually due to plant uptake rather than soil binding. This conclusion can only be definitively drawn with further study into the metals concentrations within the soil complex and leaf material of the vegetation. The metals concentrations seen at the inlet and outlet during the winter sampling period were higher than at both locations during the fall sampling period, but were more in line with concentrations seen at both locations during the spring sampling period. The future availability of metals sampling data during the summer sampling period in addition to the three seasons sampled as part of this study will be very revealing as to the variability of metals concentration in solution in the storm water wetland complex.

5.5.4 Coliform Bacteria

All of the sampling events during the winter sampling period showed outlet concentrations of *E. coli* of 100 CFU/100mL or less, which would put the effluent concentration well below the EPA recommended level for secondary recreational waters. The winter sampling period showed the lowest average outlet concentration of CFU's of the two previous sampling periods. This fact would be expected due to decreased metabolic activity of the *E. coli* bacteria due to lower temperatures.

5.6 Discussion – Spring

5.6.1 Nutrients – Orthophosphate, Total Phosphorous, and Total Nitrogen

The orthophosphate removal efficiency during the spring sampling period matches that of the summer and fall sampling periods, but the average inlet concentration was the lowest of the four sampling seasons. In addition, the average outlet concentration of orthophosphate was the lowest during the spring sampling period. Observing the lowest outlet concentration of orthophosphate during the spring sampling period does make sense because that is the form most readily usable by vegetation, and the spring sampling period is when plants are gearing up for large growth rates. Once again, the total nitrogen removal efficiency for the spring sampling period was very consistent with the results from the other three seasons indicating that total nitrogen removal is the most consistent pollutant parameter.

5.6.2 Solids – TSS and TDS

The spring sampling period displayed the highest removal efficiencies for TSS in comparison with the other three sampling seasons. However, the average inlet concentration of TSS was only larger than the winter sampling period.

5.6.3 Dissolved Metals

Both Zinc and Lead showed higher concentrations at the outlet than the inlet during the spring sampling period indicating a net input of both metals. As mentioned in previous discussion sections, longer metals analysis needs to be conducted as well as additional analysis of the soil and leaf material to determine any further conclusions about the cycling of metals through the storm water wetland system.

5.6.4 Coliform Bacteria

With the exclusion of one extreme outlying data point, the spring sampling period showed the best removal efficiency of all four sampling periods. One would think that the winter sampling period would have the highest removal efficiencies because of decreased metabolic rates due to environmental temperatures, but that was not the case. While the average inlet concentration of *E. coli* was about the same as the winter sampling period, the average outlet concentration was the lowest of all of the sampling seasons with the exclusion of the outlying sample data.

Chapter 6 – Conclusions

6.1 Introduction

The purpose of this section is to draw some general conclusions about the baseflow functionality of the storm water wetland system on the campus of Villanova University. Of course, each storm water wetland system is unique in its specifics, but the general function of these storm water BMPs should be somewhat universal on a regional scale. In addition, this section will contain a small number of recommendations for future research based on observations made during the sampling and analysis phase of this research.

6.2 Conclusions

There were a number of interesting relationships observed about phosphorous moving through the storm water wetland system. The majority of the total phosphorous removed in the wetland system during baseflow is reactive phosphorous. This is logical based on the large vegetative component within the wetland and the fact that reactive phosphorous is the form of phosphorous most readily available to vegetation. Also of note is the fact that no matter the inlet concentration, the storm water wetland system only seemed able to remove the reactive phosphorous to a specific minimum concentration at the outlet. The spring sampling period showed the lowest average outlet concentration, which is also logical based on the nature of vegetative demands for nutrients on a seasonal basis. The other three sampling seasons all had consistent levels of reactive phosphorous at the outlet despite a great deal of variation in inlet concentrations, sometimes double the average concentration from season to season. This leads to the conclusion that the volume and the nature of the vegetation within a storm water wetland system will control the removal capacity of the overall system.

Total nitrogen was the most consistently removed pollutant parameter observed throughout all four sampling seasons. The removal efficiencies met the targets established for storm event removals in addition to being so consistent, which is all the more impressive when considering the relatively low concentrations of total nitrogen consistently observed at the inlets. The increased retention time inherent with a storm water wetland design leads to continued efficient removal of nitrogen because of the nature of its cycle through the processes of nitrifying bacteria.

The TSS moving through the storm water wetland system during baseflow conditions do not meet the standard removal efficiencies established empirically and offered in the PA DEP BMP Manual for storm flows. However, there is consistent annual removal of approximately 20% for baseflow events. Variation obviously exists within and between seasons, but most importantly removals during baseflow will result in continued removals of TSS by storm water wetlands outside of storm events.

The dissolved metals analysis within a wetland system is typically measured in terms of their concentration within the soil complex or the leaf material of the vegetation within the wetland. As such, it is even more rare for standard metals removal efficiencies to be assigned to any storm water BMP. This research has not concluded a definitive relationship in terms of the removal of dissolved metals by the storm water wetland system during baseflow conditions. From season to season, there was variation in terms of an overall removal or input. However, importantly, it can be concluded that increased retention time inherent in a storm water wetland system does not lead to any significant leaching of metals from the underlying soil complex to the water column.

The removal capacity of *E. coli* CFU within a storm water wetland system is a relatively new measure of the capabilities of a storm water BMP. From this research, it seems conclusive that the necessary microbiological conditions are established within a storm water wetland system to enhance the removal of *E. coli* bacteria. The only season that exhibited overall net inputs was the summer sampling period. In this specific season, environmental temperature conditions override the wetland's ability to process *E. coli* bacteria.

6.3 Recommendations for Future Research

There are a few conclusions that have been reached during the course of this research that can serve as guideposts for future activity on this research site. Because of the unknown nature of the composition of the vegetation material on the site in terms of exact species and relative abundance, a detailed plant study should be conducted with the assistance of other departments within Villanova University or another qualified entity. This detailed vegetation community information would allow for more exact conclusions about the nature of pollutant removal capacities. The vegetation on the site is also a potential design recommendation. Additional care could be taken to ensure native species inhabit the wetland. However, due to the elevated chloride levels within the wetland, the non-native plant species may be better suited to the site conditions.

Another major area of need is simply to continue the baseflow sampling as it was conducted for the one-year period of this research. Additional data will help to rule out anomalies in the results and create better statistical analysis of the data.

The two pollutant parameters that have been least studied at this site, dissolved metals and *E. coli* bacteria, are also a source of guidance for future activities on the site. First, continued metals analysis is very important because of the variability seen in the reported metals results. Measuring the concentration of metals in solution is rare within storm water BMPs, specifically, and even in wetlands generally, so that increased volumes of data would prove valuable for determining overall trends.

The measurement of the abundance of *E. coli* bacteria within the storm water wetland was a new effort for this sampling site and seems to have yielded very definitive conclusions in terms of the removal of the pathogenic bacteria. However, a method exists, Fatty Acid MethylEster (FAME) that attempts to determine the source of the *E. coli* bacteria colonies present. The large-scale application of this method on the storm water wetland system would assist in determining if storm water runoff at the site contained human, or other pathogenic contamination. Thus, the research would show whether this storm water wetland systems can process human, animal pathogenic bacteria, or both on a small scale. Then, storm water wetland systems might be proven to be more valuable in a setting in which those types of non-point source pollution were a major concern. Preliminary analysis using the FAME method was used and did produce results indicating there may be human coliform pollution entering the storm water wetland. With further analysis, this determination could be made more definitively.

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Appendix A - Summer
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Summer
Summarized Removal Efficiencies

Nutrients - Summer
Removal Efficiencies

Date	Orthophosphate	Total P	Total N
6/9/04	-11%	9%	76%
6/24/04	63%	0%	71%
7/7/04	75%	0%	0%
7/21/04	54%	43%	78%
8/18/04	27%	26%	97%
Avg.	18%	22%	78%

Solids - Summer
Removal Efficiencies

Date	Conductivity	TSS	TDS
6/9/04	41%	DNR	DNR
6/24/04	4%	DNR	DNR
7/7/04	-38%	0%	-41%
7/21/04	-14%	92%	-12%
8/18/04	-38%	-43%	-43%
Avg.	-9%	82%	-31%

Appendix A - Summer
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Summer
Detailed Removal Data

Nutrients - Summer
Orthophosphate
n = 5 **df = 4**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
6/9/04	0.193	0.215	-11%	
6/24/04	0.045	0.017	63%	
7/7/04	0.035	0.008	75%	
7/21/04	0.038	0.017	54%	
8/18/04	0.036	0.026	27%	
Avg.	0.069	0.057	18%	
STD	0.062	0.079	32%	-0.281983

Nutrients - Summer
Total Phosphorous
n = 3 **df = 2**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
6/9/04	0.16	0.15	9%	
6/24/04	DNR	DNR		
7/7/04	DNR	DNR		
7/21/04	0.08	0.05	43%	
8/18/04	0.10	0.07	26%	
Avg.	0.11	0.09	22%	
STD	0.04	0.04	14%	-0.736542

Nutrients - Summer
Total Nitrogen
n = 4 **df = 3**

Date	Inlet Concentration (mg/L N)	Outlet Concentration (mg/L N)	Removal Efficiency	t
6/9/04	2.45	0.60	76%	
6/24/04	2.75	0.80	71%	
7/7/04	1.45	DNR		
7/21/04	2.7	0.60	78%	
8/18/04	2.8	0.09	97%	
Avg.	2.43	0.52	78%	
STD	0.50	0.26	10%	-6.706219

Appendix A - Summer
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Summer
Detailed Removal Data

Solids - Summer
TSS

n = 3 **df = 2**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
6/9/04	DNR	DNR		
6/24/04	DNR	DNR		
7/7/04	0.00	0.00	0%	
7/21/04	29.33	2.33	92%	
8/18/04	2.33	3.33	-43%	
Avg.	10.56	1.89	82%	
STD	16.30	1.71	69%	0.9156847

Solids - Summer
TDS

n = 3 **df = 2**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
6/9/04	DNR	DNR	0%	
6/24/04	DNR	DNR	0%	
7/7/04	429.00	603.33	-41%	
7/21/04	535.17	601.33	-12%	
8/18/04	434.50	621.00	-43%	
Avg.	466.22	608.56	-31%	
STD	59.77	10.82	21%	-4.058551

Appendix A - Summer
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Summer
Load Removed

Load Removals - Summer
Seasonal Removal

	Baseflow Q (cfs)	Inlet Conc. Avg.	Outlet Conc. Avg.	Seasonal Load Removed (kg)	Seasonal Load Removed (lbs.)
Orthophosphate	0.13	0.069	0.057	0	1
Total Phosphorous	0.13	0.11	0.09	1	2
Total Nitrogen	0.13	2.43	0.52	56	123
TSS	0.13	10.56	1.89	254	558
TDS	0.13	466.22	608.56	-4167	-9166
Zinc	0.13	DNR	DNR	DNR	DNR
Lead	0.13	DNR	DNR	DNR	DNR
Copper	0.13	DNR	DNR	DNR	DNR

Seasonal Data – Summer
Coliform Bacteria (*E.coli*) Removal Efficiencies

Coliform Bacteria - Summer
E. coli
n = 8 **df = 7**

Date	Inlet *E.coli* (CFU/100mL)	Outlet *Ecoli* (CFU/100mL)	Removal Efficiency (%)	t
6/2/2004	50	0	100%	
6/16/2004	900	2700	-200%	
6/23/2004	50	200	-300%	
6/30/2004	250	0	100%	
7/7/2004	200	300	-50%	
7/14/2004	50	300	-500%	
8/18/2004	100	100	0%	
8/25/2004	200	0	100%	
AVG	225	450	-94%	
STD	284	918	221%	0.6622

Appendix B - Fall
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Fall
Summarized Removal Efficiencies

Nutrients - Fall
Removal Efficiencies

Date	Orthophosphate	Total P	Total N
9/1/04	87%	38%	69%
9/15/04	60%	100%	70%
9/30/04	59%	76%	66%
10/13/04	40%	80%	75%
10/27/04	74%	71%	74%
11/9/04	50%	68%	75%
Avg.	52%	77%	72%

Solids - Fall
Removal Efficiencies

Date	Conductivity	TSS	TDS
9/1/04	-3%	33%	-3%
9/15/04	-19%	100%	-8%
9/30/04	15%	-35%	15%
10/13/04	-9%	80%	-9%
10/27/04	-5%	-80%	2%
11/9/04	0%	100%	-1%
Avg.	-4%	71%	-1%

Metals - Fall
Removal Efficiencies

Date	Zinc	Lead	Copper
9/1/04	15%	24%	59%
9/15/04	73%	86%	100%
9/30/04	93%	100%	100%
10/13/04	DNR	DNR	DNR
10/27/04	DNR	DNR	DNR
11/9/04	DNR	DNR	DNR
Avg.	63%	49%	97%

Appendix B - Fall
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Fall
Detailed Removal Data

Nutrients - Fall
Orthophosphate
n = 6 **df = 5**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
9/1/04	0.015	0.002	87%	
9/15/04	0.077	0.031	60%	
9/30/04	0.059	0.024	59%	
10/13/04	0.181	0.109	40%	
10/27/04	0.050	0.013	74%	
11/9/04	0.152	0.076	50%	
Avg.	0.089	0.043	52%	
STD	0.064	0.041	17%	-1.49044

Nutrients - Fall
Total Phosphorous
n = 6 **df = 5**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
9/1/04	0.07	0.04	38%	
9/15/04	0.15	0.00	100%	
9/30/04	0.09	0.02	76%	
10/13/04	0.20	0.04	80%	
10/27/04	0.11	0.03	71%	
11/9/04	0.10	0.03	68%	
Avg.	0.12	0.03	77%	
STD	0.05	0.02	20%	-4.258253

Nutrients - Fall
Total Nitrogen
n = 6 **df = 5**

Date	Inlet Concentration (mg/L N)	Outlet Concentration (mg/L N)	Removal Efficiency	t
9/1/04	2.55	0.80	69%	
9/15/04	2.65	0.80	70%	
9/30/04	3.5	1.20	66%	
10/13/04	4.05	1.00	75%	
10/27/04	4.25	1.10	74%	
11/9/04	3.15	0.80	75%	
Avg.	3.36	0.95	72%	
STD	0.71	0.18	4%	-8.107621

Appendix B - Fall
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Fall
Detailed Removal Data

Solids - Fall
TSS

n = 6 **df = 5**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency (% mg/L)	t
9/1/2004	2.40	1.60	33%	
9/15/2004	16.80	0.00	100%	
9/30/2004	3.40	4.60	-35%	
10/13/2004	5.97	1.20	80%	
10/27/2004	1.00	1.80	-80%	
11/9/2004	1.70	0.00	100%	
Avg.	5.21	1.53	33%	
STD	5.93	1.69	76%	-1.4598251

Solids - Fall
TDS

n = 6 **df = 5**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency (% mg/L)	t
9/1/2004	409.79	420.62	-3%	
9/15/2004	458.69	493.81	-8%	
9/30/2004	440.72	374.85	15%	
10/13/2004	487.70	532.40	-9%	
10/27/2004	434.10	425.20	2%	
11/9/2004	495.10	498.20	-1%	
Avg.	454.35	457.51	-1%	
STD	32.78	59.70	9%	0.1137072

Appendix B - Fall
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Fall
Detailed Removal Data

Metals - Fall
Zinc
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency (% ppb)	t
9/1/2004	44.75	37.92	15%	
9/15/2004	160.08	42.47	73%	
9/30/2004	15.23	1.08	93%	
10/13/2004	DNR	DNR	DNR	
10/27/2004	DNR	DNR	DNR	
11/9/2004	DNR	DNR	DNR	
Avg.	73.35	27.16	61%	
STD	76.54	22.70	40%	-1.4171886

Metals - Fall
Lead
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency (% ppb)	t
9/1/2004	3.31	2.51	24%	
9/15/2004	1.71	0.24	86%	
9/30/2004	0.42	0	100%	
10/13/2004	DNR	DNR	DNR	
10/27/2004	DNR	DNR	DNR	
11/9/2004	DNR	DNR	DNR	
Avg.	1.81	0.92	70%	
STD	1.45	1.39	40%	-1.0922014

Metals - Fall
Copper
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency (% ppb)	t
9/1/2004	6.44	2.61	59%	
9/15/2004	65.62	0	100%	
9/30/2004	3.16	0	100%	
10/13/2004	DNR	DNR	DNR	
10/27/2004	DNR	DNR	DNR	
11/9/2004	DNR	DNR	DNR	
Avg.	25.07	0.87	86%	
STD	35.15	1.51	23%	-1.6848054

Appendix B - Fall
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Fall
Load Removed

Load Removals - Fall
Seasonal Removal

	Baseflow Q (cfs)	Inlet Conc. Avg.	Outlet Conc. Avg.	Seasonal Load Removed (kg)	Seasonal Load Removed (lbs.)
Orthophosphate	0.13	0.089	0.043	0	0
Total Phosphorous	0.13	0.12	0.03	3	6
Total Nitrogen	0.13	3.36	0.95	70	153
TSS	0.13	5.21	1.53	106	234
TDS	0.13	454.35	457.51	-92	-201
Zinc	0.13	73.35	27.16	1	3
Lead	0.13	1.81	0.92	0	0
Copper	0.13	25.07	0.87	1	2

Seasonal Data – Fall
Coliform Bacteria (*E. coli*) Removal Efficiencies

Coliform Bacteria - Fall
E. coli
n = 10 **df = 9**

Date	Inlet *E.coli* (CFU/100mL)	Outlet *Ecoli* (CFU/100mL)	Removal Efficiency (%)	t
9/1/2004	650	200	69%	
9/15/2004	8450	200	98%	
9/22/2004	11000	100	99%	
9/29/2004	1650	1100	33%	
10/6/2004	4450	100	98%	
10/13/2004	47250	200	100%	
10/20/2004	650	700	-8%	
11/3/2004	1200	1700	-42%	
11/10/2004	500	0	100%	
11/17/2004	16050	0	100%	
AVG	9185	430	65%	
STD	14391	566	52%	-1.9223

Appendix C - Winter
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Winter
Summarized Removal Efficiencies

Nutrients - Winter
Removal Efficiencies

Date	Orthophosphate	Total P	Total N
12/8/04	95%	0%	26%
1/4/05	12%	64%	74%
1/19/05	65%	44%	91%
2/2/05	52%	35%	68%
2/15/05	69%	43%	57%
Avg.	79%	46%	62%

Solids - Winter
Removal Efficiencies

Date	Conductivity	TSS	TDS
12/8/04	23%	38%	24%
1/4/05	-1%	89%	-2%
1/19/05	-20%	100%	-24%
2/2/05	-138%	79%	-152%
2/15/05	40%	-408%	41%
Avg.	-19%	42%	-14%

Metals - Winter
Removal Efficiencies

Date	Zinc	Lead	Copper
12/8/04	92%	100%	70%
1/4/05	11%	-46%	73%
1/19/05	-222%	-66%	11%
2/2/05	-496%	-151%	33%
2/15/05	87%	32%	-4%
Avg.	1%	-42%	61%

Appendix C - Winter
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Winter
Detailed Removal Data

Nutrients - Winter
Orthophosphate
n = 5 **df = 4**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
12/8/04	0.508	0.026	95%	
1/4/05	0.076	0.067	12%	
1/19/05	0.043	0.015	65%	
2/2/05	0.058	0.028	52%	
2/15/05	0.085	0.026	69%	
Avg.	0.154	0.032	79%	
STD	0.199	0.020	30%	-1.36092111

Nutrients - Winter
Total Phosphorous
n = 5 **df = 4**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
12/8/04	DNR	DNR	0%	
1/4/05	0.20	0.07	64%	
1/19/05	0.16	0.09	44%	
2/2/05	0.22	0.14	35%	
2/15/05	0.37	0.21	43%	
Avg.	0.24	0.13	46%	
STD	0.09	0.06	23%	-2.14928369

Nutrients - Winter
Total Nitrogen
n = 5 **df = 4**

Date	Inlet Concentration (mg/L N)	Outlet Concentration (mg/L N)	Removal Efficiency	t
12/8/04	2.85	2.10	26%	
1/4/05	3.10	0.80	74%	
1/19/05	2.20	0.20	91%	
2/2/05	3.70	1.20	68%	
2/15/05	3.00	1.30	57%	
Avg.	2.97	1.12	62%	
STD	0.54	0.70	24%	-4.69446387

Appendix C - Winter
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Winter
Detailed Removal Data

Solids - Winter
TSS
n = 5 **df = 4**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
12/8/04	1.60	1.00	38%	
1/4/05	3.60	0.40	89%	
1/19/05	0.75	0.00	100%	
2/2/05	2.42	0.50	79%	
2/15/05	0.65	3.30	-408%	
Avg.	1.80	1.04	42%	
STD	1.23	1.31	218%	-0.94905523

Solids - Winter
TDS
n = 5 **df = 4**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
12/8/04	316.56	241.25	24%	
1/4/05	1636.91	1675.67	-2%	
1/19/05	466.19	576.24	-24%	
2/2/05	613.83	1549.85	-152%	
2/15/05	1032.03	607.11	41%	
Avg.	813.10	930.02	-14%	
STD	532.26	641.10	77%	0.31375862

Appendix C - Winter
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Winter
Detailed Removal Data

Metals - Winter
Zinc
n = 5 **df = 4**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
12/8/04	143.30	11.46	92%	
1/4/05	437.73	391.06	11%	
1/19/05	9.88	31.86	-222%	
2/2/05	56.90	338.84	-496%	
2/15/05	155.09	20.80	87%	
Avg.	160.58	158.80	1%	
STD	166.28	189.23	253%	-0.01572937

Metals - Winter
Lead
n = 5 **df = 4**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
12/8/04	0.32	0.00	100%	
1/4/05	17.49	25.61	-46%	
1/19/05	7.09	11.75	-66%	
2/2/05	12.11	30.40	-151%	
2/15/05	20.84	14.14	32%	
Avg.	11.57	16.38	-42%	
STD	8.18	12.01	96%	0.74073481

Metals - Winter
Copper
n = 5 **df = 4**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
12/8/04	39.72	12.10	70%	
1/4/05	37.90	10.16	73%	
1/19/05	1.20	1.06	11%	
2/2/05	6.65	4.45	33%	
2/15/05	8.09	8.42	-4%	
Avg.	18.71	7.24	61%	
STD	18.54	4.46	34%	-1.34547083

Appendix C - Winter
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Winter
Load Removed

Load Removals - Winter
Seasonal Removal

	Baseflow Q (cfs)	Inlet Conc. Avg.	Outlet Conc. Avg.	Seasonal Load Removed (kg)	Seasonal Load Removed (lbs.)
Orthophosphate	0.13	0.154	0.032	3	8
Total Phosphorous	0.13	0.24	0.13	3	7
Total Nitrogen	0.13	2.97	1.12	53	117
TSS	0.13	1.80	1.04	22	48
TDS	0.13	813.10	930.02	-3348	-7366
Zinc	0.13	160.58	158.80	0	0
Lead	0.13	11.57	16.38	0	0
Copper	0.13	18.71	7.24	0	1

Seasonal Data – Winter
Coliform Bacteria (*E.coli*) Removal Efficiencies

Coliform Bacteria - Winter
E. coli

n = 9 **df = 8**

Date	Inlet *E.coli* (CFU/100mL)	Out *Ecoli* (CFU/100mL)	Removal Efficiency (%)	t
12/8/04	400	100	75%	
12/15/04	150	100	33%	
12/22/04	0	0	0%	
1/12/05	50	100	-100%	
1/19/05	200	0	100%	
2/2/05	450	100	78%	
2/9/05	400	100	75%	
2/16/05	1350	100	93%	
2/23/05	2550	0	100%	
AVG	617	67	50%	
STD	828	50	65%	-1.9882

Appendix D - Spring
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Spring
Summarized Removal Efficiencies

Nutrients - Spring
Removal Efficiencies

Date	Orthophosphate	Total P	Total N
3/2/05	61%	76%	61%
3/16/05	80%	55%	57%
3/30/05	69%	56%	67%
4/13/05	75%	66%	76%
4/28/05	79%	88%	87%
5/12/05	58%	42%	45%
Avg.	72%	68%	66%

Solids - Spring
Removal Efficiencies

Date	Conductivity	TSS	TDS
3/2/05	-114%	73%	-116%
3/16/05	-117%	80%	-119%
3/30/05	10%	-48%	11%
4/13/05	-14%	75%	-7%
4/28/05	20%	54%	23%
5/12/05	-32%	100%	-26%
Avg.	-41%	65%	-63%

Metals - Spring
Removal Efficiencies

Date	Zinc	Lead	Copper
3/2/05	-37%	-126%	87%
3/16/05	-153%	69%	0%
3/30/05	-7%	-23%	-31%
4/13/05	1%	21%	34%
4/28/05	-28%	23%	10%
5/12/05	0%	99%	80%
Avg.	-34%	-40%	54%

Appendix D - Spring
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Spring
Detailed Removal Data

Nutrients - Spring
Orthophosphate
n = 6 **df = 5**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
3/2/05	0.049	0.019	61%	
3/16/05	0.081	0.016	80%	
3/30/05	0.068	0.021	69%	
4/13/05	0.057	0.014	75%	
4/28/05	0.072	0.015	79%	
5/12/05	0.040	0.017	58%	
Avg.	0.061	0.017	72%	
STD	0.015	0.003	10%	-6.98261345

Nutrients - Spring
Total Phosphorous
n = 6 **df = 5**

Date	Inlet Concentration (mg/L P)	Outlet Concentration (mg/L P)	Removal Efficiency	t
3/2/05	0.13	0.03	76%	
3/16/05	0.22	0.10	55%	
3/30/05	0.16	0.07	56%	
4/13/05	0.18	0.06	66%	
4/28/05	0.50	0.06	88%	
5/12/05	0.23	0.13	42%	
Avg.	0.23	0.08	68%	
STD	0.14	0.04	16%	-2.78454059

Nutrients - Spring
Total Nitrogen
n = 6 **df = 5**

Date	Inlet Concentration (mg/L N)	Outlet Concentration (mg/L N)	Removal Efficiency	t
3/2/05	2.80	1.10	61%	
3/16/05	3.45	1.50	57%	
3/30/05	3.35	1.10	67%	
4/13/05	3.75	0.90	76%	
4/28/05	3.95	0.50	87%	
5/12/05	3.45	1.90	45%	
Avg.	3.46	1.17	66%	
STD	0.39	0.48	15%	-8.99923844

Appendix D - Spring
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Spring
Detailed Removal Data

Solids - Spring
TSS
n = 6 **df = 5**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
3/2/05	5.1500	1.40	73%	
3/16/05	2.4500	0.50	80%	
3/30/05	1.1500	1.70	-48%	
4/13/05	2.0000	0.50	75%	
4/28/05	3.0500	1.40	54%	
5/12/05	1.8000	0.00	100%	
Avg.	2.60	0.9167	65%	
STD	1.40	0.6735	53%	-2.65074516

Solids - Spring
TDS
n = 6 **df = 5**

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal Efficiency	t
3/2/05	1966.75	4241.32	-116%	
3/16/05	640.76	1403.96	-119%	
3/30/05	728.93	649.44	11%	
4/13/05	518.73	554.21	-7%	
4/28/05	484.26	373.10	23%	
5/12/05	417.36	526.09	-26%	
Avg.	792.8003	1291.3536	-63%	
STD	585.9385	1489.9148	63%	0.76277864

Appendix D - Spring
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Spring
Detailed Removal Data

Metals - Spring
Zinc
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
3/2/05	452.17	617.72	-37%	
3/16/05	32.45	82.12	-153%	
3/30/05	47.92	51.30	-7%	
4/13/05	53.36	52.88	1%	
4/28/05	26.02	33.42	-28%	
5/12/05	53.85	54.08	0%	
Avg.	110.96	148.59	-34%	
STD	167.55	230.36	59%	0.3235669

Metals - Spring
Lead
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
3/2/05	32.91	74.38	-126%	
3/16/05	11.25	3.46	69%	
3/30/05	3.22	3.94	-23%	
4/13/05	5.28	4.19	21%	
4/28/05	10.16	7.84	23%	
5/12/05	4.43	0.05	99%	
Avg.	11.21	15.64	-40%	
STD	11.11	28.88	79%	0.35120035

Metals - Spring
Copper
n = 6 **df = 5**

Date	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Removal Efficiency	t
3/2/05	44.10	5.53	87%	
3/16/05	7.24	7.23	0%	
3/30/05	9.65	12.65	-31%	
4/13/05	6.85	4.53	34%	
4/28/05	11.20	10.13	10%	
5/12/05	14.05	2.79	80%	
Avg.	15.51	7.14	54%	
STD	14.25	3.68	47%	-1.39254261

Appendix D - Spring
Stormwater Wetlands
Baseflow Sampling

Seasonal Data – Spring
Load Removed

Load Removals - Spring
Seasonal Removal

	Baseflow Q (cfs)	Inlet Conc. Avg.	Outlet Conc. Avg.	Seasonal Load Removed (kg)	Seasonal Load Removed (lbs.)
Orthophosphate	0.13	0.061	0.017	1	3
Total Phosphorous	0.13	0.23	0.08	5	10
Total Nitrogen	0.13	3.46	1.17	67	148
TSS	0.13	2.60	0.92	49	108
TDS	0.13	792.80	1291.35	-14594	-32107
Zinc	0.13	110.96	148.59	-1	-2
Lead	0.13	11.21	15.64	0	0
Copper	0.13	15.51	7.14	0	1

Seasonal Data – Spring
Coliform Bacteria (*E. coli*) Removal Efficiencies

Coliform Bacteria - Spring
E. coli
n = 7 **df = 6**

Date	Inlet E.coli (CFU/100mL)	Out Ecoli (CFU/100mL)	Removal Efficiency (%)	t
3/9/05	100	0	100%	
3/16/05	1650	0	100%	
3/30/05	1000	0	100%	
4/6/05	300	100	67%	
4/13/05	50	0	100%	
5/4/05	150	0	100%	
5/11/05	750	100	87%	
AVG	519	325	93%	
STD	571	840	563%	-0.5049