Exploration of the Ecological Integrity of a Constructed Wetland vs. a Natural Stream on the Villanova University Campus in Southeastern Pennsylvania

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Fall 2004

Independent Study
Environmental Studies Concentration
Under the direction of Dr. Chace and Dr. Henderson.

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Introduction

Water is one of the most precious natural resources that is found on this earth. Excellent water quality is important, because it is one of the conditions that needs to be present to support all means of life and for a healthy ecosystem. Wetlands play a critical role in supporting biological life, as well as influencing water quantity/quality issues. According to the EPA wetlands are defined as, “lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface” (Wetlands Definitions, 2003). Therefore, since water, plants, and animals are an essential component of wetlands, it is important to maintain a healthy waterbody for them.

Healthy waterbodies represent ecological integrity. Ecological integrity is made up of three parts, physical, chemical, and biological integrity. Ecological integrity is a way to determine the overall health of a particular water body. When one or more of these three aspects is lacking, the whole system is likely to suffer because all of the factors that make up ecological integrity affect one another. Assessing the ecological integrity of certain waterbodies, allows scientists to get a general picture of the overall health of a waterbody (Biological Assessments and Criteria 2002).

Physical integrity is usually measured by the total amount of buffer, cover, and percent of healthy vegetation which surrounds a water body. Chemical integrity is measured by chemical tests of certain nutrients and other variables like dissolved oxygen, which can be conducted in a lab. Biological integrity is measured by biological assessments of the macroinvertebrate population in a water body. When looking at macroinvertebrate population in particular, the abundance of sensitive species, ones which are intolerant of pollution, are really the most important. Sensitive species can only be found in places where dissolved oxygen is high and other factors are perfect, therefore sensitive species are a good indicator of healthy biological communities (Macroinverterbrates and Water Quality, 1996). Certain sensitive species in southeastern Pennsylvania include: the water penny (*Arachnid*), fishing spider (*Arachnid*), gilled snail (*Gastropoda*), riffle beetle (*Coleoptera*), mayfly nymph (*Ephemeroptera*), stonefly nymph (*Plecoptera*), and non-net spinning caddisfly larvae (*Tricoptera*) (Delaware Riverkeeper Network's Volunteer Monitoring Program).

One way wetlands can improve ecological integrity is by increasing water quality. Presently, wetlands are being used for many different functions, one of which is for catching stormwater runoff from things like impervious surfaces, fertilizers from lawns, etc (Farrell and Scheckenberger, 2003). For example, Villanova University has constructed a series of stormwater wetlands primarily designed to catch water from impervious surfaces during storm events to improve the water quality leaving campus into nearby stream networks.

This paper will give a general history of wetlands in the United States, relevant studies that are related to water quality, and their use at Villanova and around the world. As a case study, it will examine the ecological assessment of Villanova's engineered, law school wetlands in comparison to a natural west campus stream.

Background/History

The first record of wetlands in the United States began around the 1600s, which is the time when early European settlers came to America. At this time, the area that was to become the United States had about 221 million acres of wetlands. This pattern started to change in the 1700s because the European settlers saw wetlands as places that were contaminated and which needed to be reclaimed so they could be used for productive purposes. Much of the wetlands in the mid 18th century were drained and used as agricultural fields. In the settlers' minds, this allowed the land to become useful as well as increasing its value (Dahl and Allord 2004).

During the 1800s, westward expansion was a main priority. Because of this large expansion, wetlands were being drained for farmland at a larger scale. From 1810-1840, new agricultural improvements like plows, rakes, and cultivators, made it easier to farm land in places like the Midwest, which was previously not able to be used for farming. This was one of the reasons for the big conversion of wetlands into farmland at this time. By the late 1800s, because of these new agricultural improvements, places like Illinois, Indiana, and Ohio started to set up draining factories, which drained about 11 million acres of land for farming purposes (Dahl and Allord 2004).

After the Civil War, the railroad industry boomed and was rapidly developing all types of lands, including wetlands. One example of this was the Black Swamp, which is located in northwestern Ohio. This forested wetland was 120 miles wide by 40 miles long, and was completely destroyed by the end of the 19th century (Dahl and Allord).

In the 20th century, two projects were most notable for the destruction of wetlands, these projects were: California's Central Valley Project (CCVP), and the lock and dam system on the Mississippi River. The CCVP was set up to drain wetlands so that they could be used for cultivation. It started in the last half of the 19^{th} century but really picked up by the early 20^{th} century. By that time only 30% of the wetlands remained untouched. The lock and dam system on the Mississippi River created dams on what was previously hundreds of natural lakes and ponds scattered throughout wooded areas. These dams were built on tributary rivers entering the valley, which prevented the changes in water levels that normally occurred in these areas; ultimately it altered the habitat and changed the types of wildlife that lived within these regions (Dahl and Allord 2004).

In the 1930s, better technology was invented and things like mechanized farm tractors overtook horses and mules which were used in the past. The invention of the tractor contributed to the loss of millions of acres of small wetlands and prairie potholes in the Midwest and the North-central States. Another negative thing that happened around this time was that the government provided free engineering services to farmers to drain wetlands (Dahl and Allord 2004).

Previously, almost all of the attitudes and actions taken toward wetlands were ones with negative implications. Only recently has there been an increased awareness of the value and important environmental functions of wetlands. In 1991, the U.S. Fish and Wildlife Service (1991) estimated that from 1987-1990 about 90,000 acres were added to the remaining 100 million or so left in the nation's wetland inventory (Dahl and Allord 2004).

Today, increased education and public awareness is on the rise, therefore, the United States is now making an effort to restore some of the wetlands that have been destroyed. For example, attempts are being made to restore the Everglade's marshes in Florida. In California, only 14% of the original wetlands in this area are left, the remainder have and still are degraded or lost by things like irrigation, hydroelectric power, and municipal and industrial water supplies (Dahl and Allord 2004). In conclusion, the United States only has an estimated 100 million acres of wetlands left, compared to the original 221 million acres (Dahl and Allord 2004). Overall, 50% of wetlands in the United States have been lost since the 1600s. As the increasing importance of healthy wetlands is being noticed, a change in attitude has followed as well.

Today, especially in highly impacted areas, degraded wetlands are being constructed and restored for a number of different reasons, which range from catching stromwater runoff to improving water quality. Stormwater wetlands are systems which remove pollutants from stormwater runoff primarily through wetland vegetation. Research on the uses of stormwater wetlands started around the 1950s. The 1980's was the first decade to really see an increase in the use of stormwater wetlands, primarily for wastewater treatment and catching runoff from agriculture. Currently wetlands are being used all over the United States to catch floodwaters and to improve water quality (Wetland History).

Literature Review

Importance of Wetlands

One main reason why wetlands are important is that they have tremendous amounts of biodiversity as well as many important ecological and economic uses. Some of the uses that wetlands provide are protecting and improving water quality, storing floodwaters, treating sewage and providing habitat for wildlife (Miller 2004: 651). Wetlands carry out these functions by decomposing and releasing nutrients that "feed" estuaries. The consumption of these nutrients and debris are consumed, this is how wetlands improve water quality. Wetlands are also the center of ecosystems; they provide energy and nutrient flow throughout ecosystems.

Biodiversity is important because it is the different life-forms and processes that presently survive among current environmental conditions. The loss of biodiversity would weaken the ability of ecosystem services, and the life in these ecosystems to handle changes in the environment. On the other hand, high diversity equals high resiliency/stability; therefore it would be harder to disrupt a natural ecosystem that has a high amount of species diversity (Miller, 76, 2004). Therefore, biodiversity is one of the major reasons why the protection and restoration of wetlands are important.

One of the ways to test the health of a wetland is by monitoring ecological integrity. According to the Environmental Protection Agency (Biological Assessments and Criteria 2002) a healthy water body has high ecological integrity. The three integrated aspects that comprise ecological integrity are the physical, chemical, and biological components of a wetland. After biological integrity is assessed then the diversity of a water body will be able to be calculated, which will help determine the amount of biodiversity that is normally present in a water body. According to guidelines stated by the EPA, Office of Water Quality, if any one of these three aspects of integrity is deficient, then the whole ecosystem suffers as a result (Spieles and Mitsch 2000).

Water Quality Issues

Previous research has shown that wetlands are not only places which have a high amount of biodiversity, but also have a number of beneficial uses. Since the 1980s, stormwater wetlands have been created for a number of different uses, some of which include: catching runoff, removing pollutants, and improving downstream water quality.

Recently, one of the many ways that wetlands have been used is for cleaning up polluted water (Landers, 2004). Landers talks about how one of the world's largest constructed wetlands of about, 2,300 to 6,700 acres, is being used to remove significant amounts of pollutants from runoff before entering the Everglades. Pollution removal is done when wetland vegetation grows absorbing many of the nutrients found in agricultural runoff like nitrogen and phosphorus. This study has shown that constructed wetlands are making tremendous improvements in water quality in places like the Everglades (Landers, 2004).

One of the major pollutants that are usually a concern when looking at water quality is phosphorous. Phosphorous is available naturally in water, in small amounts, and is a limiting nutrient. This means that naturally, plants can only grow in relation to the amount of phosphorus in the water. Therefore, if large amounts of this nutrient enter into a water body through sources like fertilizers which come from agriculture, this can have a negative effect on water quality through eutrophication. Eutrophication is caused when excessive algae blooms, because of the abundance of nutrients found in the water. When all of the algae from the bloom die, decomposing bacteria use up most of the dissolved oxygen, making oxygen levels too low for aquatic life to survive. These constructed wetlands have been designed to take out about 55 tons (50Mg) of phosphorus annually. This reduction would normally be done using wetland vegetation like cattails or other wetland vegetation to absorb this nutrient. The research conducted has shown that instead of cattails, submerged aquatic vegetation does a more efficient job of absorbing pollutants like phosphorus, and therefore is being used to enhance the absorption of this nutrient (Landers, 2004).

In another study, Bavor and Davies (2001) discuss how constructed stormwater wetlands are being used to improve pollutant management performance over detention ponds. They compared different aspects of water quality e.g., fecal coliforms, sediment particle size, phosphorus, and nitrogen, at the inlet and outlet for both a pond and a constructed stormwater wetland in close proximity. Overall, they found that the constructed stormwater wetlands did a better job at removing fine sediment particles, which is associated with reducing fecal coliform bacteria, nitrogen, and phosphorus. Therefore, stormwater wetlands can improve the chemical integrity and thus ecological integrity of a freshwater stream.

Biological Assessment

When trying to measure the ecological integrity of a water body, all three aspects are important. Physical integrity is made up of the surrounding area of a water body, and is usually measured by the amount of buffer and cover, between the water body and these characteristics (Biological Assessments and Criteria 2002). Chemical integrity is measured by the level of nutrients critical to stream function like nitrogen and phosphorus as well as dissolved oxygen and pH. Biological integrity is measured by biological assessments of the macroinvertebrate population in a water body, three of which are especially important which are; sensitive species, species richness, and diversity. After all three of these aspects are assessed, a researcher can surmise how healthy a particular water body is doing. All of these aspects of ecological integrity are equally important, but for the purpose of this study the way of measuring biological integrity is the focus and thus deserves additional attention (Biological Assessments and Criteria 2002).

‘Bioassessments’ are defined by the EPA as, “An evaluation of the biological condition of a waterbody using biological surveys and other direct measures of the resident living organisms”; these assessments are the most important when looking at biological integrity. Bioassesments are surveys which look for all types of aquatic life like worms, leeches, insects, crayfish, and many other organisms (Biological Assessments and Criteria 2002).

One of the important reasons why bioassessments are so important is that they measure the cumulative effects of things like excess nutrients, toxins, variation in temperature, and sediments of a waterbody over time. Therefore, they are important because chemical and physical measures only measure these aspects at one particular time; bioassessemnts measure the affects of all of these changes over a period of time. This is why it is important to look at all three aspects of ecological integrity together (Biological Assessments and Criteria 2002).

Generally, a bioassessment is a good indicator of how well a water body is doing, chemically and physically. Usually, if a waterbody is healthy biologically, then the chemical and physical aspects of that water body will be healthy as well; this is why testing all three aspects of a water body together (Physical, Chemical, and Biological) is important. Because all three aspects of integrity are related, testing them all together gives a good overall picture of how healthy a water body is (Biological Assessments and Criteria 2002).

Bioassessments are not required for all states in the United States. In 1994, only twenty states had started a biological assessment program for rivers and streams, and only fourteen states had these types of programs already in action. Because of the importance of biological assessments in measuring biological integrity, more states, if not all, need to start creating programs and biological criteria for all types of water bodies (Biological Assessments and Criteria 2002).

Previous research conduced by Ludwa (1994), attempted to link the relationship of wetland water quality and land use, to the biological community, in an attempt to create a biotic index based on aquatic insect communities. This study was conducted and was monitored in twenty wetlands around the Puget Sound area. Overall, the study found that the total species richness was significantly related to the changes in the watershed and urban development. These results have now led to the design of a biotic index for the wetlands around the Puget Sound region, so that researchers can better monitor the health of these wetlands (Ludwa 1994).

Another study conducted by Spieles and Mitsch (2000) looked at the macroinvertebrate community structure in constructed wetlands. They found that the area of the wetlands that they had sampled, which had the lowest species diversity, was the inflow of the wetlands. Another interesting conclusion was that the constructed wetlands did a good job at reducing nitrogen and phosphorus levels from the inflow to the outflow of the wetlands. In relation to the invertebrate community, Spieles and Mitsch (2000) found that the water quality did have a positive affect on the macroinvertebrate community, which was only significant in the beginning area of the inflow, where water quality was the worst.

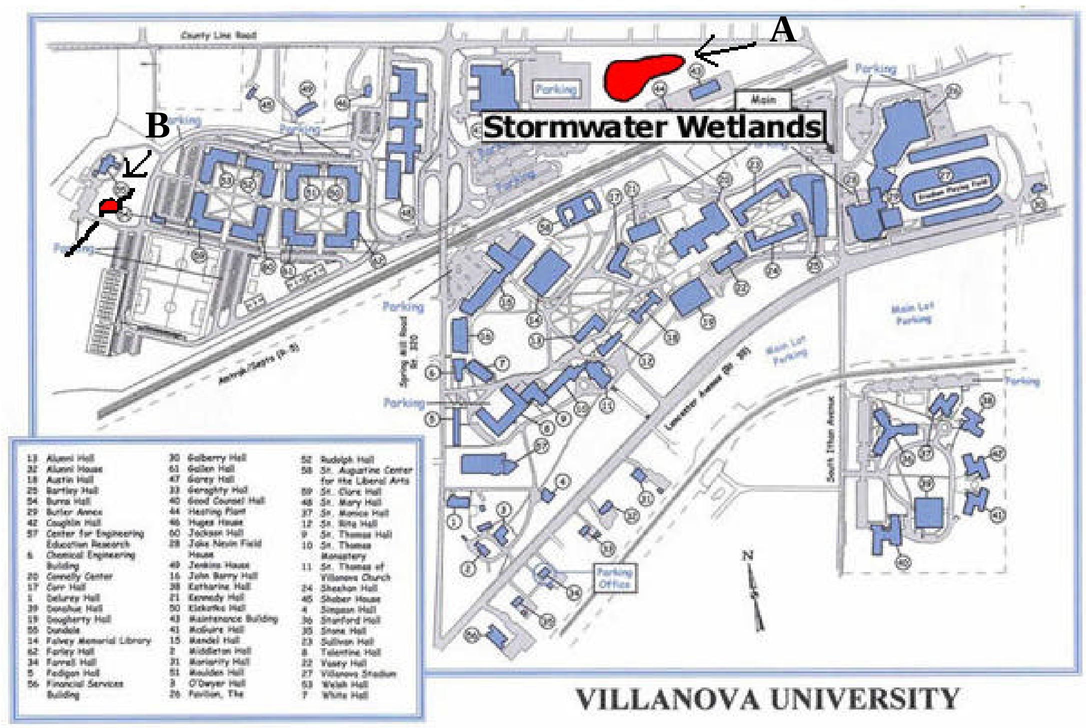
Case Study

The overall objective of my study is to assess the ecological integrity of Villanova's constructed stormwater wetlands, in comparison, to the relatively natural west campus stream. I predict that the stormwater Wetlands and the natural west campus Stream will have equal levels of biological and thus ecological integrity. The biological assessment compares richness, abundance, and species diversity of macroinvertebrates, as well as special attention to the most sensitive species. The comparison of sensitive species between the two sites provides the best measure of integrity, therefore where sensitive species are rare or absent is a clear indicator of poor water quality.

Methods

Villanova University currently has one stormwater wetland which finished construction in September of 2001. This Wetland is primarily designed to catch runoff from the 41 acres that surrounds the site and filter out excess nutrients like nitrates and phosphorous. However the biological aspects of the Wetlands were never examined and the current status of the macroinvertebrate population is unknown, which is why a biological assessment needed to be conducted.

Biological assessment of the stormwater Wetland and the west campus Stream took place, on the Villanova University campus in southeastern PA, from May 25th to October 8th, 2004. The law school stormwater wetlands ("A"), located along County Line Road, is a constructed stormwater wetland designed to catch runoff from campus and surrounding surfaces (Map 1). The west campus stream ("B"), located next to the west campus tennis courts, is man-made and has not been altered since 1996 (Map 1).



Map 1. Map of the Villanova university campus. Letter "A" shows the location of the wetlands, and figure "B" shows the location of the stream.

At both of these sites, three subsites were sampled which had different physical features. The inlet enters each site through a culvert into a stream-like manner, the pond/sediment forebay looked like a pond, and the outlet formed back into a stream. Each subsection was sampled on each sampling day.

A visual physical assessment was conducted from the Delaware Riverkeeper Network for each of the three subsites in both the wetland and the stream. The information was compiled into the Delaware River Keepers ranking system for physical characteristics of a waterbody. It ranges on a scale from 1 to 10, 10 being excellent.

Then, an average of all the physical components were taken and the scores can range from, <6 poor, 6.1-7.4 fair, 7.5-8.9 good, >9 excellent (Appendix A).

Each site was sampled on the same day, and the macroinvertebrates were identified at each site down to morphospecies. Sampling occurred once within each of the 15-day periods at the beginning and the end of the month from the 15th of May to the 15th of October, for a total of ten sampling days. Weather was calm for at least two days prior to sampling.

Macroinvertebrates were then sampled at each of these six subsites in a single day, ten times throughout the four and a half month period. Ten 1x1 meter nettings were sampled at each of the six subsites, using a Wildco Bottom Aquatic Kick Net (45.72x45.72cm) frame with 900um mesh netting. Macroinvertebrates were caught, identified, and counted down to morphospecies, using the criteria from the Delaware Riverkeeper Network as a guide (Appendix B).

Water chemical analysis was conducted by Dr. Traver's lab (CE&E) and sampling days were paired up as close as possible to the macroinvertebrate sampling days at each of the six subsites. Chemical tests included, pH, conductivity (µS/cm), orthophosphate (mg/L PO4), total nitrogen (mg/L N), and total phosphate (mg/L P).

Data were compiled and analyzed using JMP 5.01 (SAS Statistical Institute). Differences in morphospecies richness, abundance and diversity (Simpson's Index) across the six subsites, were determined with ANOVA and Student's t-test. Means and Standard Errors are reported unless otherwise noted; all statistical tests were measured at the 0.05 level of significance.

The chemical data for the inlet to the wetlands were sampled for the two inlet pipes separately, because one enters from main campus and the other from west campus. The chemical data were significantly different, but were collected separately for analysis, for a study beyond the scope of this one. Therefore the chemical analysis was averaged and entered as one value, even though the volume between the pipes may have been different.

Species abundance was calculated as the actual number of organisms of each species that was found at each subsite. *Species richness* was calculated as the number of species present. *Species diversity* was also calculated as a function of the relative amount of each species present and species richness. Species diversity is measured by the Simpson's Diversity index (reference). *Sensitive Species* was calculated and is the total abundance of sensitive species found. Sensitive species are defined as the, water penny (*Arachnid*), fishing spider (*Arachnid*), gilled snail (*Gastropoda*), riffle beetle (*Coleoptera*), mayfly nymph (*Ephemeroptera*), stonefly nymph (*Plecoptera*), and non-net spinning caddisfly larvae (*Tricoptera*).

Results

Physical - Physically, the west campus stream is very similar for all three subsites. When all three subsites were averaged, the buffer that surrounds the west campus stream extends from a range of 4.3 m on the left side to 6.9 m on the right side of the site. On average, about 50% of the site has trees and shrubs growing. Over 75% of the vegetation is alive and healthy.

Likewise, the Wetlands are very similar for all three subsites as well. When all three subsites are averaged, the buffer that surrounds the Wetlands extends from about 7.5 m on either side. On average, about 50% of the site has trees and shrubs growing. Over 75% of the vegetation is alive and healthy. Overall physical scores for all six subsites were calculated (Table 1.) The majority of the original planted vegetation, like the Pickeral Weed (*Pontederia cordata*), Arrow Arum (*Peltandara virginica*), Lizard's Tail(*Saururus cernus*), Iris(*Iris versicolor*), and Sweetflag (*Acorus calamus*) have all been over taken by the establishment of *Typha* and *Phragmites* (Plant Study).

Table 1. Overall Physical Scores of Both the Wetlands and the Stream by subsite

	Physical Score	
Subsite	Stream	Wetland
Inlet	5.00	4.25
Pond	4.00	6.70
Outlet	6.00	6.00

***Chemical* -** Between sites, the Wetlands were significantly more acidic and had a higher amount of conductivity than the Stream; the sites did not differ significantly for any other chemical tested (Table 2).

Table 2. Means (SE) of the chemical test conducted at the Wetland and the Stream on the Villanova Campus

Parameters	n	Wetland	Stream	n	*t*-valve	*P*
pH	24	6.98 (0.03)	7.20 (0.03)	24	4.471	< 0.0001
Conductivity (uS/cm)	24	661.87 (36.49)	339.02 (19.43)	24	0.912	<0.0001
Orthophosphate (mg/L PO4)	24	0.06 (0.01)	.08 (0.01)	24	-0.908	0.3665
Total Nitrates (mg/L N)	23	1.81 (0.23)	1.55 (0.17)	21	0.875	0.3690
Total Phosphates (mg/L P)	18	0.09 (0.01)	0.10 (0.02)	18	0.875	0.3875

Within sites, only total nitrates differed, where the inlet had a higher amount of total nitrates than the outlet at both locations (Figure 1.).

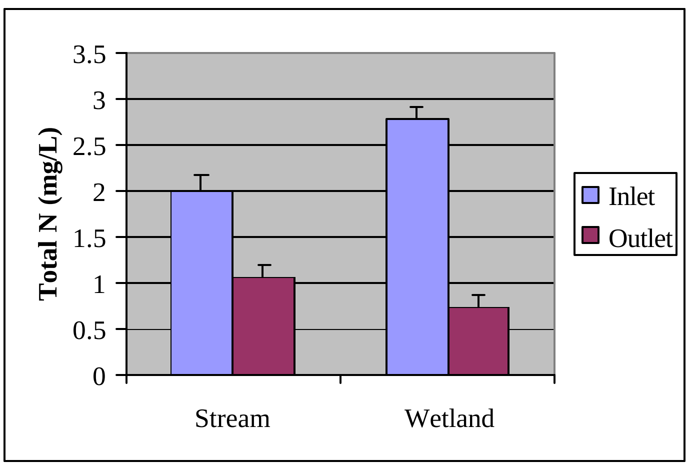


Figure 1. Mean (SE bars) difference in Total Nitrates by of the Inlet and Outlet by Location on the Villanova Campus

Biological – A mean of 8.46 species were identified at the Stream and 7.23 at the Wetlands, when looking at species richness for each day sampled. However, between sites there was no overall difference in species richness (t=1.905, df=58, P=0.0618). However, among the inlets subsites, species richness was higher in the inlet to the Stream than the inlet to the Wetlands (t=4.556, df=18, P =0.0002; Figure 1). There was no difference in species richness by site for both the pond and the outlet (Figure 1). Species richness by subsite was different in the Wetlands, no difference was found of species

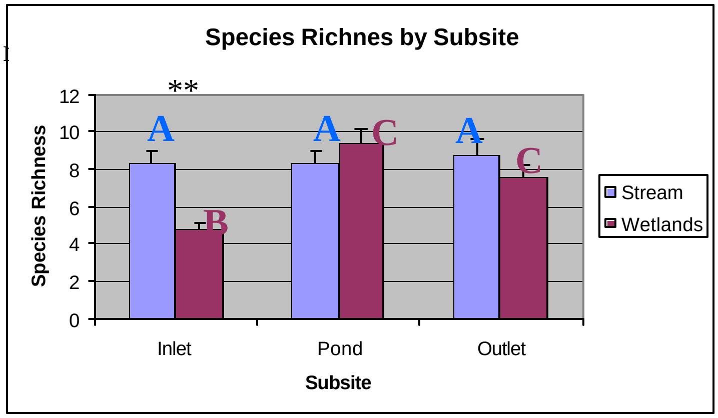


Figure 2. Mean (SE bars) macroinvertebrate species richness across three subsites on two sites on the Villanova campus, May-October, 2004. Corresponding letters denote significance (Wetlands: Tukey HSD q 2.4794, P<0.05). Significance differences between sites at each subsite noted as * P<0.05, ** P<0.01.

Between sites, species diversity was not different between the Stream and the Wetlands (t=0.986, df=58, P =0.3280). By subsite, species diversity was higher in the inlet to the Stream than the inlet to the Wetlands (t=8.788, df=1,19, P =0.0001; Figure 3). Species diversity was higher in the pond of the Wetlands than the pond of the Stream (t=-2.130, df=1,19, P =0.0472; Figure 3). However, species diversity for the outlet was not significantly different between the Stream and the Wetlands (t=1.162, df=1,19, P =0.2605; Figure 3). Species diversity by subsite was different in both the stream and the wetlands (Figure 3). Species diversity was highest in the inlet of the Stream and highest in the Pond of Wetlands (Figure 3).

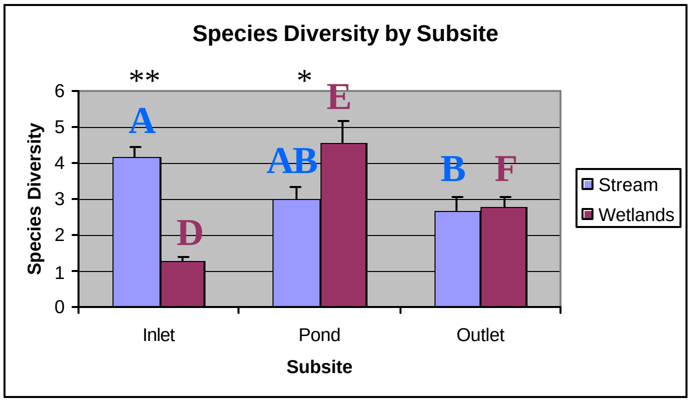


Figure 3. Mean (SE bars) macroinvertebrate species diversity (Simpson's Index) across three subsites on two sites on the Villanova campus, May-October, 2004. Corresponding letters denote significance (Stream: Tukey HSD q=2.4794; Wetlands: q=2.4794, *P*<0.05). Significance differences between sites at each subsite noted as * *P*<0.05, ** *P*<0.001.

Sensitive Species - Total sensitive species richness between the Stream and the Wetlands was not significantly different (t=1.051, df=58, P =0.2975; Figure 4). The outlet of the Stream has significantly more sensitive species than the Wetlands (t=3.095, df=1,19, P= 0.0062; Figure 4). The average number of sens itive species was similar between the inlets and ponds of the Stream (t=1.282, df=1,19, P =<0.2163) and the Wetlands (t=-1.414, df=1,19, P =<0.1745; Figure 4). Total sensitive species by subiste were different in both the Stream and the Wetlands. Total sensitive species were highest in the outlet of the Stream and lowest in the inlet of the Stream (Figure 4).

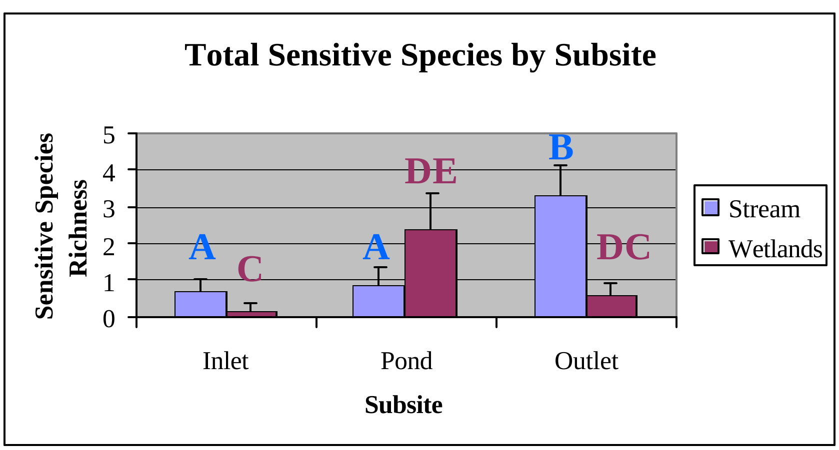


Figure 4. Mean (SE bars) total sensitive species richness across three subsites on two sites on the Villanova campus, May-October, 2004. Corresponding letters denote significance (Wetlands: Tukey HSD q 2.47942, *P*<0.05). Significance differences between sites at each subsite noted as * *P*<0.05, ** *P*<0.001

***Specific Sensitive Species Responses* -** Mayfly nymphs and damselflies were lumped together for this study because of identification difficulties. There were no stonefly nymphs or fishing spiders found in the Wetlands (Table 3.).

Table 3. Means (SE) of total sensitive species abundance at the Stream (n=30) and the Wetlands (n=30), collected between May 25th and October 8th on the Villanova University campus.

Sensitive Species	n	Wetland	Stream	*t*-valve	*P*
Stonefly Nymph	30	0.07 (0.05)	0.10 (0.07)	0.384	0.7026
Water Penny	30	0.00 (0.00)	0.83 (0.29)	2.854	0.0060
Gilled Snail	30	0.00 (0.00)	0.07 (0.05)	1.439	0.1555
Fishing Spider	30	0.00 (0.00)	023 (.11)	2.041	0.0458
Riffle Beetle	30	1.00 (.37)	0.40 (0.17)	-1.469	0.1473

Discussion

The Wetlands and the Stream had the poorest amount of buffer, cover, and/or vegetation at the inlet, but increased toward the pond and outlet. In comparison, total nitrates, were lower at the outlets of both the Wetland and the Stream. Chemically, the outlets had lower nitrates than the inlet, perhaps due to the amount of buffer, cover, and/or vegetation found at the outlets which may absorb nitrates (Bavor and Davies (2001). Species richness, diversity, and total sensitive species were consistently low at the inlet of the Wetland, suggesting that these disturbed conditions reduce macroinvertebrates in the biological community. Richness, diversity and sensitive species were highest among the pond of the Wetlands, suggesting that the activity associated with stormwater management has not impacted this area any more than what is found in the less managed Stream system. Stonefly nymphs and fishing spiders, two of the sensitive species, were not found in the Wetlands, suggesting that this community is impacted relative to the Stream.

By comparison, the Stream had no difference among species richness across subites. Interestingly, diversity at the inlet of the Stream was the highest, which is surprising, given the poor combination of buffer, cover, vegetation, and high nitrates. However, this is an area that is probably the least disturbed of all six subsites. At the outlet of the Stream, water pennies and fishing spiders were most abundant and nitrates were the lowest, suggesting that the outlet of the stream is most likely the healthiest subsite among all six subsites. Therefore, while the macroinvertebrate population of the Stream was found to be healthiest (high richness, diversity, sensitive species) at the outlet, the pond (sediment forebay) was the healthiest site among the Wetlands. Therefore, I can conclude that overall, the highly managed stormwater wetland has an ecological integrity similar to that of the less managed Stream. The Stream is complete with a macroivertebrate community that includes sensitive species.

Villanova’s constructed wetlands were primarily designed to catch runoff from impervious surfaces and improve water quality before it reaches downstream (Villanova University, 2003). Therefore, flood control and nutrient uptake are the main purposes for many stormwater wetlands, which both the Wetlands and the Stream support. These nutrients are filtered out of this system because the planted vegetation absorbs these nutrients in order to grow, which is the primary goal of the Stormwater wetlands on Villanova’s campus.

Coincident with the chemical and physical goals of a stormwater project, are the responses by the ecological community (Biological Assessments and Criteria 2002). The macroinvertebrate community is impacted by the other two aspects of ecological integrity, which are physical and chemical factors. The sensitive species were almost none existent in the Wetlands. This is common among constructed stormwater wetlands, primarily because constructed stormwater wetlands are known to have lower amounts of ecological functions than natural wetlands. Mitsch and Wilson (1996) suggest that ecological function is a combination of a number of different variables that all are interrelated like plants, soils, wildlife, hydrology, water quality and engineering. However, all of these factors are almost never met because of the different planners that are required when constructing a wetland, and the complexity of wetlands themselves (Barr Engineering Co). Therefore, while chemical remediation and habitat restoration may occur readily following the implementation of a stormwater management project, trying to match the functions of water quality along with a habitat that compliments a diverse amount of macroinvertebrates is difficult. These difficulties in bringing all of the ecological aspects of constructed wetlands arise because the design of the wetland is usually for one purpose or another. Usually, engineers, scientist, etc. have little understanding in dealing with wetland ecology and therefore the constructed wetlands is designed in a way that compromises all aspects of the wetlands ecological functions.

Bavor and Davies (2001) found that location was important when looking at species richness and diversity because it was highest at the outlet of all their study sites. In comparison, I found the Stream had the highest species diversity among the inlet, and the Wetlands had the highest species diversity at the pond. However, higher species diversity is common among ponds in stormwater wetlands because the ponds are more likely prevent most of the macroinvertebrate species, from moving down stream (Barr Engineering Co). I suspect the difference between Bavor and Davies (2000) and my study occurred because species diversity and richness in constructed wetlands tends to be highest at the pond (sediment forebay). On the other hand, the highest diversity at the inlet of the Stream was unusual, one reason for this may be because of little disturbance in this area of the stream.

Sensitive macroinvertebrates are the aquatic ecologists, “canary in a coal mine,” providing a quick index of healthy stream conditions. When conditions are poor, this causes sensitive macroinvertebrates to disappear rapidly (U.S. Environmental Protection Agency, 2004). According to the Delaware River Keepers, in southeastern PA there are seven sensitive macroinvertebrates: water penny, fishing spider, gilled snail, riffle beetle, mayfly nymph, stonefly nymph, and non-net spinning caddisfly larvae (Delaware Riverkeeper Network’s Volunteer Monitoring Program). Unfortunately, sensitive species are the most affected by pond-like structures of the sediment forebay (Pond), primarily because the pond has an affect on the flow, dissolved oxygen, and nutrients moving through the system. Therefore sensitive macroinvertebrates rarely make it to the outlet, which matches what I found. Outlet structures like sediment traps also hinder the ability of macroinvertebrates to move through the system (Taylor and Henkels, 2000).

The lack of sensitive species in the wetland may be a function of time, since the last disturbance. The last major man-made disturbance of the Wetlands was in the summer of 2003 when the sediment forebay was dredged. Sensitive macroinvertebrates can take up to anywhere from 1 to 3 years to establish themselves in a system, therefore this may be one of the reasons that sensitive macroinvertebrates are lacking it the Wetlands.

Water pennies require fast moving streams with lots oxygen and rocks. Likewise riffle beetles require fast moving streams with an abundant oxygen supply. Stoneflies require lots of oxygen and little disturbance. Gilled snails need an abundant supply of oxygen for respiration (University of Virginia, 1999). All of these sensitive species have at least one thing in common; they all require high levels of dissolved oxygen to survive. The majority of these species are usually found in stream-like habitats. The outlet to the stream has the highest amount of sensitive species which matches up nicely to the stream like habitat. In comparison, the pond of the Wetlands had the highest abundance of sensitive species, which supports Taylor and Henkels (2000) contention that ponds in wetlands hinder the movement of sensitive species through the system.

Dissolved oxygen is one of the most important factors that is needed in order for many sensitive species to survive. Dissolved oxygen, which is important to the majority of sensitive species, was not tested at any of the subsites. This is one limitation which should be tested in future studies so that a comparison can be made between sensitive species and dissolved oxygen.

Additional limitations to this study came along while doing the data analysis. Chemical data for the each pipe at the inlet to the Wetlands were tested individually, because each of the inlet pipes came from different sources around campus. However, I sampled the maroinvertebrate population at the two inlet pipes and combined the data into one which, was labeled as the “Wetlands inlet”. A future study may conduct separate samples from both of the inlet pipes to the wetlands to see how the water from different locations has an affect on the macroinvertebrate population found there. I would expect to see a difference in the two inlet pipes because the water quality varied among both inlet pipes.

Since outlet structures like, sediment traps and pipes, affect the ability of macroinvertebrates to be able to move through a system, additional future research may look at the effects of these structures on the macroinvertebrate population downstream.

One possible solution next time the sediment forebay is dredged would be to collect some of the macroinvertebrates that are already in place and keep them alive in a lab until the dredging is over. After the sediment forebay has settled back down, then these macroinvertebrates could be used as a catalyst to ‘seed’ the forebay, so that these species would not have to take time to reappear naturally.

The Stream is probably the best available site, to compare to the Wetlands. This is true because the stream is local; relatively less impacted, and does a decent job of stormwater management. However, the Stream in comparison to the Wetland has been less disturbed, which is a factor when controlling for sensitive species. The control for this research was comparing the sensitive species in both the Wetlands and the Stream. In comparison, the stream had a greater abundance of sensitive species which ultimately means that the Stream probably has not been disturbed as much as the wetlands have. On the other hand, the Wetlands had almost no sensitive species. The last time the Wetlands were majorly disturbed, was when the sediment forebay was dredged in the summer of 2003, in comparison to the pond of the Stream, which was dredged in 1996 (Personal Contact). The best control would probably be to find another stormwater wetland in southeastern Pennsylvania and compare the two wetlands. Villanova may be able to better manage the west campus stream site by avoiding the use of fertilizers on the lawns, and by creating a larger buffer around the pond.

In conclusion, the Wetlands have the highest diversity and sensitive species in the pond and the Stream had the highest abundance of sensitive species in the outlet, which is a pattern common among to both systems. On the other hand, the Stream shows the highest diversity within the inlet, but has the highest abundance of sensitive species at the outlet, which is a good sign that the outlet to the Stream is healthy. Overall, the management of the Wetland is the most important aspect of helping the ecological function of the Wetland. If practices, like dredging, could be done less often, then the disturbance of the Wetlands would be brought to a minimum. Additionally, if practices like seeding the macroinvertebrate would take place after practices like dredging, then this would help the macroinvertebrate population to recover quicker. However, since disturbance is one of the main reasons why sensitive species cannot survive, any measure taken to minimize disturbance would be helpful in trying to help the population of these sensitive species establish themselves.

Acknowledgements:

I would like to thank Villanova’s Civil/Environmental Engineering Lab and Dr. Traver for providing chemical test which were important to my study. I would also like to thank Dr. Olson and the Environmental Studies program for providing access to various field equipment. In addition, I would like to thank Dr. Chace and Dr. Henderson for helping me outline the study and making many revisions to the paper along the way. Finally, I would like to thank Taras and Kathleen Ortynsky, Kristin Hamilton, and Mary Punzi for providing help in the field.

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Appendix A

Introduction

Three factors in assessing ecological integrity are physical, biological, and chemical integrity (Biological Assessments and Criteria 2002). Therefore it is important to asses the physical characteristics of a water body. I assessed the ecological integrity of the law school wetlands and the west campus stream on the Villanova University campus in southeastern PA. (Latitude 40.0259, Longitude -75.3652). I compared two sites: the law school wetlands, and the west campus pond/stream. The law school wetlands were engineered to catch and absorb runoff from the surrounding surfaces. On the other hand, the west campus pond differs because it is a natural site that is primarily unbuffered by planted vegetation. I have conducted a brief physical assessment at both of these locations at the three subsites: the inlet, pond, and outlet. Here I provide a brief physical description of all six sampling sites.

Wetlands-Inlet

The stormwater wetland absorbs runoff from a total of 41 acres, 16 acres of which include impervious services like the law school parking lot. The water is then captured and routed to two storm drains that enter into the inlet of the stormwater wetlands in a slow moving stream type manner (Figures 1 and 2) (Villanova University, 2003).

Figure 1. First of two inlet pipes entering the Villanova stormwater wetlands

Figure 2. Second of two inlet pipes Entering the Villanova stormwater wetlands

The majority of the wetland vegetation that surrounds the inlet is more than 75% alive and healthy. There has been very little impact that has affect this site, mostly flood/storm damage from intense rains and increased storm surge, sometimes exceeding over 10cm at a time. The buffer that surrounds each side is about 9m vegetation. The herbaceous vegetation is mostly fragmities, but they are all alive and healthy, all exceeding 16cm in height. The invasive vegetation that has really overtaken this site has been a wetland type of vegetation called fragmities.

Wetlands-Sediment Forebay

The Sediment forebay has similar features to a pond and then ends with a row of gabions, this site is located approximately in the center of the wetlands (Figure 3).

Figure 3. Sediment forebay, which was designed to catch sediments and to catch water from storms in the Villanova stormwater wetlands

The majority of the wetland vegetation that surrounds the sediment forebay is more than 75% alive and healthy. There has been very little impact to this site, the main impacts are some mowing and trampling by humans. The buffer that extends to either side of the sediment forebay is about 10.6m on either side. Like the inlet, the herbaceous vegetation is mostly fragmities (*Phragmites australis*); they are all alive and healthy, all exceeding 16cm in height. Fragmities have really overtaken this area of the wetlands as well, but there are a few cattails that can be seen (Figure 4).

Figure 4. The sediment forebay, which was has lots of healthy green vegetation, primarily (*Phragmites australis*); in the Villanova stormwater wetlands

Wetlands-Outlet

The outlet drains from the wetlands and goes across the road through a culvert where it eventually drains out through two pipes (Figure 5 and 6).

Figure 5. The road the two outlet pipes go under To the exit of the Villanova stormwater wetlands

Figure 6. Two outlet pipes from the road which is the exit of the Villanova stormwater wetlands

The types of the vegetation that surround the outlet are trees, shrubs, ivy, and grass, all of which are more than 75% alive and healthy. The main impacts that can be seen at this site are mowing and trampling. The planted vegetation that surrounds the outlet only extends about 1.5-3m on either side. About 90% of the vegetation is green and is at least six inches in height. There is no invasive species that really have overtaken this portion of the wetlands.

Pond-Inlet

The inlet to the pond on west campus has one storm drain (diameter) that drains into a stream like manner and eventually flows to the pond (Figure 7). The majority of the wetland vegetation that surrounds the inlet is more than 75% alive and healthy. There has been very little impact that has affected this site, mostly flood/storm damage from intense rains. The buffer that surrounds each side is about 9m vegetation. The herbaceous vegetation is all alive and healthy, all exceeding 16cm in height.

Figure 7. Inlet pipe which is the entrance of the west campus stream on Villanova University

Pond-Pond

The Pond is mostly surrounded by grass, and some impervious services like the surrounding parking lots (Figure 8). The majority of the vegetation that surrounds the pond is more than 75% alive and healthy. There has been very little impact to this site, the main impacts are grass mowing, trampling, and geese that produce droppings which may affect the ponds water

Figure 8. West campus pond at the stream site on Villanova University

chemistry. The buffer that extends to either side of the pond is less than 1m on either side. All of the grass and other surrounding vegetation that is there is all more than 75% alive and healthy.

Pond Outlet

The outlet of the pond ends up as a long continuous stream, which meanders its way down stream (Figure 9). The types of the vegetation that surround the outlet are trees, shrubs, and tall grass, all of which are more than 75% alive and healthy. The main impacts that can be seen at this site are some trampling. The planted vegetation that surrounds the outlet on the left extends about 3m on the right side the vegetation extends over 10.6m.

Figure 9. West campus stream at Villanova University

Appendix B

Macroinvertebrate Count

Group I:	Count	Group II:	Count	Group III:	Count
Water penny larvae		Other beetle larvae		Aquatic worms	
Mayfly nymphs		Riffle beetle adults		Blackfly larvae	
Stonefly nymphs		Crane fly larvae		Leeches	
Non-net spinning caddisfly larvae		Damselfly nymphs		Midge larvae	
Fingernet Caddisfly larvae*		Dragonfly larvae		Pouched/Lunged snails	
Free-living caddisfly larvae*		Scuds		Rat-tailed maggots	
Water snipe fly larvae		Aquatic sowbugs		Horsefly larvae	
Dobsonfly larvae (hellgrammites)		Alderfly larvae		Flatworms	
Fishfly larvae		Net-spinning caddisfly larvae**		Water striders	
Fishing spiders		Crayfish		Giant water bugs	
Gilled snails		Water mites		Water boatmen	
		Clams			

* The Philopotamidae family of caddisflies, known as the fingernet caddisfly make a fragile net-like retreat like the other netspinners. However, they are sensitive to pollution. Fingernet caddisflies are usually yellow-orange in color and are almost always collected free from their dwelling. Free living caddisfly (Rhyacophilidae) is also a sensitive caddisfly that is found free from its dwelling. This family is green in color but in general, larger than the Hyropsychidae family and a brighter green.

** Net spinning caddisflies make net-like retreats that are often destroyed during collection. Two families of netspinners that are considered tolerant to pollution include the Hyropsychidae family and the Polycentropodidae family. The Hydropsychidae family, known as the common netspinners, have brushes or gills on their abdomens and are often green in color. The Polycentropodidae family of caddisflies, known as the trumpet net or tubemaker caddisflies, appear yellow in color. Both are collected free from their dwelling.

Notes/Comments: ____

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