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Environmental Evaluation of a Quaternary Wastewater Treatment Wetland

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Abstract

Constructed wetlands for wastewater treatment have become a sustainable alternative to environmentally harmful traditional wastewater treatment methods. This case study evaluated the Schroeder Wildlife Sanctuary, a wetland area constructed for removal of nutrients from wastewater. An environmental evaluation of the wetland was completed that addressed three parameters: the water quality of wetland effluent, the avian biodiversity within the sanctuary, and an assessment of community outreach and education initiatives. Water quality testing was conducted using rudimentary LaMotte and Hach testing kits. The data was contrary to the literature and showed no nutrient removal occurring. However, the results were inconclusive because the wetland was lacking well-established vegetation, which was necessary for nutrient removal. Bird data obtained over the past two years by a bird specialist indicated a high degree of biodiversity, likely due to presence of several habitats within the sanctuary. The community outreach and education assessment based on a walkthrough of the sanctuary indicated that community outreach and education initiatives were inadequate and recommendations were given for improvement.

1. Introduction

Conventional wastewater treatment facilities require large amounts of energy to function. Consequently, they contribute to environmental degradation through use of nonrenewable fossil fuels to provide energy. Conventional wastewater treatments also produce sludge (a semi-solid waste composed from solids that settle during the treatment process), which is discharged back into the environment. Sludge can contain heavy metals and toxic waste that are harmful to organisms. Constructed wetlands offer a more sustainable alternative for wastewater treatment and can have many additional benefits. According to Rousseau *et al*. (2008), constructed wetlands are "man-made copies of natural wetlands that optimally exploit the biogeochemical cycles that normally occur in these systems for the purpose of wastewater treatment." Two types of constructed wetlands exist: surface flow and subsurface flow. Surface flow wetlands have water above the substrate bed or bottom layer, with plants growing through the water column. Subsurface flow wetlands keep the water below the substrate bed by filtering it through pores in the substrate (Sundaravadivel and Vigneswaran, 2001).

This paper investigates the use of constructed wetlands for wastewater treatment and the implications of constructed wetlands for environmental sustainability within the community. The focus area is the Schroeder Wildlife Sanctuary, which has been constructed in conjunction with the Southeast Wastewater Treatment Facility as a quaternary treatment surface flow wetland, treating wastewater after it has first gone through three previous treatment stages. This paper begins with a discussion of the water purification processes wetlands employ to function sustainably. It then considers the benefits and challenges of constructed wetlands as discussed in the literature and identifies the gaps in the literature that form the basis for this study. The remainder of this paper will focus on the methodology used in this study, results obtained, and recommendations for the Schroeder Wildlife Sanctuary as a means for promoting sustainability within the community.

2. Water Purification Processes in Constructed Wetlands

Constructed wetlands employ biological, chemical, and physical processes to treat wastewater sustainably. These processes occur naturally in the environment rather than being artificially induced as in conventional wastewater treatment plants.

2.1 Biological Processes

The first type of purification process is biological. In constructed wetlands, plants are especially important for the biological purification processes. Through respiration, plants provide oxygen to the water. Oxygen drives the process of nitrification as well as the breakdown of organic pollutants (Sundaravadivel and Vigneswaran, 2001). Additionally, plants provide a place for microorganisms to reside. These bacteria play an extremely important role in the nitrification and denitrification processes too. Nitrification is the breakdown of ammonia into nitrites, which are then turned into nitrates. This process is followed by denitrification, which turns the nitrates produced by the nitrification process into nitrogen gas. The nitrogen gas is released into the atmosphere, thus removing nitrogen from the water (Sundaravadivel and Vigneswaran, 2001). Additionally, plants absorb nutrients such as nitrates and phosphates, helping to decrease their concentrations in the water (Gopal, 1999). The denitrification process and the absorption of nutrients by plants are important so that eutrophication does not occur. Eutrophication happens when nutrients such as nitrates and phosphates occur in excess, causing increased algae growth. When the algae decays, it consumes all the oxygen in the water, resulting in the deaths of other organisms.

2.2 Chemical Processes

The second way that water purification occurs in wetlands is through chemical means. Chemical reactions assist with the purification process of wastewater in many ways. Some organic pesticides can break down in water in the presence of sunlight. Also, plants can release antibiotic chemicals which can remove pathogens in the water (Sundaravadivel and Vigneswaran, 2001). Adsorption is another important reaction whereby toxic chemicals and heavy metals attach to suspended solids in the water (Peterson, 1998). This is important because then the solids can filter out of the water through sedimentation to purify the water. Additionally, the process of precipitation causes heavy metals to settle out of the water as solids which are deposited through sedimentation, thereby purifying the water. These processes are naturally occurring, contrary to the methods used by traditional wastewater treatment plants. Generally, traditional wastewater treatment plants must induce these processes by adding a coagulant. The coagulant binds with organic material creating sludge rather than removing the organic matter (Peterson, 1998). The production of sludge is undesirable because it can contain toxins and heavy metals. It must be discharged into the environment where it can harm organisms.

2.3 Physical Processes

Physical processes make the third contribution to the water purification processes in wetlands. In particular, physical processes affect the sedimentation of solids suspended in the water. Plants in the water serve to slow down the forward movement of solids, helping them settle. The substrate also acts as a filter, thereby filtering suspended solids (Sundaravadivel and Vigneswaran, 2001). Often the suspended solids consist of organic matter. Filtering the suspended solids causes the primary reduction of BOD or biological oxygen demand, which is a measure of oxygen used by organisms to break down organic matter (Gopal, 1999). The lower the demand for oxygen, the less waste is present in the water. This is important because if large amounts of waste are present, the organisms decomposing the waste will consume all the oxygen in the water. Then all other aquatic life will die from oxygen starvation.

3. Benefits of Constructed Wetlands

The water purification processes just discussed provide some background for understanding the benefits and drawbacks of constructed wetlands. In two landmark studies, Seidel was the first researcher to show in 1966 that bulrushes could be used in wastewater treatment (Gopal, 1999) and in 1976 that aquatic plants could be used to resolve water pollution issues (Stober *et al.*, 1997). Since then, the use of constructed wetlands for wastewater treatment has gained some popularity. Further research has shown that wetlands constructed for wastewater treatment purposes can have a wide range of benefits. They are often more sustainable than conventional wastewater treatments, they provide additional ecological benefits for wildlife habitat and public use, which conventional wastewater treatment plants lack, and they are more cost-effective than their conventional counterparts.

3.1 Sustainability

As noted, the primary benefit of constructed wetlands is that they are sustainable alternatives to traditional wastewater treatment conventions. Before traditional wastewater treatment plants can discharge their water, they must disinfect it. Often, chemicals such as chlorine are used for this purpose, which incur safety hazards for those handling the chemicals. Addition of these chemicals to the water can also result in harmful by-products; for example, use of chlorine creates organic chlorine compounds which can be carcinogenic (Werker *et al.*, 2002). Delivery of these chemicals to the waste treatment facility requires transportation, which burns fossil fuels. In comparison, constructed wetlands do not need the addition of potentially harmful chemicals, and therefore do not require the burning of fossil fuels in their production or transport (Kivaisi, 2001). Also, fossil fuels are not used to power constructed wetlands as they are for conventional treatment plants. Furthermore, as mentioned above, conventional water treatment plants produce large amounts of sludge, which pollutes the environment by discharging large amounts of semi-solids which may contain heavy metals and toxins. Constructed wetlands do not produce sludge (Peterson, 1998). Since constructed wetlands have no use for fossils fuels and do not produce sludge, they are beneficial because they reduce pollution, providing a sustainable wastewater treatment alternative.

3.2 Nutrient Removal Efficiency

Constructed wetlands are also ecologically beneficial because they can remove nutrients from the water. Certain nutrients, particularly nitrates and phosphates, are undesirable in wastewater effluent. Once the effluent is released back into the environment, excess nitrates and phosphates can contribute to the eutrophication of ponds and lakes (House *et al.*, 1994). The Illinois Environmental Protection Agency (EPA) sets the maximum contaminant level for nitrates in drinking water at 10 mg/L. If infants drink water with nitrate levels higher than the maximum contaminant level, they can exhibit shortness of breath and blue-baby syndrome, which lowers the ability of the blood to carry oxygen (Illinois EPA, 2001). The Illinois EPA has not set drinking water standards for phosphates (Wetlands Initiative). Constructed wetlands have the ability to remove these nutrients using natural processes. Ng (2008) surveyed the literature and found phosphate reductions of up to 88% in constructed wetlands around the central US and Northern Europe. Further, Ng cited 37% removal of total nitrogen in a study of three experimental wetlands in Illinois. Rousseau *et al*. (2008) also surveyed the literature and found phosphorus removal efficiencies of 60-90%. In a study of three pilot-scale constructed wetland systems in central Illinois, total phosphorous was reduced by 25-40% in all three systems and nitrates were reduced by over 60% in the floating aquatic plant wetland system (Jin, 2002). Differences in results could potentially be accounted for by variation in environmental factors, amount and type of existing vegetation at each wetland, and water residence time (the length of time that the water takes to move through the wetland).

3.3 Wildlife Habitat

A further ecological benefit is that surface flow treatment wetlands can serve as a habitat for invertebrates, fish, reptiles, amphibians, birds, and mammals. Generally, the greater the diversity in plant species, the greater the animal diversity will be (Knight, 1997). Only one study has been done to quantify wildlife biodiversity across constructed wetlands and this was summarized by Knight *et al*. (2001). The data gathered was from the North American Data Base (NADB), which was created by the EPA's Environmental Technology Initiative. This database contains information regarding vegetation, wildlife, metals/organics, biomonitoring, and human use for 257 treatment wetland sites. The study found that in both constructed and natural surface flow treatment wetlands across North America, more than 1,400 species had been recorded. These species were comprised of "more than 700 species of invertebrates, 78 species of fish, 21 species of amphibians, 31 species of reptiles, 412 species of birds, and 40 species of mammals" (Knight *et al*., 2001). This study shows the impact that increased use of wetlands can have on biodiversity.

3.4 Public Use

In addition, constructed wetlands can have many applications for public use. They can serve as areas for recreation such as hiking, jogging, biking, and bird watching (Knight, 1997).

They can also serve as areas for picnicking and relaxing (Rousseau *et al*., 2008). Furthermore, they are useful for scientific study and public education regarding ecological processes and diversity of plant and animal life (Knight, 1997). Public use of wetlands has not been widely surveyed. According to Knight *et al*. (2001), the NADB only has data on human use for a few wetland treatment systems. The wetland receiving the most visitors is the Arcata Marsh and Wildlife Sanctuary in Arcata, California, which receives about 100,000 visitors per year (Knight *et al*., 2001).

3.5 Cost-Effectiveness

Furthermore, over the long term, constructed wetlands are likely to be more cost-effective than conventional wastewater treatment plants. Initially, constructed wetlands cost more to develop because they need to be constructed according to each particular environment, so there are no standard designs or construction materials. Conventional treatment plants on the other hand have standardized technology so construction materials are cheaper to buy and easy to install. However, after the initial investment of capital for construction, maintenance and service costs for constructed wetlands decline, while those for conventional wastewater treatment plants increase. This is because conventional plants require lots of energy, components that will need to be replaced, and technicians to run the plant. Constructed wetlands have few if any technological devices or energy inputs, saving money on energy and maintenance. It is estimated that the higher development cost of constructed wetlands can be overturned within two to three years due to money saved on maintenance costs (Mannino *et al*., 2008).

4. Challenges of Constructed Wetlands

While constructed wetlands have many benefits, they are not without their challenges. The following section addresses several issues of concern. These issues relate to environmental safety, aesthetics, and functionality of constructed wetlands for wastewater treatment.

4.1 Toxic Metals

One of the largest concerns regarding constructed wetlands used for wastewater treatment is the introduction of toxic metals to the environment. These toxic metals will be introduced to the environment if they are present in the wastewater being discharged into the wetland. Toxic metals can bioaccumulate in organisms such as fish and invertebrates in the wetland. Consequently, water foul and other consumers that eat these organisms can experience adverse effects due to biomagnification of these metals. These effects can largely be avoided through use of pretreatment. Pretreatment lessens the concentrations of toxins to safer levels, though it does not completely get rid of toxins. Since toxicity cannot be completely eliminated when using wetlands to treat wastewater, there may be less diversity in species. Only species with a high tolerance for greater toxicity will be able to survive (Knight, 1997).

4.2 Clogging

A second concern specifically for subsurface flow wetlands is clogging, which impedes the wetland's ability to function. In subsurface flow wetlands, the water must drain through pores, which can become clogged. Clogging can be prevented in several ways. One method of prevention is to reduce the inputs into the wetland. A second method, if separate bodies of water or cells exist within the wetland, is for one cell to be taken out of use for a period of time; this allows for organic material that could be clogging the pores to compost. Unfortunately, if inorganic material is preventing filtration through the pores, the wetland must be dug up and refilled, which is costly (Rousseau *et al*., 2008).

4.3 Mosquitoes

Mosquitoes are a third concern, especially for surface flow wetlands. They pose an aesthetic, as well as potentially hazardous challenge for constructed wetlands. Because surface flow wetlands require a body of open water, they are potential breeding habitats for mosquitoes. Mosquitoes tend to lay eggs in small areas of water, where the water is idle and stagnating. Therefore, subsurface flow wetlands are advantageous for averting this problem since the water flow is below ground. Wetlands with a big food web and large diversity of species can also help prevent mosquitoes from multiplying by consuming them (Rousseau *et al*., 2008). On the other hand, large organic inputs to the wetland cause vegetation to grow uncontrolled, which can increase mosquito reproduction. In order to control mosquito populations, pretreatment to lessen organic inputs is therefore essential. Additionally, wetland vegetation should be controlled to avoid dense growth and allow for the surface waters to be adequate habitat for other organisms that prey on mosquito larvae (Knight, 1997). Applying non-harmful chemicals and introducing species that are parasitic to mosquitoes, such as nematodes are other ways of controlling mosquitoes (Kivaisi, 2001). Understanding such preventative measures is particularly important because of mosquitoes' ability to carry diseases, particularly where constructed wetlands are being used in developing countries where mosquitoes may carry malaria.

4.4 Odor

With the use of constructed wetlands for wastewater treatment, the possibility of offensive odors is a fourth concern. Odors vary with the wastewater quality and amount of dissolved oxygen (Kivaisi, 2001). Odors tend to occur in constructed wetlands that have anaerobic conditions, where oxygen demand exceeds oxygen production. In such situations, the odor is produced during anaerobic decomposition. To lesson the odor, an aerobic environment should be created. An aerobic environment can be created "by means of shallow basins or by implementation of cascading outfall structures" (Rousseau *et al*., 2008). This is especially important for constructed wetlands near populated areas.

4.5 Design Criteria

Finally, designing a constructed wetland can pose significant difficulty. Since wetlands can be constructed in many different environments and will function differently in each one as mentioned above, no one blueprint exists for the installation of wetlands. Instead, each proposed wetland must be designed on a case-by-case basis, making the planning and implementation of a constructed wetland a rigorous process. Numerous factors need to be considered. The water quality of the wastewater being treated must be analyzed and appropriate pretreatment measures need to be taken to reduce concentrations of toxins and maintain the necessary levels of dissolved oxygen. Extensive research must also be done regarding which native plant species to incorporate into the wetland. Greater diversity of plant species can result in greater biodiversity. Plants that can survive year-round must also be chosen if the wastewater treatment is to operate all year. Vegetation selected should be types that grow quickly because once it is installed, the wetland will not function at peak levels until the vegetation has grown sufficiently (Sundaravadivel and Vigneswaran, 2001). If the wetlands are being designed with public use in mind, considerations need to be taken to make them aesthetically pleasing and free of mosquitoes or odor. Also, the wetland must be publicized and educational displays should be installed in order to attract visitors and engage the public about the sustainable benefits of constructed wetlands. Boardwalks and observation points would also need to be installed so the wetland is accessible to the public (Knight, 1997). The intensive planning of constructed wetlands, some aspects of which are not necessary for traditional wastewater treatment methods, requires that wastewater engineers have a different area of expertise and may thus make constructed wetlands a less appealing option for wastewater treatment.

5. Literature Discussion

It should be noted that many of the studies discussed above, and their conclusions, have been drawn from experimental and pilot-scale constructed wetlands for wastewater treatment. This is not to say that studies have not been done on longer-term existing wetlands constructed for wastewater treatment. However, the literature is significantly lacking in studies on already functioning constructed wetlands to analyze their performance in wastewater treatment. Many studies are available regarding constructed wetlands in foreign countries, but these may not be as applicable to the installation of constructed wetlands in the US. No studies were found that addressed the expanding use of wetlands across the US. Additionally, while it is generally concluded that increased biodiversity is a benefit of constructed wetlands, only one study (Knight *et al*., 2001) has actually been done to quantify the increase in biodiversity among different wetlands. As noted above, the data in this study was drawn from NADB and it reflects aggregate data from all treatment sites. No study has been done regarding the biodiversity benefits just one wetland can have.

6. Case Study

This study therefore sets out to consider one wastewater treatment wetland, the Schroeder Wildlife Sanctuary in central Illinois. The sanctuary is a constructed wetland that was built on what was previously cropland. It is now functioning as a quaternary wastewater treatment system in conjunction with the Southeast Wastewater Treatment Facility. Currently, influent to the treatment facility undergoes three treatments: a primary gravity treatment allowing large solids to settle out, a secondary biological treatment, and a tertiary filtration and ultraviolet disinfection treatment. Then the wastewater is pumped into the wetland. The goal of the constructed wetland is to aid in treatment processes with the hope that studies will show sufficient nutrient removal for the constructed wetland to sustainably replace some of the water treatments occurring in the facility at present (Callahan).

This study was designed for three purposes: first, to determine the wetland's effectiveness for wastewater treatment; second, to quantify the sanctuary's effect on biodiversity; third, to assess community education displays and outreach. Considering the gaps in the literature, this study is important because it evaluates an existing, functional wetland, constructed for the purpose of wastewater treatment. Analyzing the wetland's ability to treat wastewater and provide other services is an important step in the development of sustainable wastewater treatment systems. Data derived from currently operating systems will be stronger in demonstrating the benefits of a natural wastewater treatment system than small-scale pilot or experimental studies. Also, as little data exists regarding wildlife biodiversity, this study will be instrumental in demonstrating the ecological benefits of constructed wetlands. Furthermore, community education of constructed wetlands is important for garnering public support for them and promoting sustainability within the community.

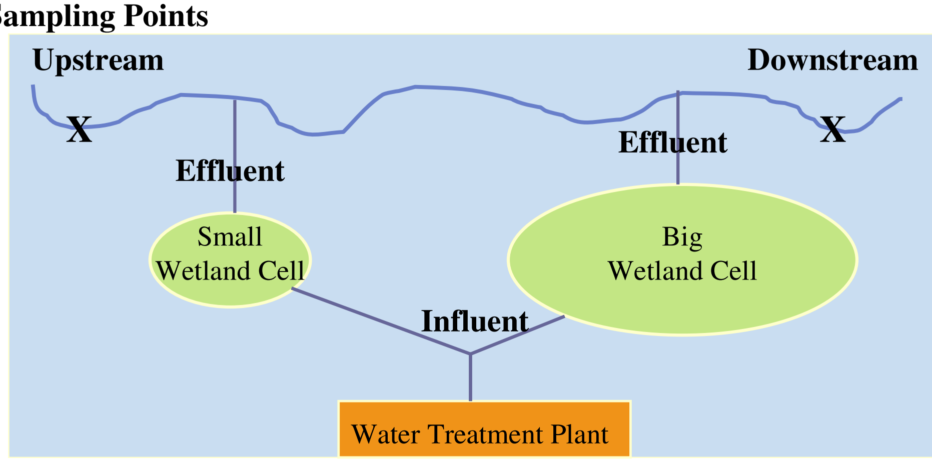
7. Methods

Several methods were used in order to establish whether the wetland was meeting the three goals stated above. To determine the wetland's effectiveness for wastewater treatment, the water quality of the wetland was tested. Additionally, avian biodiversity in the sanctuary was analyzed from bird data collected. Finally, community education displays and outreach were assessed.

7.1 Water Quality Testing

The Schroeder Wildlife Sanctuary consists of two wetland cells, a small cell and a large cell. Five sampling points were chosen for water quality measurements. The first point measured the influent, which came from the same source for both wetland cells. The second and third points measured the effluent as it was discharged from each wetland cell. The fourth point was chosen upstream before effluent discharge, and the fifth point was downstream of the effluent discharge.

Figure 1: Sampling Points



This diagram shows the water quality sampling points chosen at the Schroeder Wildlife Sanctuary.

All samples were taken from surface water since nutrient concentrations may vary with water depth. Samples were collected between October 12 and November 2 of 2008. The water quality tests were run the day after collection, and the samples were preserved by refrigeration.

At each sampling point, temperature, turbidity, pH, phosphates, nitrates, and nitrites were measured. Heavy metals were not tested for because it was assumed that they were removed during tertiary treatment at the water treatment plant. Rather than using EPA standard methods, for simplicity, LaMotte and Hach testing kits were employed instead. Turbidity is a measure of how clear the water is, which is influenced by the quantity of suspended solids in the water. A turbidity tube was filled and placed over a Secchi disk. The clarity of the Secchi disk was compared to known standards to determine the clarity of the water. Measurements were recorded in Jackson Turbidity Units (JTU).

The acidity or pH of the water was then measured. pH is measured on a scale from 0-14. A pH of 7.0 is considered neutral, while a pH below 7.0 is acidic and a pH of greater than 7.0 is basic. To measure pH, a 10 mL test tube was filled. A pH Wide Range TesTab, a tablet which dissolves in the water sample and varies in color with pH, was added. The color of the water sample was then compared to a color chart of known standards to determine the water's acidity.

Phosphorus is a nutrient that causes plant and algal growth, which in excess, can cause eutrophication. To measure phosphates, a vial was filled with 5 mL of water. A PhosVer 3 Phosphate Reagent powder was dissolved in the sample, which reacts with the phosphorus to form a blue complex. The resulting color was compared to known color standards and measured in milligrams per liter (mg/L) to determine the concentration of phosphates.

Excess nitrogen can also cause eutrophication. Nitrates and nitrites are two sources of nitrogen in water. To measure nitrates, a 5 mL sample was taken. Nitrate #1 Tablets were added to the sample and mixed, followed by the addition and dissolution of Nitrate #2 CTA Tablets. The resulting color change was matched against the known color standards and recorded in ppm.

To measure nitrite, a 4 mL sample of water was taken. Then 10 drops of Nitrite Nitrogen Reagent A was added. An additional 10 drops of Nitrite Nitrogen Reagent B was added and then mixed for 30 seconds. Next, 0.15 grams of Nitrite Nitrogen CR was dissolved into the mixture. The test tube was inserted into the Nitrite Comparator, which matches the sample against a known color standard. Results were recorded in ppm.

7.2 Avian Biodiversity and Community Education Assessment

Avian biodiversity and community education initiatives were also assessed. Due to the time constraints of the study, data regarding avian biodiversity was obtained from Dale Birkenholz, a retired professor from Illinois State University. He has recorded a list of birds observed in the Schroeder Wildlife Sanctuary over the past two years (2007-2008) during all times of the year including migrations. His data consists of a checklist of different bird species. Only the diversity of species was recorded, not the quantity of each species observed. His data shows the range of avian biodiversity in the wetland.

Community education initiatives were assessed based on a walk-through of the sanctuary where community education displays were gauged. In addition, the literature available to the public was evaluated.

8. Results, Discussion, & Recommendations

The results of the water quality, avian biodiversity, and community education assessment of the Schroeder Wildlife Sanctuary will be presented and discussed. The discussion will also incorporate several recommendations for improvement.

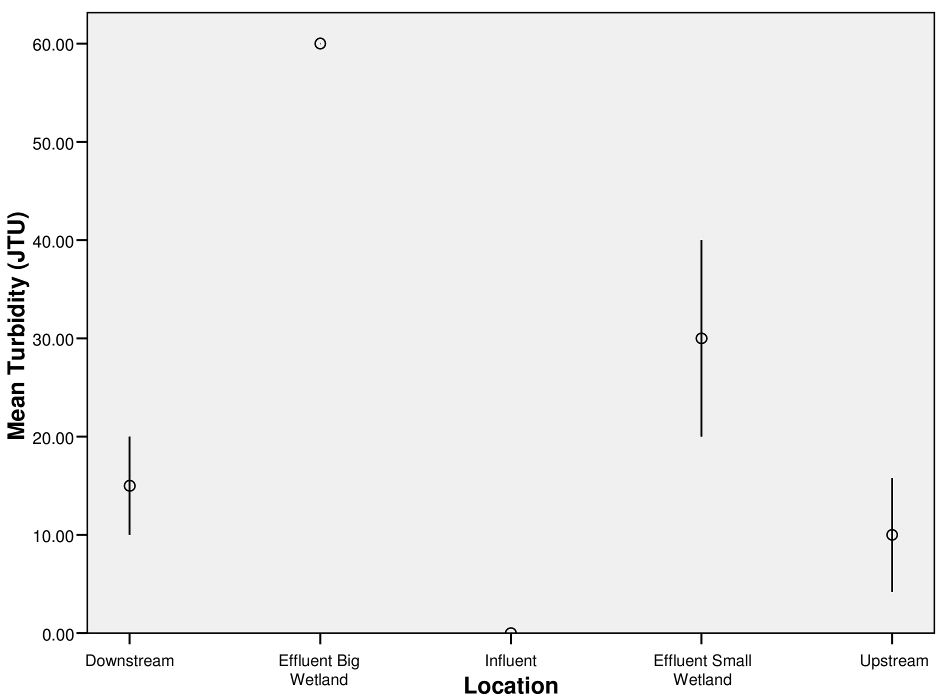
8.1 Water Quality

Three sets of samples were taken over the course of a month. The results from the first set of samples (10/12/2008) were discarded due to the imprecision of the test kits and more precise test kits were obtained for the second (10/19/2008) and third (11/2/2008) sets of samples. A short period of rain occurred before the second set of samples was taken. The third set of samples was taken after a period of no rain. Only turbidity, nitrates, and phosphates were analyzed because the measurements for the other parameters tested were identical.

Due to the inconsistent weather conditions, a one-way analysis of variance (ANOVA) test was conducted to determine whether the results from the samples taken after the period of rain differed significantly from those taken after the dry period. The ANOVA test compares two or more means and produces an F statistic, which is then used to determine a P-value. A P-value less than 0.05 indicates that the results are significant, and it is unlikely that they were caused by chance alone. A P-value greater than 0.05 indicates the results are not significantly different. The ANOVA test showed that there was no significant difference in turbidity ($F_{1,18} = 0.964$, $P = 0.339$), nitrates ($F_{1,18} = 1.331$, $P = 0.264$), and phosphates ($F_{1,18} = 0.094$, $P = 0.763$) between the samples taken after the period of rain and the samples taken after the dry period. Therefore, the data sets from both sampling dates were combined for analysis to increase sample size.

Three additional one-way ANOVA tests were conducted for turbidity, nitrates, and phosphates to determine whether there was a significant difference in each parameter between the five sampling sites in the wetland. The ANOVA test indicated that there was a significant difference between the five sampling sites for turbidity ($F_{4,15} = 17.211$, $P < 0.001$), nitrates ($F_{4,15} = 15.355$, $P < 0.001$), and phosphates ($F_{4,15} = 46.691$, $P < 0.001$). However, the ANOVA tests did not indicate which specific sites were significantly different for each parameter so a Hochberg GT2 follow-up test was run.

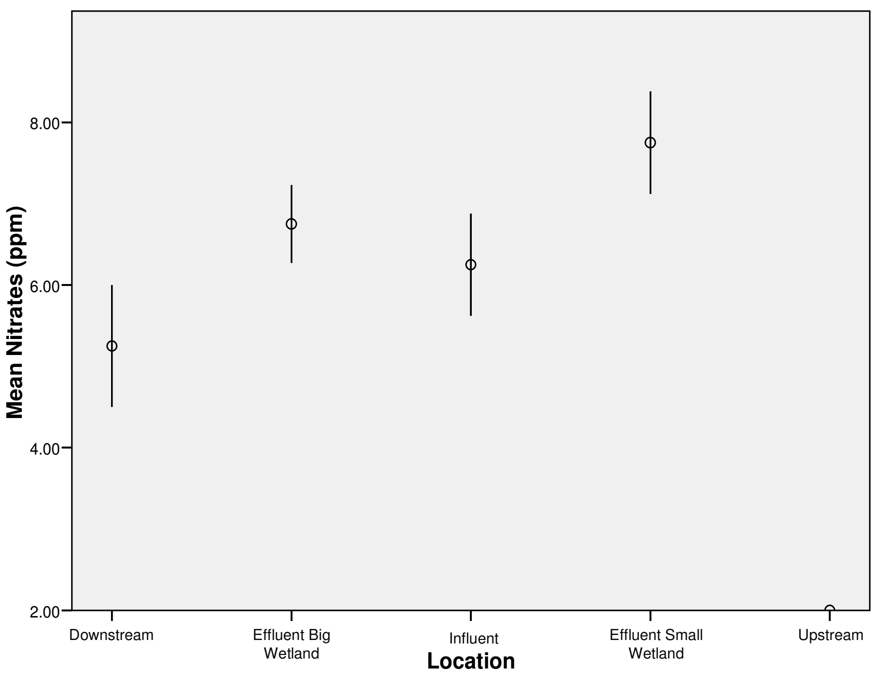
Figure 2: Mean Turbidity (JTU) vs. Location



(Each dot represents the mean and the bars represent ± one standard error.)

As shown in Figure 2 above, the Hochberg GT2 follow-up test for turbidity indicated that the effluent from the big wetland (60 ± 0.0 JTU; mean ± standard error) had significantly greater turbidity than water downstream (15 ± 5.0 JTU; $P < 0.001$), the influent (0 ± 0.0 JTU; $P < 0.001$), the effluent of the small wetland (30 ± 10.0 JTU; $P = 0.017$), and water upstream (10 ± 5.77 JTU; $P < 0.001$). Additionally, the effluent from the small wetland had significantly higher turbidity than the influent ($P = 0.017$). The results suggested that turbidity was significantly higher as water exited the wetland cells than before it entered the wetland. This may be due to the fact that the samples were collected in the autumn as the vegetation in the wetland was dying. As the vegetation broke down, it would have contributed more organic material to the water, hence increasing turbidity. Furthermore, the vegetation was not well-established within each wetland cell, so less vegetation was available to anchor the substrate. Therefore, loose particles from the substrate may have increased the turbidity of the water as it flowed out of the wetland cells. This turbid water could cause detrimental effects in the stream after discharge such as a reduction in aquatic vegetation, which may not be able to grow if light cannot penetrate the water for photosynthesis. Fewer plants growing means less oxygen will be entering the water through respiration. Therefore, organisms in the water will die because they will have no source of oxygen.

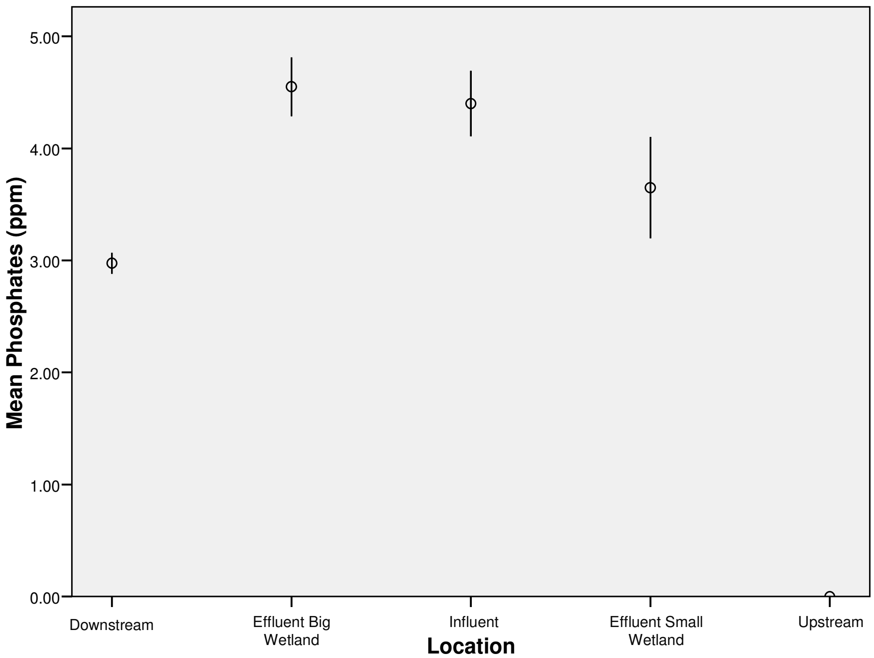
Figure 3: Mean Nitrates (ppm) vs. Location



(Each dot represents the mean and the bars represent ± one standard error.)

As displayed in Figure 3 above, the Hochberg GT2 follow-up test for nitrates indicated that nitrates upstream (2 ± 0.0 ppm) were significantly lower than nitrates downstream (5.25 ± 0.75 ppm; $P = 0.009$), nitrates in the effluent from the big wetland (6.75 ± 0.48 ppm; $P < 0.001$), nitrates in the influent (6.25 ± 0.63 ppm; $P = 0.001$), and nitrates in the effluent from the small wetland (7.75 ± 0.63 ppm; $P < 0.001$). This suggested that the influent from the water treatment plant was not experiencing a significant reduction in nitrates after treatment by the wetland cells, and the effluent discharged from the wetlands increased the nitrate concentrations in the water downstream. These results are contrary to the literature, which indicated a 37-60% removal of nitrates (Ng, 2008; Jin, 2002). The apparent ineffectiveness of nitrate reduction by the two wetland cells in the Schroeder Wildlife Sanctuary may be explained by the lack of well-established vegetation within each cell.

Figure 4: Mean Phosphates (ppm) vs. Location



(Each dot represents the mean and the bars represent ± one standard error.)

As presented in Figure 4 above, the Hochberg GT2 follow-up test for phosphates indicated that phosphates found upstream (0 ± 0.0 ppm) were significantly lower than those found downstream (2.98 ± 0.09 ppm; $P < 0.001$), in the effluent of the big wetland (4.56 ± 0.26 ppm; $P < 0.001$), in the influent (4.4 ± 0.29 ppm; $P < 0.001$), and in the effluent from the small wetland (3.65 ± 0.45 ppm; $P < 0.001$). Furthermore, downstream was significantly lower in phosphates than the effluent from the big wetland ($P = 0.009$) and from the influent ($P = 0.019$). The data suggested that, similar to nitrates, the influent was not experiencing a significant change in phosphates after treatment in the wetland. This is also contrary to the literature, which showed 25-88% phosphate reduction (Jin, 2002; Rousseau *et al.*, 2008; Ng, 2008). Because downstream was significantly lower in phosphates from the big wetland cell, this indicated that the wetland effluent was not having as large an impact downstream as it was for nitrates. Again, since the vegetation was not well-established, this may have accounted for the lack of reduction in phosphates in the big wetland.

The only vegetation that has grown in the wetlands is reed canary grass. Many other species have been planted such as cattails, sedges, arrowhead, iris, and water hyacinths, however, none have taken root. The vegetation may not be growing because the treatment plant does not have adequate control over water depth in the wetland cells. With water too deep, light cannot penetrate far enough for photosynthesis, and therefore plants cannot grow and take root. The treatment facility is aiming to get new controllers for water depth in the future, which may aid vegetation establishment and thereby the effectiveness of the wetland (Callahan).

8.2 Avian Biodiversity

The data obtained from Dale Birkenholz of bird species observed within the sanctuary showed a large amount of biodiversity with a total of 68 different species observed. This large amount of biodiversity can be explained by the presence of several other habitats in addition to the constructed wetland. The sanctuary contains several tracts of farmland, a large area of prairie, and a woodland area. Since there is more diversity in vegetation, there is greater diversity in animal species. This is significant because the land was previously all cropland, and with only one type of vegetation, this span of biodiversity likely did not exist before construction of the sanctuary. Table 1 presents the results of all the bird species observed within the Schroeder Wildlife Sanctuary.

Table 1: Total Bird Species Observed

Canada Goose	Wood Duck	Mallard
Ring-Necked Pheasant	Northern Bobwhite	Great Blue Heron
Green Heron	Red-Tailed Hawk	American Kestrel
Killdeer	Spotted Sandpiper	Mourning Dove
Yellow-Billed Cuckoo	Eastern Screech-Owl	Great Horned Owl
Chimney Swift	Belted Kingfish	Red-Headed Woodpecker
Red-bellied Woodpecker	Downy Woodpecker	Northern Flicker
Eastern Wood-Pewee	Willow Flycatcher	Eastern Phoebe
Great Crested Flycatcher	Eastern Kingbird	Warbling Vireo
Red-Eyed Vireo	Blue Jay	American Crow
Purple Martin	Tree Swallow	House Finch
Barn Swallow	Black-Capped Chickadee	Tufted Titmouse
White-Breasted Nuthatch	Carolina Wren	House Wren
Eastern Bluebird	Wood Thrush	American Robin
Gray Catbird	Northern Mockingbird	Brown Thrasher
Cedar Waxwing	European Starling	Yellow Warbler
Common Yellowthroat	Yellow-Breasted Chat	Eastern Towhee
Chipping Sparrow	Field Sparrow	Vesper Sparrow
Song Sparrow	Northern Cardinal	Rose-Breasted Grosbeak
Indigo Bunting	Dickcissel	Red-Winged Blackbird
Eastern Meadowlark	Common Grackle	Brown-Headed Cowbird
Orchard Oriole	Baltimore Oriole	Northern Rough-Winged Swallow
American Goldfinch	House Sparrow	

Moreover, it can be assumed that current biodiversity is underestimated because this data only accounts for bird species and not any other mammals such as deer that are present within the sanctuary. Further biodiversity study of other animals is needed in order to quantify total biodiversity in the sanctuary.

8.3 Community Education Assessment

Upon a walkthrough of the Schroeder Wildlife Sanctuary and an evaluation of the literature available to the public, the community outreach and education initiatives were found to be inadequate. No website exists for the public to learn of the existence of the Schroeder Wildlife Sanctuary as a place for recreation, particularly for bird-watching. The lack of a website is also important because the sanctuary was constructed with public use in mind, however, without a website, there is no effective means of advertising the existence of this sanctuary to the public. This is a shame because, as shown above, the wetland has drawn many birds to the area, creating an ideal bird watching site. Instead, the sanctuary must rely on word of mouth to draw visitors, which is less efficient. Furthermore, there are no signs on the road pointing visitors in the direction of the sanctuary. There is one sign announcing the entrance of the sanctuary, however, the sign is parallel to the road, facing the opposing cornfield. It cannot be read as visitors approach the sanctuary, only as they drive past it. This may make it difficult for visitors to find the sanctuary, should they happen to hear about it. Once visitors enter the sanctuary, no pamphlets or literature of any kind are available to the public to educate them about the constructed wetland.

Within the wetland itself, several forking gravel roads are present within the sanctuary, but the entrance sign is the only sign. There are no further signs within the sanctuary giving visitors directions as to where these forking roads lead or giving visitors directions to the grassy parking area. The parking area is also not clearly shown to be an acceptable parking area and it may not be obvious to visitors because the area is unpaved. Additionally, the wetland has a couple of trails, however, there is no map to show visitors where the trails go. One of the trails leads to the bird blind, an enclosed structure that visitors can sit in for bird watching. The trail provides a scenic route to the bird blind and allows visitors to approach and climb into the blind from behind so as not to scare the birds. Since there is no map showing visitors that they can take this trail to the bird blind, people may try to approach it from the front, and in doing so would scare away all the waterfowl present. Additionally, there is no sign to denote the bird blind as such so visitors may not understand its purpose and may fail to participate in bird watching.

In order to publicize the Schroeder Wildlife Sanctuary, it would be beneficial to create a website as well as educational pamphlets. These pamphlets could be given to local environmental centers such as the Ecology Action Center or Sugar Grove Nature Center, who could then distribute them to increase the sanctuary's publicity. It would also be helpful to readjust the entrance sign to the sanctuary so that it is perpendicular to the road and can be seen from a distance by approaching visitors. Furthermore, adding signs within the sanctuary to point visitors in the right direction, map out the trails, and describe the function of the bird blind would make the sanctuary more user-friendly. Finally, an educational board should be constructed by the parking area to educate the public about the wetland. A brief history of the sanctuary, a description of the water purification process, and mention of the ecological and sustainability benefits might be appropriate. This is particularly important in order for the public to realize the implications the wetland has for promoting sustainability within the community.

9. Conclusion

While the literature indicates that significant reductions in nutrients were observed in experimental/pilot wetlands, this was not found to be the case at the Schroeder Wildlife Sanctuary. However, the data is inconclusive because the results were likely due to the lack of well-established vegetation in the wetland cells and to the autumn sampling during a time when vegetation that was established was dying. More studies should be undertaken at a later date once the vegetation has become established. Avian biodiversity data consisted of 68 species, representing a large amount of bird diversity in a small area, probably due to the existence of a diverse range of habitats. Further study is needed of other animal species to quantify total biodiversity within the sanctuary. The community education and outreach initiatives were found to be inadequate and much improvement is needed in the form of a website, signage, and educational pamphlets and displays for visitors.

These findings have several implications for promoting sustainability within the community. Although the wetland has not been functioning as intended with regard to nutrient removal, it is expected that with the development of well-established vegetation, nutrient removal will improve, making the wetland a sustainable alternative for wastewater treatment. Furthermore, the wetland is already functioning as intended with regard to biodiversity, providing ecological benefits to wildlife and potentially to the community as a place for recreation and to enjoy the beauty of nature. Unfortunately, the community is most likely not actively involved with the sanctuary yet since the sanctuary has not been widely publicized. It is imperative that steps be taken to address this issue so that the sanctuary can be used by the public as was intended during its construction. With the addition of educational displays, the Schroeder Wildlife Sanctuary will also serve as an educational area for the public to learn about sustainability and the benefits to the community of this constructed wetland.

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