Plant Establishment and Water Quality Changes in a Constructed Wetland Designed to Treat Agricultural Runoff

By

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ABSTRACT

A variety of constructed wetlands are used to treat agricultural runoff. Research was carried out on a small pond located on private property in Fairfield Township, Columbiana County, Ohio. The pond receives runoff from two small streams that drain a small cattle farm and surrounding crop land. The excess of nutrients in the pond is causing heavy growth of duckweed and algae. A constructed wetland was built to remove nutrients from the pond inflow to improve as a means of improving the water quality and making the pond more aesthetically appealing.

Pre-wetland construction and post construction water quality sampling and analyses were conducted to evaluate the effectiveness of the wetland in improving water quality. Water Quality parameters included: biochemical oxygen demand, total solids, total suspended solids, Escherichia coli (E. coli), coliform, dissolved oxygen and temperature. Local wetland plant species were transplanted from two established wetland sites to populate the new constructed wetland. A plant count was performed to determine the percent growth and proliferation of the wetland plants.

Statistical analysis of the pre and post wetland construction water testing results showed a significant decrease in total suspended solids in 2011 from 2010. The boxplot tests showed decreases of the average number in total suspended solids, total solids, biochemical oxygen demand, E. coli, and coliform bacteria. An increase in dissolved oxygen and temperature was also shown in the SPSS boxplot tests. The univariate test between temperature and dissolved oxygen showed a slight significance between the two parameters. The total percent growth rate for both of the wetland cells was found to be 2900%, with cattails being the dominate species.

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INTRODUCTION

1.1 Wetland Overview

Wetlands are a vital part of the environmental that cover only 3% of Earth's surface and produce an ecosystem that has unique characteristics of soil, plants and hydrology. These unique conditions make wetlands an important feature of any watershed. The term wetland describes an area of land where water is the primary factor that controls the environment and the lives of the plants and animals that use them (Ramsar, 1998). Wetlands are found where the land is covered by shallow water or where the water table is at or near Earth's surface. Wetlands can be classified into five main types. The first type is marine and coastal wetlands including rocky shores. Deltas, tidal marshes and mangrove swamps all fall under the classification of an estuary. Riverine wetlands are associated with rivers or streams. Palustrine wetlands are marshes, swamps or bogs. Lastly lacustrine wetlands are associated with lakes (Kandasamy et al., 2008).

The geographic location and types of plants determine the type of wetland. Swamps are wetlands that are dominated by woody plants that have a high tolerance to water. Soft stemmed plant species are found in marshes, and mosses are found in bogs. Both marshes and swamps can be found in fresh and salt water environments (Kandasamy et al., 2008).

Wetlands absorb and soak up excess surface water runoff. They also clean and filter water as it flows through the wetland (Melbourne-Water, 2005). Wetlands offer protection from wave action, floods, pollution and provide habitats for plants and animals, several which are threated or endangered species. Nurseries for fish and other marine and freshwater life are also a critical function of this type of environment (Kandasamy, 2008).

1.2 Constructed Wetlands Overview

According to J. Kandasamy (et al., 2008) "constructed wetlands are a multifunctional shallow water detention, pollutant retention structures, constructed with predominantly natural materials such as soil, water and biota to facilitate the desirable hydrological, physical, chemical and biological process of natural wetlands in a controlled manner".

Constructed wetlands can be classified based on water depth as periodically drying out (ephemeral) and permanently inundated wetlands (permanent). Wastewater treatment wetlands can be further classified into two groups; free water surface flow wetlands (FWS) that have the majority of water flow running across the wetland (Figure 1.0); and sub-surface flow wetlands (SSF) that have the majority of water flow running through relatively permeable soil (Figure 1.1) (Kandasamy et al., 2008).

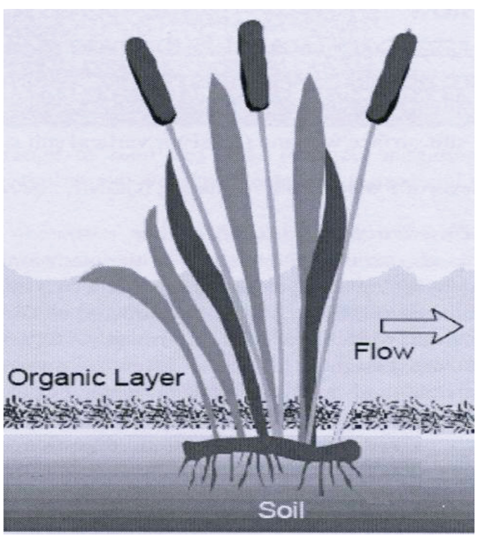

Figure 1.0: Free Water Surface Flow Wetlands (FWS) (Kandasamy et al., 2008)

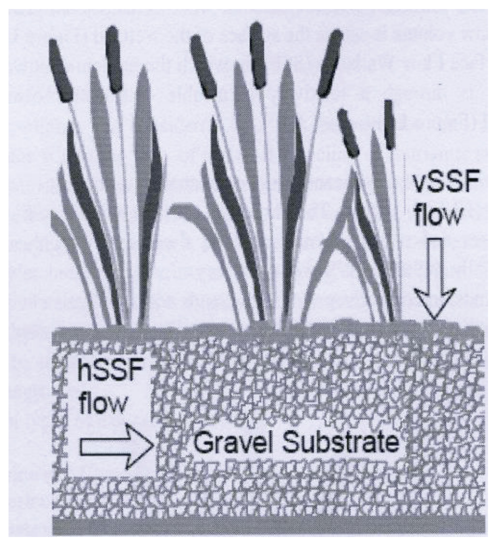

Figure 1.1: Sub-Surface Flow Wetlands (SSF) (Kandasamy et al., 2008)

It is well established that constructed wetlands have a high potential to treat the impacts of anthropogenic pollution sources on the hydrological cycle and supported ecosystems. They use natural process to remediate storm and wastewater and they are designed and constructed for a variety of purposes (DLWC 1998, Lawrence and Breen, 1998, Sundaravadivel and Vigneswaran, 2008). These include:

- Providing recharge zone groundwater, and controlling sediment erosion and movement
- Reducing runoff downstream from the wetland by providing flood control
- Acting as waste and stormwater treatment systems to improve water quality, and reduce nutrients, sediment, heavy metals, pathogens and hydrocarbons from the water.
- Creating and conserving habitats to balance out the loss of natural wetlands due to human development.

A constructed wetland typically has two separate components or treatment cells. The first component is a pond with a deep open body of water and a defined edge between land and pond water. There may be submergent aquatic plants present. The second part of the treatment cells is the wetland itself. The wetland has a macrophyte zone, with an ephemeral shallow or permanent body of water with a considerable variety of vegetation. The location of vegetation is determined by the water depth and frequency and duration of flooding events (Melbourne-Water, 2005). Constructed wetlands can have a variety of designs, with most commonly containing the following seven zones (Kandasamy et al., 2008):

- Pre-treatment zones
- Inlet zone and high-flow bypass
- Macrophyte zone
- Open water zone
- Ephemeral and littoral zones
- Outlet zone
- Terrestrial landscaping

The order in which the zones are constructed is an important aspect to consider when creating a wetland. It is also essential that the wetland zones are arranged to maximize long-term effectiveness. Figures 1.2 and 1.3 show where these zones could be incorporated in a constructed wetland when the primary purpose is the improve water quality. Figure 1.2 shows the offline wetland construction method. This is the preferred method when building a wetland. Figure 1.3 is the online wetland with high flow bypass (Kandasamy et al., 2008).

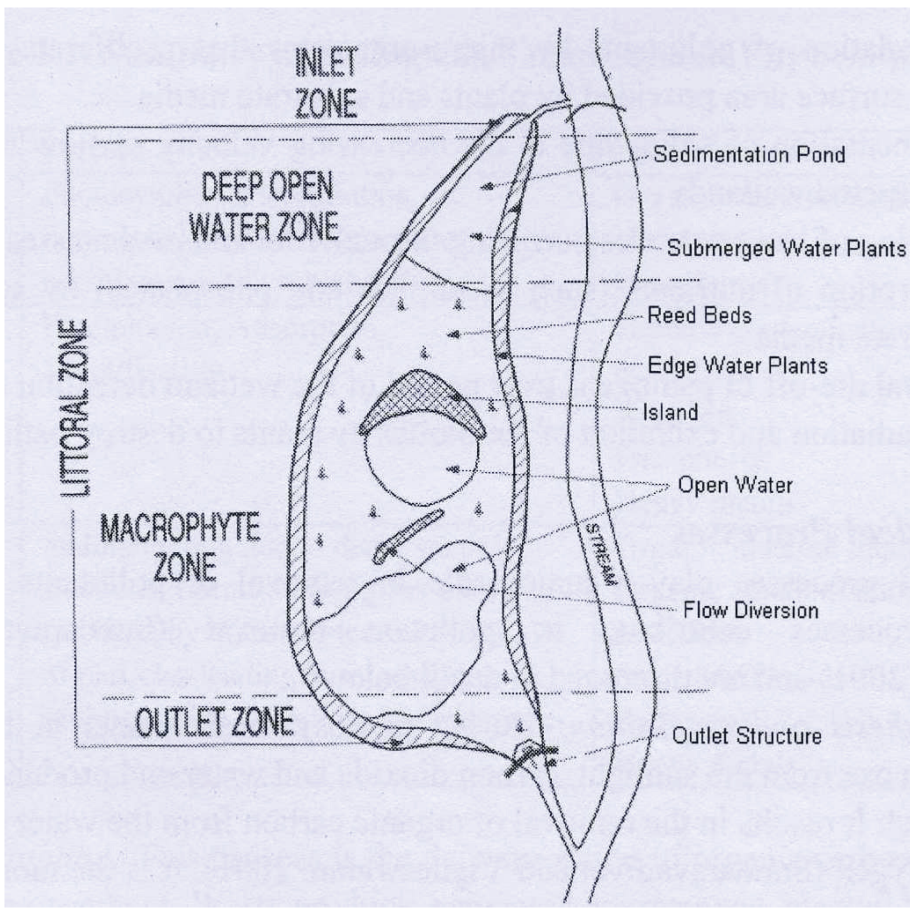

Figure 1.2: Wetland Zone Locations (Kandasamy et al., 2008)

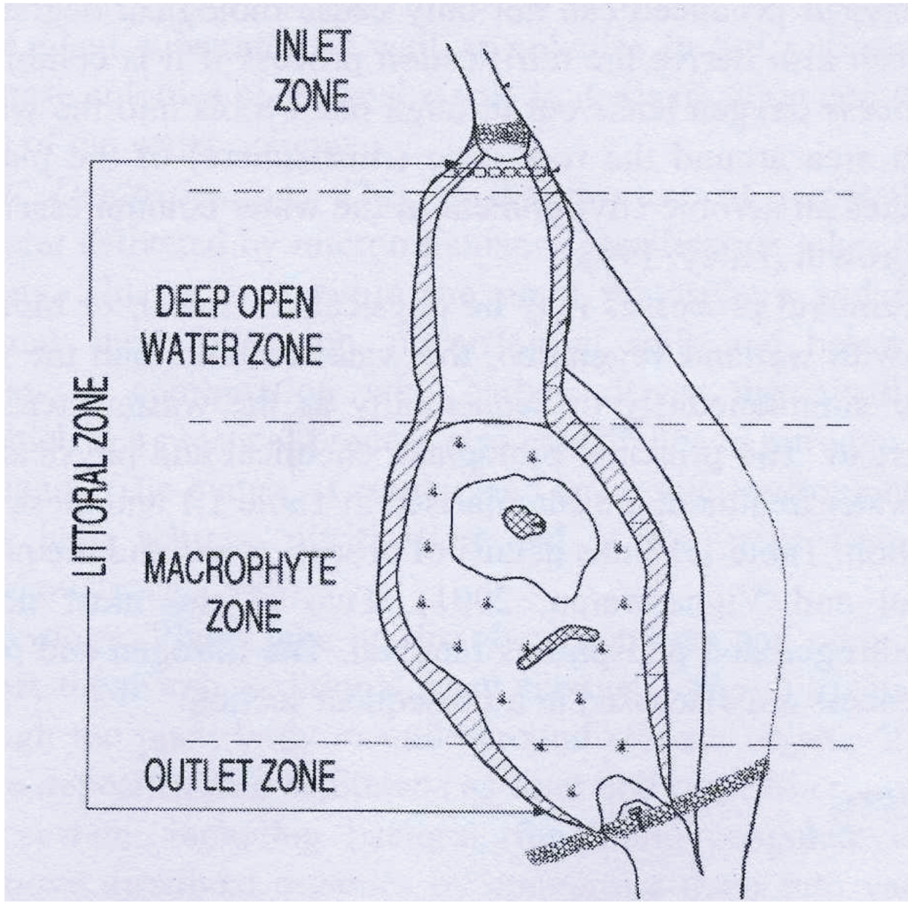

Figure 1.3: Wetland Zone Locations (Kandasamy et al., 2008)

1.3 Wetland Plant Overview

The species of wetland vegetation that is planted in a constructed wetland is an important aspect of both design and efficiency of nutrient removal. Wetland vegetation also increases the amount of the habitat that is available for the microbial population in the water column, in the litter layer and in the rhizosphere (Hammer, 1997). The species of plants that are preferred to populate wetlands have seven desirable attributes. They are:

adaption to local climate and soil, tolerance to pollutants in the water, high biomass production, perennial species, rapid growth and colonization, non-weedy, aesthetic habitat and values for wildlife habitat (Hammer, 1997).

There are numerous species of wetland plants. A few of the most commonly used species of plants in constructed wetlands include cattails (*Typha* spp.), bulrush (*Scirpus* spp.), rush (*Juncus* spp., *Cyperus* spp., *Fimbristylis* spp., *Eleocharis* spp.), and giant reed (*Phragmites australis* Trin.) (Hammer, 1997). There should be a mixture of plant species to maximize plant diversity and to increase stability of the constructed wetland (Hammer, 1997).

1.4 Plant Selection

The plants chosen to populate the wetland thrive in mid to deep water depths. Mid water depths range 15cm to 50cm and include the emergent species cattails and some rush species such as river bulrush (Hammer, 1992). Emergent wetland plants are those rooted in soil with the root portion growing beneath the surface of the water, but the leaves, stems and reproductive organs are above the water and in the air (Anderson and Samargo, 2007). Both wide and narrow leaved cattail species reach maximum growth at a water depth of 50 cm. Other species that thrive in mid water depths are spikerush (*Eleocharis spp.*), arrowhead (*Sagittaria latifolis* Willd.), pickerelweed (*Pontederia cordata* L.), and arrow arum (*Peltandra cordata Raf.*) (Hammer, 1992). Bulrush species such as hardstem bulrush (*Schoenoplectus acutus* Muhl.), prefer water depths that range from 50cm to 200cm (Hammer, 1992). Hardstem bulrushes can grow in waters at a maximum depth of 2.5 meters. Other species that thrive in deep water are Giant reed

(*Phragmites australis (Cav.) Trin. ex Steud.*), Tapegrass (*Vallisneria americana Michx.*), Spatterdock (*Nuphar luteum* L.) and Bladderwort (*Utricularia spp.*) (Hammer, 1992).

1.5 Statement of Problem

A small pond (2,730 m^2 (or 0.67 acres) located on private property in Fairfield Township, Columbiana County, Ohio receives runoff that includes intermittent input from two small streams that drain a small cattle farm and surrounding crop land. The volume of the pond is about 416m^3 (14,700 ft^3), and has a maximum depth of approximately 2.89m (9.5ft.) The water quality of the pond varies, depending on the weather conditions and available surface runoff. After rain or storm events the pond becomes turbid and an increase of nutrients and sediments occur due to the erosion of surrounding agricultural land. In the summer months, the pond exhibits eutrophic conditions brought on by oxygen consumption and lack of aeration. A heavy layer of algae and duckweed forms on the pond surface during summer months, decreasing the overall water quality of the pond.

CHAPTER 2

LITERATURE REVIEW

2.1 Eutrophication

Eutrophication is the process by which a body of water accumulates high concentrations of nutrients. The two main nutrients that contribute to eutrophication are phosphorus and nitrogen (USGS a, 2011). In some cases eutrophication is a process that occurs naturally, but it is more frequently caused by human activity. This type of eutrophication is called cultural eutrophication and is considered an undesirable effect and a form of pollution (Lawrence et al., 1998).

The contaminates that cause eutrophication generally come from two different sources. The first is point source contaminates. Point source contaminates can be tracked to a specific point from where they are discharging, for example wastewater treatment plants, combined sewers, and factories are point source contaminates. The second contributing factor is non-point sources. This source is the leading cause of water quality decline, causing a harmful effect on recreation, drinking water, fisheries, and wildlife. Non-point sources of contamination include pesticides and fertilizers from residential and agricultural fields. They also include nutrients from septic systems, pet waste and farm animal waste (USGS b, 2012).

Nutrients from point and non-point source contaminates promote the excessive growth of algae. As the algae dies, it begins to decompose by microorganisms. The oxidation of the organic matter by the microorganisms depletes the water's available dissolved oxygen. The low levels of dissolved oxygen can cause the suffocation of other organisms and reduces the diversity of life that the water can support. The more the microorganisms work, the more oxygen they use and the higher the measure of the biochemical oxygen demand (BOD). A high measure of BOD means that more oxygen will be depleted in the water system leaving less oxygen free for other aquatic life (Earth Force, 2012).

Fecal coliform contamination is also caused by excess run off from point and non-point source areas. Fecal coliforms are a type of bacteria that is found in the waste of humans and animals. This bacterium enters into aquatic ecosystems from untreated sewage, leaking septic systems, animal waste runoff, and from agricultural runoff (Earth Force, 2012). Consuming or exposure to water with high levels of fecal coliform can cause nausea, fever, stomach cramps, gastroenteritis, and ear infections.

2.2 Previous Research

Constructed wetlands have been used in a variety of situations to remove excess nutrients in surface waters resulting from agricultural activities and wastewater treatment. In a research study by Auburn University's Sand Mountain Agricultural Experiment Station in DeKalb County, Alabama, a constructed wetland was built for the treatment of swine waste (Hammer et al., 1993). Wetlands were constructed in 1988 to remediate waste from 500 animals. Prior to the wetland construction, the runoff crossed over a small meadow and into Bray Creek, contaminating it with swine waste. The design of the constructed wetland is relatively simple. Wastewater from the swine barns were released into a two-celled lagoon system (Figure 2.0). The water was discharged from the lagoons into a mixing pond, which also receives water from a farm stormwater pond located upstream from the wetland (Hammer et al., 1993). The mixture of water and swine effluent flowed into five pairs of cells that are populated with marsh vegetation. As a final step in the process, the mixture flowed into a wet meadow for further remediation. The soil and plants used in the construction are native to the area.

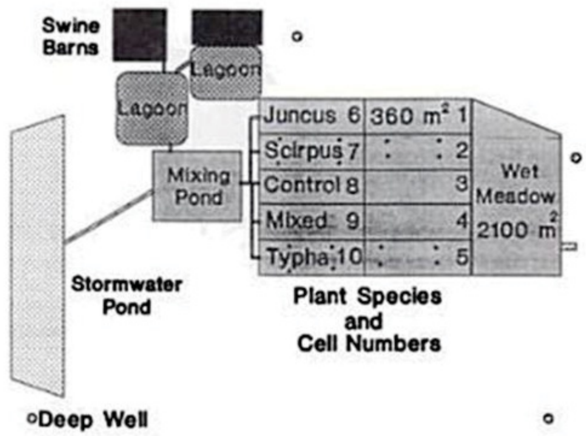

Figure 2.0: Layout of Sand Mountain Constructed Wetlands (Hammer et al., 1993)

The plants used in the Auburn study included cattails (*Typha latifolis* L.), soft-stem bulrush (*Scirpus validus* Muhl.), giant cutgrass (*Zizaniopsis miliacea* Michx.), halifax maidencane (*Panicum hemitonmon* Schult.), common reed (*Phragmites australis* Cav.), and water chestnut (*Eleocharis dulcis* Burn.f.). Even though these were the vegetation planted, the wetland was quickly populated by other specie (Hammer et al., 1993). A total of four groundwater monitoring wells and sixteen lysimeters were installed beginning in November 1990. Water samples were collected monthly from the wells and lysimeters, along with the mixing pond, wetland cells and wet meadow. The samples were analyzed for the following parameters, BOD, chemical oxygen demand (COD), suspended solids, fecal coliforms, fecal streptococci, ammonia-nitrogen, pH, conductivity, total Kjeldahl nitrogen (TKN), nitrates, and phosphorus.

It was found that the species of vegetation present did not have an effect on the total performance of the wetland cells. Despite having a variation of loading rates, the removal rates for BOD, TKN, total phosphorus, suspended solids, and ammonia-nitrogen were constant. There was a significant reduction of TKN, ammonia-nitrogen, total phosphorus, and fecal streptococci by the replicate tier design of the wetlands. The wet meadow showed enhanced removal of suspended solids, BOD, and fecal coliform. The overall percent removed of each pollutant and average concentration of pollutants is shown in Figure 2.5 (Hammer et al., 1993).

The constructed wetland was generally reliable and effective at treating the swine lagoon effluent to produce acceptable wastewater treatment standards for suspended solids, nitrogen, phosphorus, and BOD in the first year of operation (Hammer et al., 1993). Even though fecal coliform and fecal streptococci levels were still too high to be discharged, the densities of the bacteria were removed by 98.4% to 99.4% (Table 2.0). It is thought that since bacteria are removed from wastewaters by absorption and filtration, that the wetland should improve these conditions over the subsequent years as plant densities increase.

Table 2.0: Overall Percent Removed of Each Pollutant and Average Concentration of Pollutants (Hammer et al., 1993)

Wetlands component	BOD_5 (mg/L)	TSS (mg/L)	Fecal col[a] (CFU/100 ml)	Fecal str[b] (CFU/100 ml)	Tot-P (mg/L)	TKN (mg/L)	NH_3-N (mg/L)
Lagoon eff.	110.8	346	817,500	118,750	48.8	116.0	84.0
Farm pond	32.5	51	1,022	679	2.9	3.8	1.1
Mixing pond	63.7	105	175,164	76,727	25.8	69.8	54.7
Upper wetlands							
Cell 6	17.6	31	3,005	3,780	11.9	18.9	13.2
Cell 7	4.9	21	2,530	5,008	7.3	7.8	4.9
Cell 8	15.6	21	3,798	4,634	10.9	25.2	20.3
Cell 9	16.4	35	2,438	3,403	11.9	18.5	12.8
Cell 10	15.3	19	1,894	5,873	10.6	18.9	13.8
Lower wetlands							
Cell 1	9.2	23	1,760	944	7.8	8.5	5.0
Cell 2	8.5	44	4,307	1,405	5.4	5.9	3.4
Cell 3	16.6	29	1,366	2,203	8.2	13.3	8.8
Cell 4	12.5	42	2,421	2,136	10.6	11.9	6.9
Cell 5	5.6	18	3,808	1,279	5.3	4.8	2.4
Final eff.	6.1	9	1,040	1,192	6.2	6.0	3.5
Loading rate (kg/ha/d)	3.5	2.8			1.4	3.0	
Removal (%)	90.4	91.4	99.4	98.4	75.9	91.4	93.6

[a] Fecal col = fecal coliform.
[b] Fecal str = fecal streptococci.

2.2.1 Evidence for Wetland Plant Nutrient Removal

A series of constructed wetlands were studied to evaluate the effectiveness of wetland plants with respect to reduction of nutrient load. The wetlands in this study were located in Georgia. The first one is located in Putnam County, and the second in Ochlocknee County. The Putnam County wetlands are both located on dairy farms, McMichael Dairy and Key Farm (Surrency, 1993). Both dairies have tributaries that drain in to Lake Sinclair. The wetland system located on Key Farm because is of most interest because it was operational, whereas the McMichael Dairy wetland was still in the development process.

The Key Farm wetland is a three-celled constructed surface flow wetland. Cell one contained cattails, cell two contained bulrush (*Scirpus californicus* C.A. Mey.), and cell three contained halifax maidencane (*Panicum hemitonmon* Schult.) (Surrency, 1993). Cell three was also planted with 100 canna lily (*Canna flaccida* Salisb.), pickerelweed (*Pontederia cordata* L.), elephant ear (*Colocasis esculenta* L.), arrowhead (*Sagittaria latifolis* Willd.), and prairie cordgrass (*Spartina pectinata* Bosc.). Beginning in July 1990, water samples were collected and analyzed quarterly. The monitoring of non-point source run off from the surrounding ungrassed feed lots and holding areas were also examined. The wetland plants were well established when effluent from the animal waste was discharged into the wetland. The water level was raised in the wetlands about six inches and effluent was added to allow for proper mixture and acclamation of the increasing nutrient load. The parameters measured in this study were ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus, total organic carbon, and total suspended solids.

The analysis of the water quality at Key Farm before wetland construction showed an elevated concentration of nutrients during active lagoon discharges from the dairy lagoons. The concentrations of total nitrogen and phosphorus exceeded 160 mg/L and 35 mg/L, respectively. After the wetland was constructed, the amount of total nitrogen was reduced by 90%, and the amount of total phosphorus was reduced by 80%. There was also a reduction in nutrients and solids loading into area streams (Surrency, 1993).

In Ochlocknee, Georgia the constructed wetland was built to remediate domestic waste water from homes, stores, and local businesses. A total of four acres were used to create two 2-celled wetland system. A one acre oxidation pond was also built to allow solids to settle and to retain the water before it was discharged into the constructed wetland by a receiving stream. The first third of the individual wetland cells were planted with giant cutgrass (*Zizaniopsis miliacea* Michx.) and the second third was planted with cattails (*Typha latifolia* L.) and the final third was planted with halifax maidencane (*Panicum hemitonmon* Schult.) (Surrency, 1993). Every month water samples were collected and analyzed for dissolved oxygen, pH, BOD, ammonia, suspended solids, and flow.

The Ochlocknee constructed wetland was successful. Post construction water quality analysis showed a substantial reduction of ammonia, BOD, TKN, and total suspended solids. Both pH and dissolved oxygen levels from the wetland were more favorable than the receiving stream (Surrency, 1993).

The Key Farm constructed wetland demonstrated that giant bulrush (*Scirpus californicus* C.A. Mey and *S. validus* C.C. Gmel.), giant cutgrass (*Zizaniopsis miliacea*

Michx.), halifax maidencane (*Panicum hemitonmon* Schult.), pickerelweed (*Pontederia cordata* L.), arrowhead (*Sagittaria latifolis* Willd.) and cattail (*Typha latifolia* L.) are the most effective aquatic plants to use in a constructed wetland that treats wastewater from animal operation runoff and for municipal wastewater (Surrency, 1993). Giant bulrush is recommended for wetlands with high ammonia concentrations, due to its tolerance to ammonia. Cattails performed well and set the standard for comparison of wetland plant performance. Cattails were found to be prone to insect damage and showed stress in high levels of ammonia. Overall, both of the Georgia wetlands performed well with the plants that were selected.

A similar study was conducted to examine plant biomass and nutrient uptake efficiency of eight emergent aquatic plant species (Tanner, 1995). The eight plant species used were jointed twig rush (*Baumea articulate Gaudich.), river bulrush (Bolboschoenus fluviatilis Torr.), umbrella sedge (Cyperus involucratus L.), reed sweetgrass (Glyceria maxima S. Watson), common rush (Juncus effusus L.), common reed, soft-stem bulrush (Scirpus validus Vahl.),* and manchurian wild rice (*Zizania latifolia Griseb.) (Tanner, 1995)*. The plants were grown in three separate 0.238 m^2 by 0.6 m deep gravel bed wetland mesocosms. A mesocosm is an experimental unit designed to contain important components and to show important processes occurring in a whole ecosystem (Draggan and Reisa, 1980). The mesocosms were supplied with dairy farm wastewaters that were pre-treated in an anaerobic lagoon. The plants were allowed to grow and uptake nutrients for a total of 124 days.

After this time period, the plant biomass, nutrient uptake and treatment performance were analyzed. Biomass was determined by drying and weighing all below and above ground plant samples that were collected, and grouped by their species. Nutrient uptake of the plants was determined by collecting dried samples of plant tissue that were ground and analyzed for macro and micronutrients.

The average total biomass for all plant species were examined prior to analysis of individual biomass for all plant species, and above ground and below ground biomass. The average total biomass for all of the plant species was found to range from 0.3 to 7.4 kg m^{-2}. Above and below ground biomass rations were found to range between 0.35 and 3.35 kg m^{-2}. Manchurian wild rice and reed sweetgrass had the largest above ground biomass values. They ranged from 3 kg m^{-2} to 4 kg m^{-2}. Overall growth in jointed twig rush and common rush was poor compared to the other plant species. Tissue analysis for N and P, found the average concentrations to range between 15 to 32 mg g^{-1} N and 1.3 to 3.4 mg g^{-1} respectively. The highest plant accumulations of N and P were found to be 135 g N m^{-2} and 18.5 g P m^{-2} and accounted for about 30% of the levels supplied in wastewaters. The average percent of suspended solids removed was found to be between 76-88%, 77-91% for BOD, 79-93% of total phosphorus, and 65-92% of total nitrogen (Tanner, 1995). The removal of total nitrogen showed a positive linear correlation with the plants biomass. Overall, it was found that the eight emergent plant species did reduce the amount of nutrients found in the wastewater and could be used in constructed wetland systems to remediate wastewaters from animal runoff.

2.3 Removal Mechanisms for Plant Nutrient Uptake

When wetlands are used as the main component in treating wastewaters, the aquatic plants play a key role in the removal process. Pollutants are removed in every wetland system by an intricate range of biological, physical and chemical processes

(Watson et al., 1989). Plant established wetland treatment systems are the most diverse treatment systems and some of the treatment processes are attributed to the microorganisms that live on and around the plants. Wetland plants remove pollutants by providing the surface for a suitable environment for the microorganisms to transform the pollutants and reduce their concentrations. They also remove pollutants by directly absorbing them into their tissues. Oxygen transfer by the aquatic plants into the rhizosphere is essential for certain microbial pollutant removal process to function correctly (Moorhead and Reddy, 1990, Reddy et al., 1989). Table 2.1 lists the most important removal mechanism found in constructed wetlands.

Suspended Solids	Sedimentation/filtration
BOD	Microbial degradation (aerobic and anaerobic)
	Sedimentation (accumulation of organic matter/sludge on the sediment surface)
Nitrogen	Ammonification followed by microbial nitrification and denitrification
	Plant uptake
	Ammonia volatilization
Phosphorus	Soil sorption (adsorption-precipitation reactions with aluminum, iron, calcium, and clay minerals in the soil)
	Plant uptake
	(Phosphine production)
Pathogens	Sedimentation/filtration
	Natural die-off
	UV radiation
	Excretion of antibiotics from roots of macrophytes

Figure 2.1: Important Removal Mechanisms in a Constructed Wetland (Hammer, 1989)

Suspended solids are removed primarily in a pretreatment cell. The pretreatment cell is normally built up gradient of the wetland. Any suspended solids that remain in the wastewater after it leaves the pretreatment cell are removed in the wetland by sedimentation and filtration. This physical removal process also removes other wastewater contaminants, such as BOD, nutrients, and pathogens (Moshiri, 1993). Bacteria aerobically degrade soluble organic compounds that are attached to the plant and sediment surfaces. During periods where oxygen is depleted in the water column and anaerobic sediments, anaerobic degradation will occur. The anaerobic degradation can be significant in some cases (Brix, 1990). Oxygen needed to support aerobic processes are supplied directly from the atmosphere by diffusion through the sediment or water atmosphere interface, by photosynthetic oxygen production within the water column, and by leakage of oxygen from the aquatic plants roots (Moorhead and Reddy, 1990).

Nitrification-denitrification is the major removal process for nitrogen in constructed wetlands. Any ammonia is oxidized to nitrate by nitrifying bacteria in aerobic zones of the wetland. The nitrates are then transformed to dinitrogen gas (N_2) by denitrifying bacteria in anoxic zones. Oxygen required for the nitrification process is provided from the atmosphere, the water, and/or the sediment surface. Plants also directly uptake nitrogen and incorporate it into the biomass of their tissues (Reddy et al., 1989, Gersberg et al., 1983).

Phosphorus is removed in constructed wetlands by means of adsorption, complexation, and precipitation by reaction with aluminum, iron, calcium, and clay minerals in the sediment (Richardson, 1985). Uptake of phosphorus by plants has been found to be significant in wetland systems where the area specific loading rate is low (Breen, 1990, Reddy and DeBusk, 1985).

Undesirable environmental conditions cause a natural die off of pathogens that may be found in a wetland system (Watson et al., 1989, Gersberg et al., 1987, Lance et al., 1976). Wetlands also remove pathogens by sedimentation and filtration when wastewater is passed through the system. Finally, ultraviolet radiation has a significant effect to wetland systems with open water to reduce bacteria (Moeller and Calkins, 1980).

2.4 Objective and Hypothesis

The objective of this project is to construct a wetland and populate it with native wetland plant species as an effort to reduce suspended solids and remediate the nutrient loaded agricultural runoff water before it enters the pond. It is hypothesized that the water quality in the pond after wetland constructed will improve.

CHAPTER 3
MATERIALS AND METHODS

3.1 Wetland Description

The wetland was constructed upstream of the pond to reduce the nutrients and sediments that were entering the pond from the adjacent farm land. The goal of the wetland is to improve the water quality of the pond for aesthetic purposes, to support indigenous fish populations (bass, bluegill, and catfish) and attract a variety of wildlife.

Figure 3.0 shows the general location of the pond, the surrounding agricultural use, runoff collection area, and intermittent stream paths. The red lines show the flow of the runoff water into the pond. The area shaded in white is agricultural land used for corn and soybean crops. Areas on the map shaded with blue are agricultural land used for planting hay. The area shaded in pink above the pond is the location of the constructed wetland. The area shaded in orange is cattle farm pasture.

The wetland was constructed on 0.4 acres. Initially, a 15.2m x 12.1m (50ft x 40ft) setting pond was constructed below the two foot diameter inlet pipe to catch and hold sediment entering the system (Figure 3.1 and 3.2). The sediment pond has a depth of approximately 0.914m (3ft) for the catchment and storage of trapped sediment. Runoff water flows into the sediment pond before it enters wetland cell number one. Wetland cell number one is 0.914m (3ft) below the sediment pond full-pool elevation and receives inflow from the sediment pond via a 3.04m (10ft) wide spillway. Wetland cell one is rectangular in shape and one measures 1m (41ft) wide and 16.7m (55ft) long. The water from wetland cell number one enters wetland cell number two by passing through a stop log flow control structure. A small intermittent tributary stream enters cell two directly below the flow control structure. Wetland cell number two has an elevation of about

0.152m (0.5ft) above the full pool level of the pond. Wetland cell number two has a basic triangular shape with a base measurement of 18.2m (60ft) and a height of 13.3m (44ft) (Vemuri, 2011). The outflow from wetland cell number two exits directly into the pond. A stop log flow control structure will be constructed at the outflow of cell two during summer 2012.

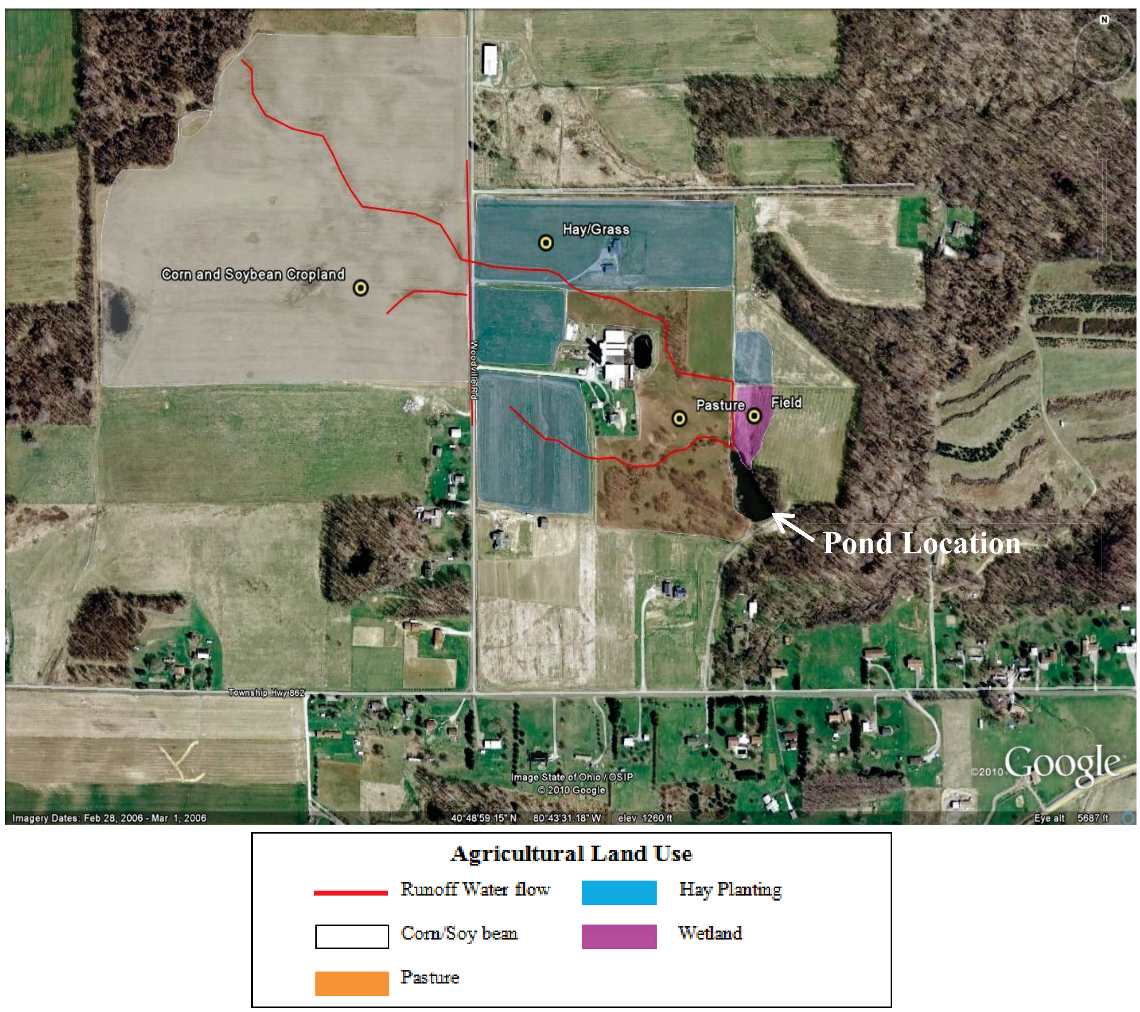

Figure 3.0: Pond and Surrounding Agricultural Area (Google, 2012)

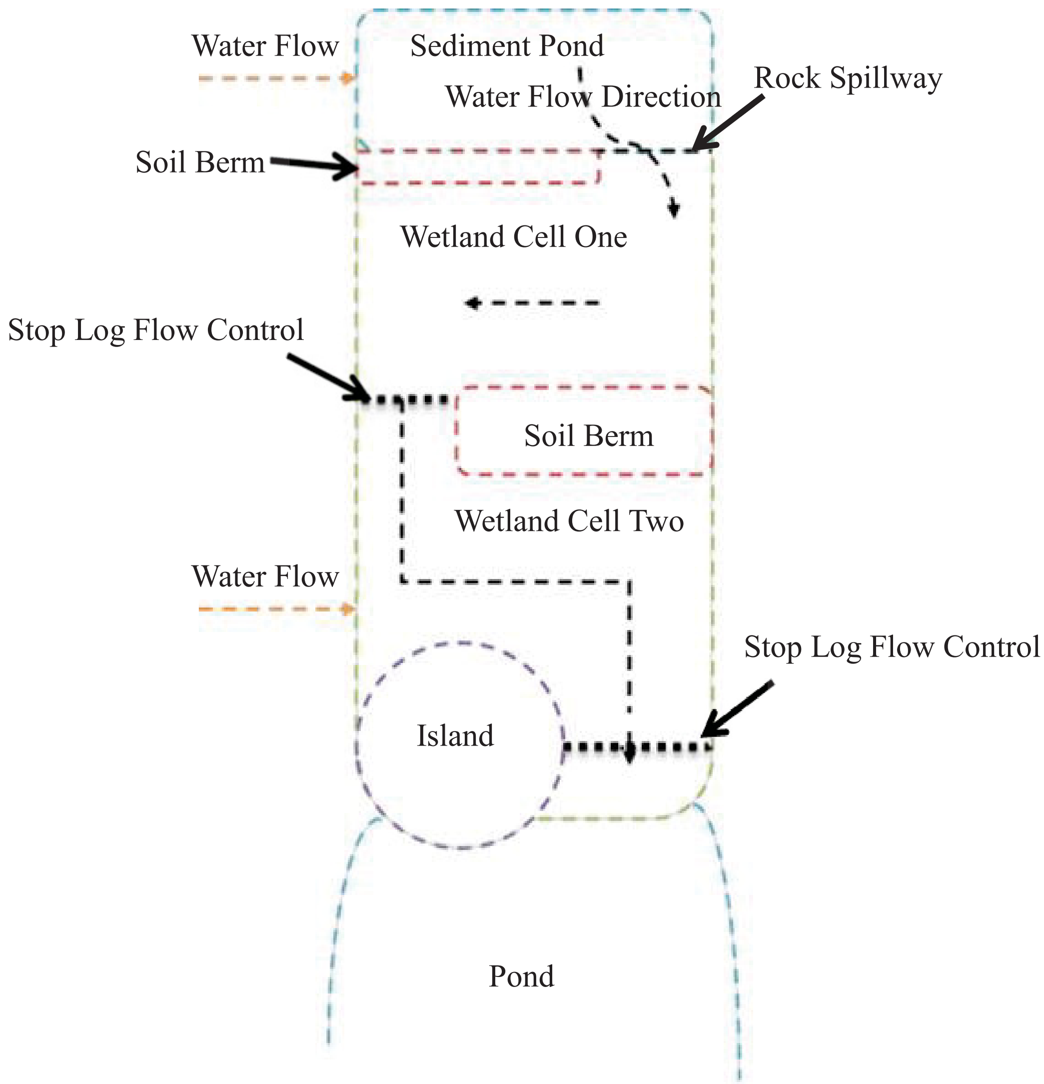

Figure 3.1: Wetland Design

Stop-log flow control structures will be used to control the depth in each cell. They are designed to retain water/increase residence time, enhance sedimentation, and regulate water depth as a means of controlling invasion of non-wetland plant species. The increased residence time should allow for greater removal of contaminants/nutrients phosphorus and nitrogen. Starting left to right, the pond, wetland cell number two, cell number one and sediment pond are shown in Figure 3.2.

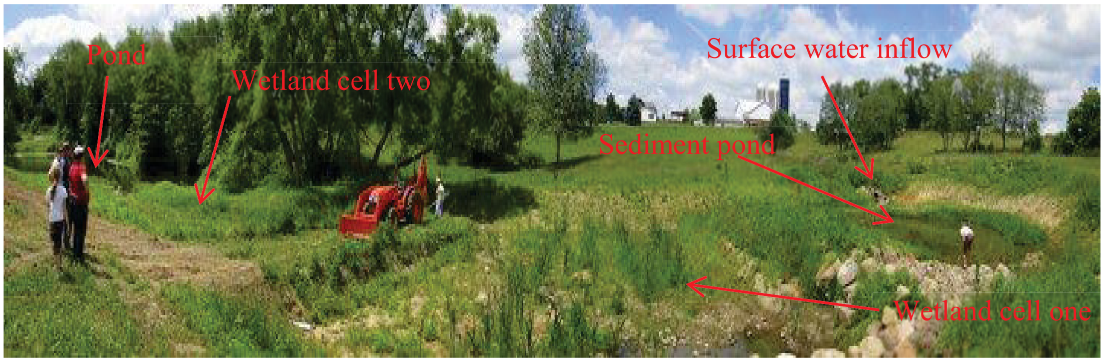

Figure 3.2: Constructed Wetland Showing Each Component

3.2 Wetland Plant Collection Sites

The wetland was vegetated during October and November 2010 and June 2011 with native wetland plants including broadleaf cattail *(Typha latifolia* L.), narrow leaf cattails (*Typha angustifolia* L.) and various sedge and rush species such as common rush (*Juncus effusus* L.) and green bulrush (*Scirpus atrovirens* Willd) (Braun, 1967). Plants were collected from a wetland located on a closed rest stop on Ohio State Route 11, four miles south of Ohio State Route 224 (Figure 3.3), and from private wetlands within the Shenango River watershed in Trumbull County (Figure 3.4). All of the plants were uprooted with a shovel and placed in a bucket or plastic shopping bag to be transported back to the constructed wetland. Soil surrounding the individual plants was retained to provide a seed bank for future plant growth. Approximately one-hundred and forty-two cattail plants, *Typha latifolia* L. and *Typha angustifolia* L. and two skunk cabbages, *Symplocarpus foetidus* L., and fourteen various sedges, and rushes were transplanted in cell one. Wetland cell number two was populated with approximately one-hundred and eleven cattails, five skunk cabbages and fourteen various sedges and rushes.

Figure 3.3: Ohio State Route 11 Wetland

Figure 3.4: Shenango Wetland Trumbull County (Google, 2012)

3.3 Wetland Plant Count

October 23rd, 2011 a plant count was performed on wetland cells number one and two. A sampling grid with 3.81m x 3.81m plots (12.5 x 12.5 ft) was constructed by measuring wetland cell number one with a tape measure. The cell measured 22.8 m (75ft.) wide by 15.3m (50.5ft) long. Metal stakes were placed in the ground every 3.81m (12.5ft). Green string was used to grid the wetland plot into 3.81m (12.5ft) squares (Figure 3.5), and the grid plots were numbered from 1 to 24. Plots 12, 18, and 24 are located on the edge of the wetland and were omitted for plant count, along with square 5 due to the water being too deep and square 6, due to the rocks from the sediment over flow cell (Figure 3.6). The remaining square numbers were randomly selected for plant count. Three plots were chosen to get a 10 percent coverage representation of the wetland plants. Plot numbers 1, 9 and 11 were selected. Finally, individual plant species were counted within each wetland plot. The total number of each plant was divided by three to get the number per-plot. Then, that number was then multiplied by 24 to get a reorientation of how many of those plants were found in wetland cell one.

The entire plant population in wetland cell number two was counted to obtain the plant count in that cell. Two factors contributed to this method. Due to the irregular shape of wetland cell number two, a square grid was impossible to make. Also, the flow control dam for wetland cell number two was not in place yet. This caused the wetland to be dryer than cell number one, allowing for greater growth in weeds and grass, and not as many aquatic plants.

Figure 3.5: Wetland Cell One Grid in the Field

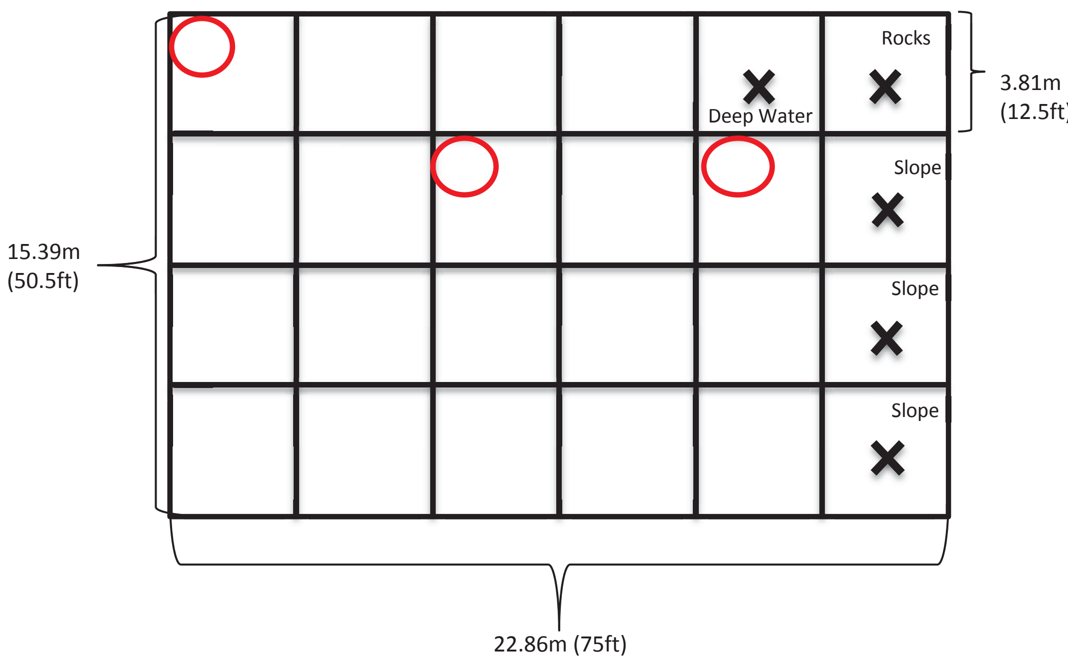

Figure 3.6: Wetland Cell One Grid Design to determine Plant Species Count

3.4 Sampling Overview

Water quality samples were collected for laboratory analysis in the summer and fall of 2010 and 2011. Pre-wetland construction water quality analysis was conducted during the summer and fall 2010 months to determine the water quality of the pond before the wetland was constructed and able to evaluate the overall wetland performance on reducing nutrient input. Subsequently, the post-wetland construction water quality was monitored during the summer and fall 2011 months.

3.5 Parameters Measured

The following water quality parameters were measured to evaluate the water quality in the pond from pre and post-construction: dissolved oxygen, water temperature and depth, BOD, coliform, Escherichia coli, total suspended solids, and total solids. (Table 3.0). The samples were brought to the Youngstown State University Environmental Studies lab and analyzed. All analytical methods except e-coli were followed from *Standard Methods for the Examination of Water and Wastewater* (Standard Methods et al., 1998). For the coliform test, pond water sample size varied for coliform tests, ranging from 1µ to 100mL. The amount of water sample to be used was selected based on the rain amount in the area. First, a filter membrane was placed into the filter system. Then 50mL of deionized water was put in a filter system and sample water was added along with. Another 50mL was added and the sample was filtered through the membrane. The filter holder was then rinsed with deionized water to clear out any remaining bacteria. Using sterile tweezers, the filter membrane was place into a premade agar plate and incubated for 24 hours.

After the 24 hour period, the blue colonies of bacteria that grew were counted. The BOD methods were modified so that every BOD sample bottle received 3mL of seed sample. Except for the first sampling day, the sample size for BOD analysis stayed consistent at 3, 10, and 15mL for seed, 50, 150, 200 and 300mL of sample pond water for the deep and shallow samples. The amounts for the first sampling day for BOD were 3, 10, 25mL seed, and 3, 10, 50, 150, 300 and diluted 10 times 10mL. This was done to find the appropriate range of seed and sample water to be used. The 3mL seed BOD bottle was used as the seeded blank since it was found to be the proper amount to use to ensure the seed was working. Also, 3mL of seed was added to every pond water BOD bottle. Methods for e-coli testing were followed from the Colilert Test Kit instructions, based on IDEXX's Defined Substrate Technology (IDEXX, 2008). Each 10mL sample were put into Colilert Tubes and incubated for 24 hours. After 24 hours the presence or absence of total coliform and E. coli were determined. If the tubes were yellow in color they were positive for coliform. If they fluoresced under an ultra violet light, they were positive for E. coli. A chart was used to determine the most probable number of bacterial colonies per 100mL. Unused water samples were stored and preserved in a refrigerator at about 36°F.

Table 3.0: Water Quality Parameters Measured (Standard Methods et al., 1998)

Parameter	Method
Dissolved Oxygen	YSI Model 57 Meter
Temperature	YSI Model 57 Meter
Depth	YSI Model 57 Meter
Biochemical Oxygen Demand	5210 B. 5-Day BOD Test
Coliform	9222 B. Standard Total Coliform Membrane Filter Procedure
Escherichia coli	Colilert Pre-dispensed MPN
Total Suspended Solids	2540 D. Total Suspended Solids Dried at 103-105°C
Total Solids	2540 B. Total Solids Dried at 103-105°C

3.6 Sampling Locations and dates

Water samples were collected from two locations in the pond at a depth of 0.61m (2ft). One location is at the deep end of the pond and the second at the shallow end (Figure 3.7). Dissolved oxygen, and water temperature were measured at 0.304m increments (1ft) starting at the bottom and working up to the surface. The actual water depth varies with pond level and the maximum recorded depth was 2.89m (9.5ft) in the deep end of the pond. The maximum record depth of the shallow end of the pond was 1.52m (5.0ft).

Figure 3.7: Shallow and Deep Water Sampling Locations (Google, 2012)

The pre-construction water sampling of the pond began in summer of 2010. Six samples were collected during the pre-construction monitoring. The first sampling date started in July of 2010 and lasted until September 2010 (Table 3.1). The post-construction water sampling began in spring of 2011 and continued into the fall. A total of seven samples were collected. Excluding two April sampling dates, every sample taken in 2011 was taken on the exact same date as the samples from 2010.

Table 3.1: Sampling Sites, Dates, and Max Pond Depth

	Shallow Pond	**Deep Pond**
	Sample Location	**Sampling Location**
	maximum depth (ft)	**maximum depth (ft)**
7-Jul-2010	5.0	9.5
13-Jul-2010	5.0	9.5
27-Jul-2010	5.0	9.5
3-Aug-2010	5.5	9.5
18-Aug-2010	5.5	9.5
8-Sep-2010	5.5	9.5
3-Apr-2011	5.0	9.0
24-Apr-2011	5.0	9.0
7-Jul-2011	5.0	9.0
13-Jul-2011	5.0	9.0
27-Jul-2011	5.0	9.0
3-Aug-2011	5.0	9.0
18-Aug-2011	5.0	9.0
8-Sep-2011	5.0	9.0

3.7 Preparation of Sample Containers and Laboratory Equipment

One liter Nalgene plastic bottles were used to collect water samples for the shallow and deep sampling sites. A total of three liters was collected for each site. To reduce contamination, all of the sample bottles were acid washed for 20 minutes in a 1.05% HCl solution and soaked for 20 minutes in deionized water. All of the glassware used in the laboratory analysis was acid washed and rinsed. Before the samples were brought back to the lab, all of the laboratory equipment was cleaned and prepared according to *Standard Methods for the Examination of Water and Wastewater* (Standard Methods et al., 1998).

An YSI 5100 Dissolved Oxygen Meter was used to test the dissolved oxygen levels in the BOD bottles. Pond water sample size varied for coliform tests, ranging from 1µ to 100mL.

3.8 Field Measurements

Field measurements of DO and temperature were made with an YSI Model 57 meter. The meter was calibrated according to the user manual specifications prior to each sample event. A paddle boat was used to access the sampling sites in the pond. The YSI meter was used to take the measurements of dissolved oxygen and temperature. Depth was measured using the pre-determined markings on the meter's cord. Dissolved oxygen and temperature were taken at various depths in the pond, starting with the deepest depth and working up in the water column. The meter was allowed to stabilize for three minutes before each reading was recorded in a notebook. A stopwatch was used to time the three minutes. After the dissolved oxygen and temperature were measured, the water samples were collected at a depth of two feet with a PVC horizontal water bottle sampler and poured into a Nalgene 1000mL plastic bottle. The bottles were rinsed with pond water prior to sampling to eliminate any leftover deionized water or contaminates from the washing process.

3.9 Statistical Analysis

A Wilcoxon Rank Sum (or Mann-Whitney) test in Statistical Packages for the Social Sciences 18 (SPSS) was used to determine the statistical significance of the pre and post wetland construction data. The Wilcoxon Rank Sum test is a nonparametric test used to compare two groups of data. It was used to compare the two groups of data from 2012 and 2011. P values close to or below 0.05 were considered to be significant. The Asymp. Sig. (2-tailed) data from the Wilcoxon Rank Sum test were used to determine the p value of the data. When the p value was 0.05 or less, the null hypothesis, stating that there was no relationship between the pre-construction and post-construction water quality parameters, was rejected. Boxplots run in SPSS gave a simple graphical representation of the distribution of the data. They were also used to compare the averages and determine any change in water quality levels from pre and post wetland construction and to show outliers and extreme outliers that may have skewed the statistical results. A univariate test was used in SPSS to look at two single variables. This information was used to compare and find any significance between dissolved oxygen and temperature. Any value close to or below 0.05 was once again considered to be significant. A high f value close to or greater than 10 was also taken into consideration.

CHAPTER 4

RESULTS

4.1 Water Quality Data

All 2010 data from the pond is pre-wetland construction and the initial plant count is from the 2010 planting phase. The data from 2011 is from the pond after the wetland was constructed. All raw data for the parameters measured can be found in Appendices B-F. The statistical test results for all sample parameters are summarized in Tables 4.0 and 4.1. The corresponding boxplots of each sample parameter are shown in Figures 4.0, 4.1 and 4.2.

The biochemical oxygen demand (BOD) results from 2010 ranged between 1.33 mg/L to 37.4 mg/L and 1.03 mg/L to 4.41 mg/L in 2011. When BOD was analyzed in SPSS to compare two samples with the Wilcoxon Rank Sum Test, a p-value of 0.391 was found (Table 4.0). The boxplot data for BOD showed a decrease of 0.3 mg/L in 2011 from 2010 (Figure 4.0). The results for the 5 day BOD glucose glutamic acid check in 2010 and 2011 were in the range of 167.5 to 228.5 mg/L, which are in the acceptable range of 198 ± 30 mg/L (Appendix A). This test was performed to check that the seed is active enough to initiate a reaction.

Dissolved oxygen (DO) results from 2010 ranged from 1.10 mg/L to 3.31 mg/L. The DO values for 2011 ranged from 0 mg/L to 5.31 mg/L in 2011. The Wilcoxon Rank Sum Test showed a p-value of 0.668 (Table 4.0). An increase in DO from 2010 to 2011 was found to be 0.520 mg/L and is showed in Figure 4.0 boxplots.

The coliform bacteria plates ranged from 13.0 to 56.0 colonies in 2010 and 1.0 to 63.0 colonies in 2011. A p value of 0.105 (Table 4.0) was found and the boxplots showed a decrease in coliform bacteria in 2011 (Figure 4.1). The decrease was found to be 11.5 colonies.

The temperature range in 2010 was 19°C to 25.1°C (66.2°F to 77.2°F). In 2011 the temperature range was 19°C to 26.6°C (66.2°F to 79.9°F). The Wilcoxon Rank Sum Test showed a p-value of 0.391. The temperature average in 2011 was higher than in 2010 (Figure 4.1). The increase was by 0.80 degrees. When using the univariate test in SPSS to compare Temperature with DO, a p value of 0.680 and an F value of 6.90 are found (Table 4.1).

A range for total solids (TS) in 2010 was 75.0 mg/L to 87267 mg/L and 98.0 mg/L to 185 mg/L in 2011. A p-value of 0.467 was found. The boxplots showed an equal average in TS for both years (Table 4.2). They also show that the data from 2011 has less of a range of TS than 2010.

Total suspended solids (TSS) ranged from 3.78 mg/L to 8.53 mg/L in 2010 and 0.730 mg/L to 8.80 mg/L in 2011. The Wilcoxon Rank Sum Test showed a significant p-value below 0.05 of 0.025 (Table 4.0). Boxplots for TSS show a decrease in 2011 that are two times as low as the TSS for 2010 (Figure 4.2). The decrease was found to be by 2.60 mg/L.

Table 4.0 P values for BOD, TS, TSS, Coliform Plates, DO and Temperature

Test Statistics[b]

	BOD	TS	TSS	Coliform Plates	DO	Temperature °C
Mann-Whitney U	47.000	49.000	26.000	35.500	53.500	47.000
Wilcoxon W	125.000	127.000	104.000	113.500	108.500	102.000
Z	-.857	-.727	-2.242	-1.621	-.429	-.858
Asymp. Sig. (2-tailed)	.391	.467	.025	.105	.668	.391
Exact Sig. [2*(1-tailed Sig.)]	.418[a]	.497[a]	.025[a]	.107[a]	.674[a]	.418[a]

a. Not corrected for ties.

b. Grouping Variable: Date

Table 4.1 F and P Values for Temperature and DO: Tests of Between Subjects Effect

Dependent Variable: Temperature

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	114.284[a]	18	6.349	6.901	.068
Intercept	11123.282	1	11123.282	12090.524	.000
DO	114.284	18	6.349	6.901	.068
Error	2.760	3	.920		
Total	11681.560	22			
Corrected Total	117.044	21			

c. R Squared = 0.976 (Adjusted R Squared = 0.835)

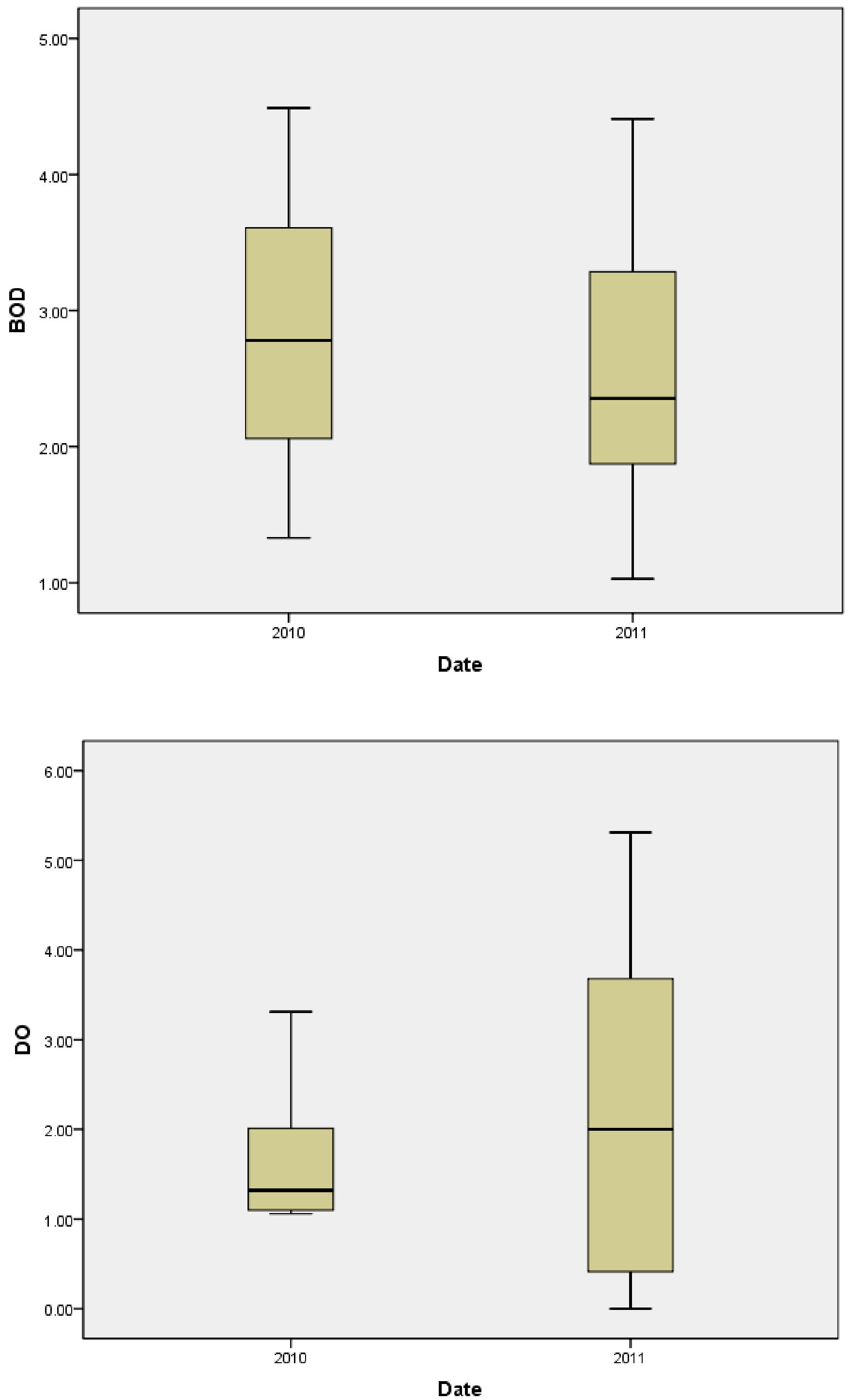

Figure 4.0: Biochemical Oxygen Demand and Dissolved Oxygen Boxplots

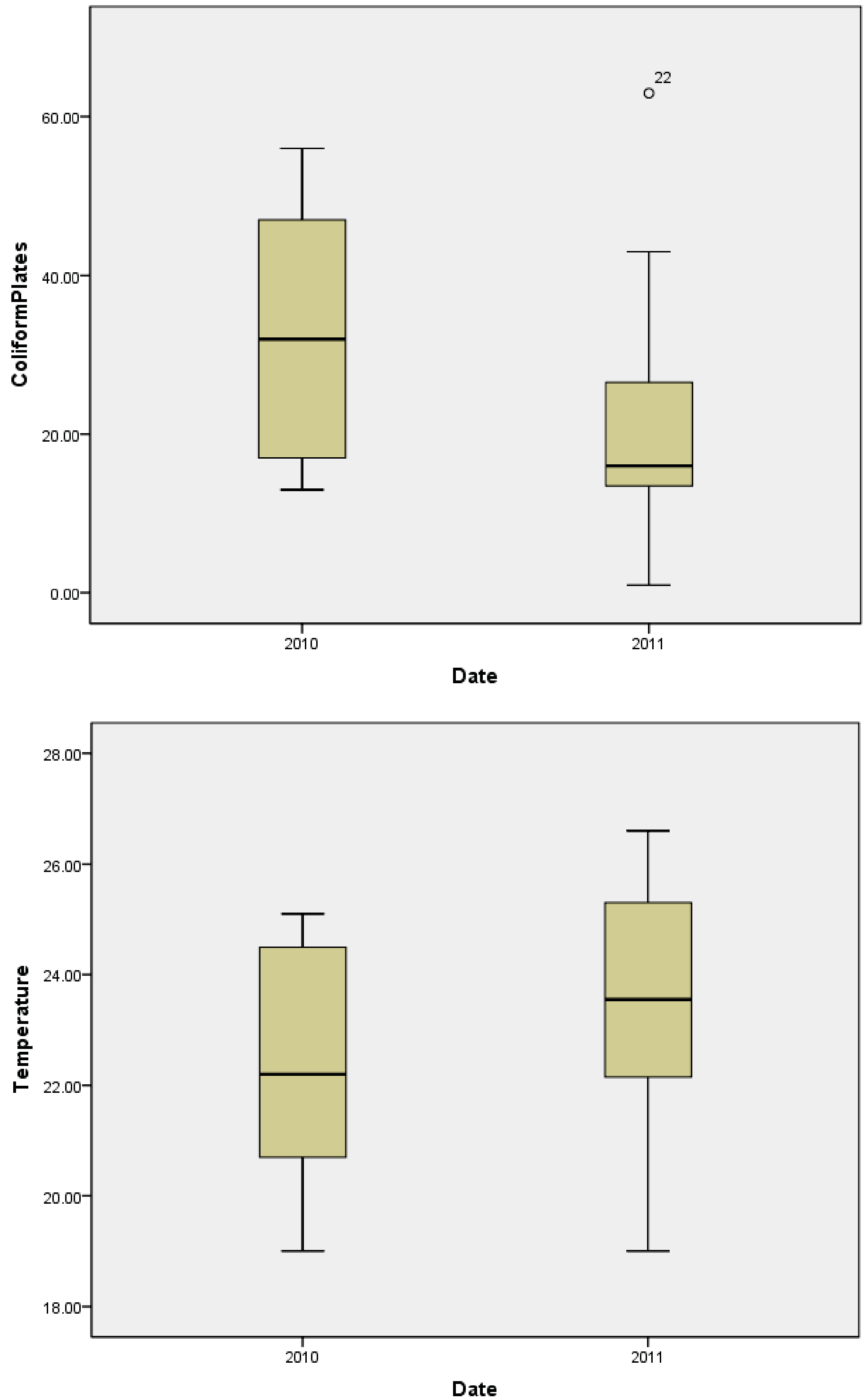

Figure 4.1: Coliform Plates and Temperature Boxplots

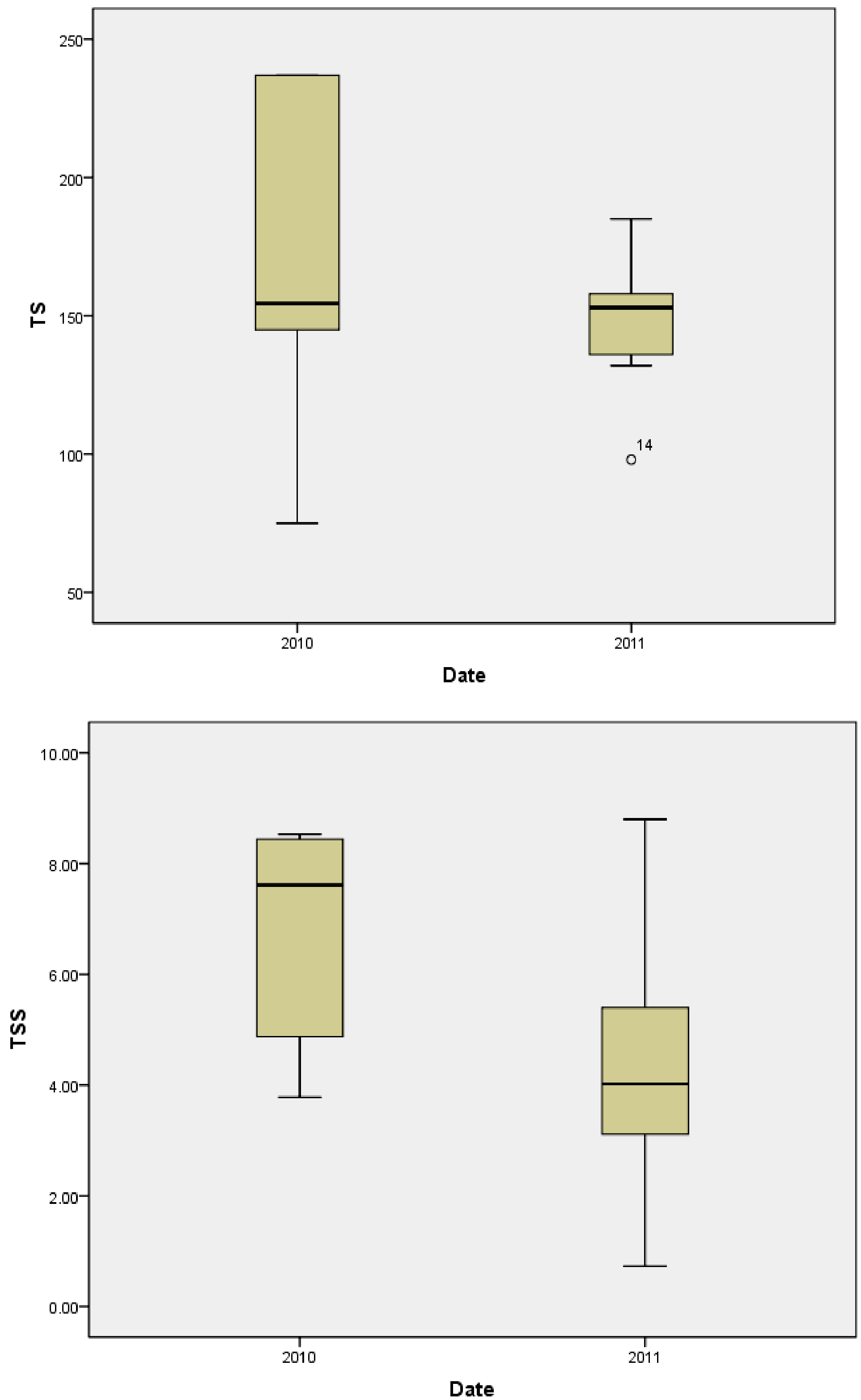

Figure 4.2: Total Solids and Total Suspended Solids Boxplots

The Colilert tube results for coliform were the same for 2010 and 2011. They were all found to have a most probably number (MPN) per 100 mL of greater than 16 coliform colonies per 100 mL of sample water (Table 4.2). Table 4.2 also shows that there was a drop in *Escherichia coli* (Mig.) Castellani and Chalmers (E. coli) on 7/27/2010, 8/3/2010 and 9/8/2010. Over all there were five samples that had a drop in E. coli. Post-construction 2011 E. coli results showed a total of eight samples that had a drop in E. coli. The drop in E. coli in 2011 occurred over the entire sampling season, whereas the 2010 E. coli amounts only dropped in the last few months of sampling.

Table 4.2: Coliform and E. coli Most Probable Number as Determined by Colilert Tubes

Site	Date	Coliform	E. coli	Date	Coliform	E. coli
Shallow	7/7/2010	>16	>16	7/7/2011	>16	9.2
Deep	7/7/2010	>16	>16	7/7/2011	>16	>16
Shallow	7/13/2010	>16	>16	7/13/2011	>16	16
Deep	7/13/2010	>16	>16	7/13/2011	>16	5.1
Shallow	7/27/2010	>16	16	7/27/2011	>16	16
Deep	7/27/2010	>16	>16	7/27/2011	>16	16
Shallow	8/3/2010	>16	9.2	8/3/2011	>16	>16
Deep	8/3/2010	>16	2.2	8/3/2011	>16	2.2
Shallow	8/18/2010	>16	>16	8/18/2011	>16	2.2
Deep	8/18/2010	>16	>16	8/18/2011	>16	2.2
Shallow	9/8/2010	>16	16	9/8/2011	>16	>16
Deep	9/8/2010	>16	9.2	9/8/2011	>16	>16

4.2 Plant Count Results

A post-construction plant count was performed on October 23rd, 2011 to assess plant growth and plant population changes. The plant count results of the three randomly selected plots of wetland cell one (#11, #9, and #1) (Figure 3.5) are as follows: Plot number 11 was filled with water and had 35% coverage with slender naiad (*Najas flexilis* Willd.), 45% grass and 30% coverage with duckweed (*Lemna minor* L.). A mix of broad and narrow leaf cattails totaled 90, common rush totaled four and green bulrush (*Scirpus atrovirens* Willd) totaled three; Plot number 9 had 90% grass coverage, 5% duckweed, and 5% slender naiad and 63 cattails; Plot number 1, had 70% grass coverage, 53 cattail mix, 11 strawcolored flatsedge (*Cyperus strigosus* L.), nine common rush, and 1 spike rush (*Eleocharis ovata* Rush.). In total there were 1648 cattails, 104 common rushes, 24 green bulrushes, and eight spike rushes. There was a 1060% increase of cattails, and a 971% increase of rushes and sedges compared to initial planting in 2010.

In wetland cell two a total of 205 mix of cattails species (broad and narrow leaf) was counted, 80 common rush, one spike rush, 13 strawcolored flatsedges, and two green bulrushes. There was a 184% increase in cattails and a 685% increase in rushes and sedges. No skunk cabbages were counted in either wetland cell. During heavy rainfall events in April 2011, it was observed that the skunk cabbages were uprooted and washed away.

CHAPTER 5

DISCUSSION

5.1 Data Exclusion

A total of fourteen water sampling events were completed between July 7, 2010 and September 8, 2011. Even though there is water quality data for July 7th 2010, April 3rd 2011, and April 24th 2011, this data was left out of the analysis. The data for July 7th is missing values for TS and had a high occurrence of BOD at 37.4 mg/L. The missing July 7th values are due to errors in the lab analysis process. The high BOD level is likely erroneous due to the unnaturally high value and the fact that the 37.4 mg/L was the only value of its kind. The April 2011 data was excluded for several reasons. First, there is no April 2010 data to compare results to, so no conclusion could be made if the wetland had an effect in that time period. Also the weather conditions played a great role in the water quality results. April 2011 was unusually wet, with a rainfall amount of 7.70 inches (NOAA, 2011). The average rainfall for the state of Ohio in April is about 3.37 inches (Weather b, 2012). During this time period the wetland experienced a heavy amount of rain, runoff water, and sediment from the surrounding agricultural field. This caused an increase in TS, TSS, coliform, and a decrease in dissolved oxygen (Appendix A).

April 2011 was unusually cold. The levels of DO in April 2011 were found to range from 11.6 to 12.2 mg/L on April 3rd and 5.27 to 5.33 mg/L on April 24th. The colder air temperatures in April caused the water temperature in the pond to range from 6°C to 10.6°C (42.8°F to 51.1°F). The temperature in April had a direct effect on the DO concentrations. The average temperature in Columbiana, Ohio for the month of April is around 16°C (60.8°F) (Weather a, 2012). The higher levels in DO are due to the fact that cold water can hold more dissolved oxygen than warmer water can. In the winter and early spring months the dissolved oxygen levels are lower than the summer and the fall, when the DO concentrations are low from the warmer water (USGS c, 2012). Decomposition is another factor that may play a role in the higher DO concentrations. Algae, duckweed and other aquatic plants had not begun to grow. When the aquatic plants die they settle to the bottom of the pond and begin to decompose. The decomposition process uses the available oxygen in the pond. The lower decomposition in April provides more available oxygen for other organisms, resulting in the high DO concentrations. It is also possible that the increase in DO could be the result of higher volumes of runoff in the month of April which created turbulence thereby increasing DO.

5.2 Water Quality

The null hypothesis assumes there is no relationship between tested water quality parameters before and after construction of the wetland. The Wilcoxon Rank Sum Test considers any p value close to or less than 0.05 significant. When the p value was 0.05 or less, the null hypothesis was rejected. The only water quality parameter that showed significance in the Wilcoxon Rank Sum Test was the TSS versus sampling date data. Having a p value of 0.025, the null hypothesis was rejected. This suggests that the TSS had a pre and post construction correlation. Adding in the data from the boxplots further indicates that TSS in fact differed in 2011 from 2010. The boxplot (Figure 4.2) shows the average TSS levels decreased fifty percent from 2010 to 2011. The reduced TSS indicates the sediment pond and wetland effectively reduced the amount of suspended sediment that was entering the pond.

Even though the other water quality parameters did not differ statistically (Table 4.0), the boxplot data suggests some improvement of the pond water quality. The boxplots (Figures 4.0, 4.1 and 4.2) and excel data (Appendix A-F) do show a post construction decrease in the average values for BOD, TS, TSS, coliform, and E. coli. There was post construction increase in DO and temperature (Figure 4.0 and 4.1). The decrease in BOD can be attributed to the increase of DO and vice versa, the increase in DO can be attributed to a decrease in BOD. The increase in temperature was caused by yearly variation in temperature.

The slight decrease in TS is the result of the sediment pond and wetland trapping sediment and withholding it from entering the pond. The two data sets with extremely high TS values (July 13th and 27th) are thought to be from rainfall events leading up to the sampling dates (Appendix A). During the five days before and on the July 13th sampling date there was a total of three days with less than 0.75 inches of rain. The week before the sampling day of July 27th there was a total amount of rainfall of $\leq$ 2.05 inches (NOAA 2, 2011). The other sampling dates did not have any significant rainfall before sampling. These rainfall events contributed to the abnormally high TS results for those two sampling days. The Coliform boxplot (Figure 4.1) shows a post construction decrease in coliform colonies in 2011. There was also a decrease in the amount of E. coli (Table 4.2) in the pond during the same sampling period. It is thought that this was caused by three factors. The first factor being that the wetland allowed for sedimentation/filtration, increased UV radiation exposure, or the excretion of antibiotics from the roots of the macrophytes (Hammer, 1989). The second factor was the typical decreased rainfall experienced during summer months. The dry weather allowed for a decrease in runoff containing coliform from the surrounding agricultural land. Another contributing factor could be the pond water samples weren't collected immediately following a rainfall event (Vemuri, 2011).

Dissolved oxygen amounts in a body of water fluctuate on a 24 hour basis. Dissolved oxygen is tied to photosynthesis activity and increases during the day and decreases at night (Floyd, 2011). Boxplots for DO also show a slight increase for 2011. It is thought that the slight increase in DO is independent of wetland construction. Any increase in DO is expected to be from normal mixing and cycles that naturally occur in the pond. Temperature boxplots shows that the average temperature for 2011 was slightly higher than the average temperature in 2010.

An observed increase of aquatic plant and algae cover had a likely impact on DO (Figure 5.0). The pond was completely covered for most of the late summer sampling dates. When visually comparing the pond surface biomass from 2011 to 2010, it was concluded that the thicker plant coverage, and decomposition of decaying biomass at the bottom of the pond contribute to the overall low DO amounts for 2011 (Appendix A).

Aquatic plant and algae cover effectively reduced the available solar radiation to aquatic plants lower in the water column. This resulted in the plants either having a slowed down photosynthesis process or the photosynthesis process was reversed to respiration. The reversal of photosynthesis would cause the plants to respire and take in oxygen and release carbon dioxide, resulting in low DO content in the pond. The excess decaying biomass at the bottom of the pond also contributed to the decrease in oxygen. The slight increase in air and water temperature also contributed to the decrease in DO since increased temperature reduces the ability of oxygen to dissolve in water.

Phosphorus modeling was conducted on the pond and wetland in a related study also conducted with this one. The data showed that the post construction wetlands mean total phosphorus concentrations were less than pre-construction levels measured in 2010 (Vemuri, 2011). Vemuri's study noted decreased phosphorus in the sediment pond, and weak evidence from chlorophyll tests showed that the wetland reduced the amount of algal biomass.

5.3 Wetland Plant Establishment

The establishment of plants in the wetland was very successful. Over all there was a combined 172% increase in plant population in wetland cell one and two. Cattails were the most successful plant to grow and populate the wetland. Several stands of cattails were established in areas where no planting occurred. As an example; the sediment pond above wetland cell one received no planting, yet has numerous well-established cattail stands (Figure 5.1). These cattails are thought to have grown there by seeds traveling to the sediment pond from nearby cattails in wetland cell one. Cattail seeds could have also been transported to this area by animals in the area.

Cattail growth and proliferation was greatest in submerged portions of the wetland cells. Wetland cell one had more plant growth than wetland cell two. This is likely the result of the stop log flow control structure at the junction of wetland cell one and wetland cell two. The structure was installed July 1st, 2011. It maintained standing water within wetland cell one throughout the summer and fall, allowing for plants to flourish and multiply. Wetland cell two remained relatively dry with standing water restricted to the lower end of the cell adjacent to the pond. It was concluded that wetland cell number two was not well enough established to get a proper plant count. Cattail growth was greatest within submerged areas of the wetland cell. The drier areas saw an increase growth in grass, and sedges and rushes. Along the outer rim of wetland cell two, common rushes were able to establish a large community. From the wetland entrance into the pond to the soil berm that separates the two cells, a line of common rushes could be seen (Figure 5.0). This was due to the favorable water depth conditions. It is thought that the duckweed and slender naiad got into the wetland by means of transportation by animals. A Muskrat den was found in plot number 16 of wetland cell one. It is probable that when traveling from the pond to wetland cell one, the Muskrats transported some duckweed and slender naiad with them, allowing these plants to populate wetland cell one.

Construction of a flow control structure at the junction of wetland cell two and the pond is planned for July 2012. After the second flow control dam is built, it will hold water back into wetland cell two, the grass will die off, and the aquatic plants will be able to grow more and take over the area.

Figure 5.0: Aquatic Plant and Algae cover (arrow) and Common Rush Line in the Pond and Wetland Cell Number One

Figure 5.1: Sediment Pond with Cattail Growth

5.4 Comparison to Previous Research

Even though the constructed wetland is in its infancy, the data shows reductions in TS, TSS, BOD, coliform, and an increase in DO and temperature. Previous research by Hammer et al. (1993) shows that wetlands take time to establish and need time to start working in order to effectively treat water. The wetland system in Hammer's study was constructed in 1988 and was not sampled until 1990. This gave the wetland two years to grow and remove contaminants. Due to the time the wetland was given to establish, the results for Hammer's study had significantly more contaminate removal than the results of this wetland study. The wetland in this study was established in late fall 2010, and post construction water analysis was April to September the following year. That did not allow much time for a significant amount of change to occur. Even though in another study in Ochlocknee, Georgia by Surrency, the wetland establishment time and sampling times were closer than this study, they still showed significant results. This is due to the differences between his study and this one. Significant differences in plants, effluent type, and wetland design all contributed to the Surrency wetland study, allowing for more results in a shorter period of time.

5.5 Future Plans

A pond water circulation system that cycles water from the bottom of the pond and discharge back to the pond and wetland will be constructed in summer 2012. The circulation system has four different functions: pond aeration, maintenance of wetland water levels, increase residence and enhanced nutrient removal by wetland plants. Some of the benefits of using a circulation pump and recycling the pond water include reduced concentration of the biochemical oxygen demand, controlled transport of contaminants to achieve effective treatment, and controlled production of odors (Moshiri, 1993). The circulation system is driven by a high-capacity centrifugal pump (220 gpm at 4.57m (15ft) head) that draws water off the bottom of the pond at its maximum depth of 3.04m (10ft). The water will then be piped to a constructed waterfall feature designed to aerate the water by creating turbulent flow over a series of rock cascades at a 2.43m (8ft) elevation change. Finally, the water will gather in a small containment pond that serves to control and direct water flow back to the pond and upper wetland cell.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Even though only one of the parameters tested (TSS) statistically showed a significant difference between 2010 (pre-construction) and 2011 (post-construction) the remaining data looks promising. The boxplots and raw data show a decrease in TS, BOD, coliform, and an increase in DO. This shows that even in a small amount of time, the wetland has begun to slowly remediate the water. The complimentary study (Vemuri, 2011) showed the mean total phosphorus concentrations in the wetland were below the levels that were seen before construction. The sediment pond and wetland cell one provided a decrease in phosphorus, and weak evidence showed that the wetland reduced the amount of algal biomass. This once again shows that the wetland is starting to establish and remove contaminates before they get to the pond. It is concluded that when the wetland is complete with the second stop log flow control and circulation pump, the water quality will begin to further improve.

The construction of the pond water circulation/aeration system and second flow control dam should significantly increase DO and BOD should show a corresponding decrease. The controlled cycling of pond water though the wetland and increased residence time should also decrease the concentration of contaminates (TSS, coliform, phosphorus, nitrogen) in the water before it is released into the pond. Being able to control the flow of the water will help with maintaining water levels essential to plant growth and proliferation. If the area experiences drought, water from the pond can simply be pumped into the wetland to alleviate the drought conditions.

6.2 Recommendations

The following recommendations are made to improve the quality of the wetland and to further monitor its effect on the water quality of the pond:

- The wetland needs to be monitored over several years to observe any changes in water quality data and to evaluate the wetlands effect on the pond.
- Data should be collected during all seasons and storm events to effectively study the impact of the temperature and precipitation on the wetland.
- Studies of the plant growth and population should also continue. If any reduction in species, or die off occurs, the population may need to be reestablished by another outside source. Also, more or different wetland plant species that may increase the productivity of the wetland could be added over time.
- The plant count in wetland cell number two should be taken again after the second flow control dam and installed the wetland cell has a chance to flourish.
- The flow pump and second flow control dam need to be completed for the wetland to take full effect.
- Soil cores should be taken from the wetland to ensure that the soil conditions are appropriate for wetlands, and have the proper components (air, water organics, and minerals) that make up successful wetland soils.
- Collection of data from the inflow pipe to get an amount of contaminates coming into the sediment pond/wetland.
- Test the flow rate and residence time of the water through the wetland.

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APPENDIX A

Average amounts for biochemical oxygen demand, total solids, total suspended solids, coliform plates, dissolved oxygen and temperature.

Site	Date	BOD (mg/L)	TS (mg/L)	TSS (mg/L)	Coliform Plates	D.O. (mg/L)	Temperature (°C)
Shallow	7/7/2010	37.364	N/A	3.78	0	2.65	25
Deep	7/7/2010	4.46	N/A	5.2	100	2.59	20.1
Shallow	7/13/2010	3.61	168	5.69	40	1.83	25.1
Deep	7/13/2010	4.49	13803	4.87	50	1.06	20.7
Shallow	7/27/2010	2.92	237	8.51	56	1.25	25.1
Deep	7/27/2010	4.25	87267	8.44	47	1.1	22.5
Shallow	8/3/2010	1.33	160	3.78	24	1.11	24.5
Deep	8/3/2010	1.96	145	4.36	19	1.06	21.5
Shallow	8/18/2010	2.06	75	8.53	47	2.01	24.5
Deep	8/18/2010	2.19	78	8.27	16	1.39	21.9
Shallow	9/8/2010	3.01	149	7.47	13	3.31	19.8
Deep	9/8/2010	2.64	149	7.76	17	2.89	19
Shallow	4/3/2011	2.27	211	2.62	8	12.2	6.25
Deep	4/3/2011	2.30	215	3.29	5	11.6	6
Shallow	4/24/2011	1.89	203	22.91	626	5.33	10.6
Deep	4/24/2011	1.82	144	26.4	714	5.27	9.84
Shallow	7/7/2011	1.88	155	3.8	16	4.37	25
Deep	7/7/2011	1.91	159	3.91	13	2.7	22.5
Shallow	7/13/2011	3.24	136	4.13	20	5.05	25.6
Deep	7/13/2011	2.73	98	4.91	16	2.99	23
Shallow	7/27/2011	4.41	149	3.58	29	5.31	26.6
Deep	7/27/2011	3.33	132	4.51	24	1.71	24.1
Shallow	8/3/2011	2.66	136	5.89	16	2.29	26.2
Deep	8/3/2011	1.87	157	2.64	14	1.39	24.1
Shallow	8/18/2011	1.61	151	2.04	2	0.54	22.7
Deep	8/18/2011	1.03	159	0.73	1	0.284	21.8
Shallow	9/8/2011	2.05	185	7.33	43	0	19.2
Deep	9/8/2011	3.82	155	8.8	63	0	19

APPENDIX B

Raw excel data calculations for biological oxygen demand.

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/7/2010	Seed 3 mL	3	8.46	7.2	1.26						
7/7/2010	GA 1	6	8.45	1.65	6.8	5.54	0.02	277			
7/7/2010	GA 2	6	8.4	1.68	6.72	5.46	0.02	273			
7/7/2010	Shallow 3 mL	3	8.45	6.02	2.43	1.17	0.01	117	37.364	48.1	1.29
7/7/2010	Shallow 10 mL	10	8.43	5.54	2.89	1.63	0.0333	48.9			
7/7/2010	Shallow 50 mL	50	8.52	5.45	3.07	1.81	0.167	10.86			
7/7/2010	Shallow 150 mL	150	8.62	4.29	4.33	3.07	0.5	6.14			
7/7/2010	Shallow Dilute 10x	1	8.41	6.41	2	0.74	0.00333				
7/7/2010	Shallow 300 mL	300	8.77	3.59	5.18	3.92	1	3.92			
7/7/2010	Deep 3 mL	3	8.45	7.08	1.37	0.11	0.01		4.46	0.91	0.20
7/7/2010	Deep 10 mL	10	8.47	7.09	1.38	0.12	0.0333				
7/7/2010	Deep 50 mL	50	8.49	6.68	1.81	0.55	0.167				
7/7/2010	Deep 150 mL	150	8.7	5.53	3.17	1.91	0.5	3.82			
7/7/2010	Deep Dilute 10x	1	8.4	7.04	1.36	0.1	0.00333				
7/7/2010	Deep 300 mL	300	8.78	2.42	6.36	5.1	1	5.1			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/13/2010	Seed 3 mL	3	8.42	7.67	0.75						
7/13/2010	Shallow 50 mL	50	8.51	6.93	1.58	0.32	0.167		3.61	0.439	0.122
7/13/2010	Shallow 150 mL	150	8.75	5.94	2.81	1.55	0.500	3.1			
7/13/2010	Shallow 200 mL	200	8.87	5.03	3.84	2.58	0.667	3.87			
7/13/2010	Shallow 300 mL	300	9.06	3.95	5.11	3.85	1	3.85			
7/13/2010	Deep 50 mL	50	8.59	6.97	1.62	0.36	0.167		4.49	0.245	0.055
7/13/2010	Deep 150 mL	150	8.97	5.59	3.38	2.12	0.500	4.24			
7/13/2010	Deep 200 mL	200	9.23	4.97	4.26	3	0.667	4.5			
7/13/2010	Deep 300 mL	300	9.63	3.64	5.99	4.73	1	4.73			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/27/2010	Seed 3 mL	3	8.07	7.14	0.93						
7/27/2010	Shallow 50 mL	50	8.23	7.1	1.13	-0.13	0.167		2.92	0.389	0.133
7/27/2010	Shallow 150 mL	150	8.75	6.15	2.6	1.34	0.500	2.68			
7/27/2010	Shallow 200 mL	200	8.99	5.92	3.07	1.81	0.667	2.715			
7/27/2010	Shallow 300 mL	300	9.48	4.85	4.63	3.37	1	3.37			
7/27/2010	Deep 50 mL	50	8.23	6.96	1.27	0.01	0.167		4.25	0.659	0.155
7/27/2010	Deep 150 mL	150	8.41	5.4	3.01	1.75	0.500	3.5			
7/27/2010	Deep 200 mL	200	8.55	4.3	4.25	2.99	0.667	4.485			
7/27/2010	Deep 300 mL	300	8.58	2.57	6.01	4.75	1	4.75			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
8/3/2010	Seed 3 mL	3	8.74	8.09	0.65						
8/3/2010	Shallow 50 mL	50	8.59	7.47	1.12	-0.14	0.167		1.33		
8/3/2010	Shallow 150 mL	150	8.31	6.64	1.67	0.41	0.500				
8/3/2010	Shallow 200 mL	200	8.11	6.21	1.9	0.64	0.667				
8/3/2010	Shallow 300 mL	300	7.76	5.17	2.59	1.33	1	1.33			
8/3/2010	Deep 50 mL	50	8.76	7.68	1.08	-0.18	0.167		1.96	0.287	0.147
8/3/2010	Deep 150 mL	150	8.88	6.72	2.16	0.9	0.500	1.8			
8/3/2010	Deep 200 mL	200	8.93	6.48	2.45	1.19	0.667	1.785			
8/3/2010	Deep 300 mL	300	9.02	5.47	3.55	2.29	1	2.29			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
8/18/2010	Seed 3 mL	3	8.13	7.14	0.99						
8/18/2010	Shallow 50 mL	50	8.13	6.76	1.37	0.11	0.167		2.06	0.220	0.107
8/18/2010	Shallow 150 mL	150	7.97	5.8	2.17	0.91	0.500	1.82			
8/18/2010	Shallow 200 mL	200	7.89	5.22	2.67	1.41	0.667	2.115			
8/18/2010	Shallow 300 mL	300	7.66	4.15	3.51	2.25	1	2.25			
8/18/2010	Deep 50 mL	50	8.29	6.91	1.38	0.12	0.167		2.19	0.199	0.091
8/18/2010	Deep 150 mL	150	8.54	6.27	2.27	1.01	0.500	2.02			
8/18/2010	Deep 200 mL	200	8.64	5.95	2.69	1.43	0.667	2.145			
8/18/2010	Deep 300 mL	300	8.88	5.21	3.67	2.41	1	2.41			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
9/8/2010	Seed 3 mL	3	8.32	7.46	0.86						
9/8/2010	Shallow 50 mL	50	8.76	7.29	1.47	0.21	0.167		3.01	0.357	0.119
9/8/2010	Shallow 150 mL	150	9.5	6.89	2.61	1.35	0.500	2.7			
9/8/2010	Shallow 200 mL	200	9.9	6.69	3.21	1.95	0.667	2.925			
9/8/2010	Shallow 300 mL	300	10.63	5.97	4.66	3.4	1	3.4			
9/8/2010	Deep 50 mL	50	8.67	7.24	1.43	0.17	0.167		2.64	0.183	0.070
9/8/2010	Deep 150 mL	150	9.48	6.89	2.59	1.33	0.500	2.66			
9/8/2010	Deep 200 mL	200	9.92	7.03	2.89	1.63	0.667	2.445			
9/8/2010	Deep 300 mL	300	10.67	6.6	4.07	2.81	1	2.81			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
4/3/2011	Seed 3 mL	3	7.7	7.03	0.67	-0.59	0.010				
4/3/2011	GA1	6	7.61	3.05	4.56	3.3	0.020	165			
4/3/2011	GA2	6	7.66	3.03	4.63	3.37	0.020	168.5			
4/3/2011	Shallow 50 mL	50	8.33	7.11	1.22	-0.04	0.167		2.27	0.410	0.181
4/3/2011	Shallow 150 mL	150	9.27	7.34	1.93	0.67	0.500				
4/3/2011	Shallow 200 mL	200	10.41	7.83	2.58	1.32	0.667	1.98			
4/3/2011	Shallow 300 mL	300	13.57	9.75	3.82	2.56	1	2.56			
4/3/2011	Deep 50 mL	50	8.18	7.21	0.97	-0.29	0.167		2.30		
4/3/2011	Deep 150 mL	150	9.03	7.35	1.68	0.42	0.500				
4/3/2011	Deep 200 mL	200	9.92	7.96	1.96	0.7	0.667				
4/3/2011	Deep 300 mL	300	13.3	9.74	3.56	2.3	1	2.3			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
4/24/2011	Seed 3 mL	3	8.28	7.55	0.73	-0.53	0.010				
4/24/2011	Shallow 50 mL	50	8.32	7.28	1.04	-0.22	0.167		1.89	0.313	0.166
4/24/2011	Shallow 150 mL	150	8.45	6.37	2.08	0.82	0.500	1.64			
4/24/2011	Shallow 200 mL	200	8.69	6.24	2.45	1.19	0.667	1.785			
4/24/2011	Shallow 300 mL	300	9.01	5.51	3.5	2.24	1	2.24			
4/24/2011	Deep 50 mL	50	8.3	7.24	1.06	-0.2	0.167		1.82	0.182	0.100
4/24/2011	Deep 150 mL	150	8.55	6.48	2.07	0.81	0.500	1.62			
4/24/2011	Deep 200 mL	200	8.83	6.34	2.49	1.23	0.667	1.845			
4/24/2011	Deep 300 mL	300	9.07	5.83	3.24	1.98	1	1.98			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/7/2011	Seed 3 mL	3	8.17	7.69	0.48	-0.78	0.010				
7/7/2011	GA1	6	8.2	2.67	5.53	4.27	0.020	213.5			
7/7/2011	GA2	6	8.07	2.67	5.4	4.14	0.020	207			
7/7/2011	Shallow 50 mL	50	8.41	7.24	1.17	-0.09	0.167		1.88	0.230	0.122
7/7/2011	Shallow 150 mL	150	8.92	6.77	2.15	0.89	0.500	1.78			
7/7/2011	Shallow 200 mL	200	9.21	6.52	2.69	1.43	0.667	2.145			
7/7/2011	Shallow 300 mL	300	8.82	5.84	2.98	1.72	1	1.72			
7/7/2011	Deep 50 mL	50	8.39	7.2	1.19	-0.07	0.167		1.91	0.437	0.229
7/7/2011	Deep 150 mL	150	8.87	6.85	2.02	0.76	0.500	1.52			
7/7/2011	Deep 200 mL	200	9.13	6.66	2.47	1.21	0.667	1.815			
7/7/2011	Deep 300 mL	300	9.21	5.57	3.64	2.38	1	2.38			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/13/2011	Seed 3 mL	3	8.17	6.66	1.51	0.25	0.010				
7/13/2011	GA1	6	8.27	2.41	5.86	4.6	0.020	230			
7/13/2011	GA2	6	8.17	2.4	5.77	4.51	0.020	225.5			
7/13/2011	Shallow 50 mL	50	8.58	6.56	2.02	0.76	0.167	4.56	3.24	0.883	0.273
7/13/2011	Shallow 150 mL	150	9.13	6.51	2.62	1.36	0.500	2.72			
7/13/2011	Shallow 200 mL	200	9.45	6.29	3.16	1.9	0.667	2.85			
7/13/2011	Shallow 300 mL	300	10.11	6.03	4.08	2.82	1	2.82			
7/13/2011	Deep 50 mL	50	8.49	6.53	1.96	0.7	0.167		2.73	0.355	0.130
7/13/2011	Deep 150 mL	150	8.76	6.31	2.45	1.19	0.500	2.38			
7/13/2011	Deep 200 mL	200	9.37	6.05	3.32	2.06	0.667	3.09			
7/13/2011	Deep 300 mL	300	9.86	5.88	3.98	2.72	1	2.72			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
7/27/2011	Seed 3 mL	3	8.39	6.81	1.58	0.32	0.010				
7/27/2011	GA1	6	8.41	2.44	5.97	4.71	0.020	235.5			
7/27/2011	GA2	6	8.32	2.46	5.86	4.6	0.020	230			
7/27/2011	Shallow 50 mL	50	8.74	6.4	2.34	1.08	0.167	6.48	4.41	1.39	0.316
7/27/2011	Shallow 150 mL	150	8.78	5.76	3.02	1.76	0.500	3.52			
7/27/2011	Shallow 200 mL	200	8.86	5.11	3.75	2.49	0.667	3.735			
7/27/2011	Shallow 300 mL	300	9.16	4.01	5.15	3.89	1	3.89			
7/27/2011	Deep 50 mL	50	8.66	6.76	1.9	0.64	0.167		3.33	0.273	0.082
7/27/2011	Deep 150 mL	150	8.94	5.86	3.08	1.82	0.500	3.64			
7/27/2011	Deep 200 mL	200	9.17	5.82	3.35	2.09	0.667	3.135			
7/27/2011	Deep 300 mL	300	9.27	4.8	4.47	3.21	1	3.21			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
8/3/2011	Seed 3 mL	3	8.33	7.01	1.32	0.06	0.010				
8/3/2011	GA1	6	8.3	3.24	5.06	3.8	0.020	190			
8/3/2011	GA2	6	8.21	3.36	4.85	3.59	0.020	179.5			
8/3/2011	Shallow 50 mL	50	8.34	6.45	1.89	0.63	0.167		2.66	0.841	0.316
8/3/2011	Shallow 150 mL	150	8.32	5.25	3.07	1.81	0.500	3.62			
8/3/2011	Shallow 200 mL	200	8.29	5.5	2.79	1.53	0.667	2.295			
8/3/2011	Shallow 300 mL	300	8.17	4.85	3.32	2.06	1	2.06			
8/3/2011	Deep 50 mL	50	8.31	6.91	1.4	0.14	0.167		1.87	0.160	0.086
8/3/2011	Deep 150 mL	150	8.42	6.31	2.11	0.85	0.500	1.7			
8/3/2011	Deep 200 mL	200	8.41	5.9	2.51	1.25	0.667	1.875			
8/3/2011	Deep 300 mL	300	8.28	5	3.28	2.02	1	2.02			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
8/18/2011	Seed 3 mL	3	8.49	7.4	1.09	-0.17	0.010				
8/18/2011	GA1	6	8.52	3.04	5.48	4.22	0.020	211			
8/18/2011	GA2	6	8.44	3.03	5.41	4.15	0.020	207.5			
8/18/2011	Shallow 50 mL	50	8.23	6.62	1.61	0.35	0.167		1.61	0.077	0.048
8/18/2011	Shallow 150 mL	150	7.52	5.47	2.05	0.79	0.500	1.58			
8/18/2011	Shallow 200 mL	200	7.02	4.63	2.39	1.13	0.667	1.695			
8/18/2011	Shallow 300 mL	300	6.28	3.47	2.81	1.55	1	1.55			
8/18/2011	Deep 50 mL	50	8.27	6.98	1.29	0.03	0.167		1.03		
8/18/2011	Deep 150 mL	150	7.82	6.17	1.65	0.39	0.500				
8/18/2011	Deep 200 mL	200	7.38	5.55	1.83	0.57	0.667				
8/18/2011	Deep 300 mL	300	6.76	4.47	2.29	1.03	1	1.03			

Date	BOD (mg/L)	Volume of water used	D1	D2	D1-D2	D-B	P	BOD_5	Average	Stdev	Coef Variation
9/8/2011	Seed 3 mL	3	8.48	8	0.48	-0.78	0.010				
9/8/2011	GA1	6	8.46	3.69	4.77	3.51	0.020	175.5			
9/8/2011	GA2	6	8.38	3.77	4.61	3.35	0.020	167.5			
9/8/2011	Shallow 50 mL	50	8.13	6.86	1.27	0.01	0.167		2.05	0.16	0.08
9/8/2011	Shallow 150 mL	150	7.29	4.92	2.37	1.11	0.500	2.22			
9/8/2011	Shallow 200 mL	200	6.66	4.12	2.54	1.28	0.667	1.92			
9/8/2011	Shallow 300 mL	300	5.57	2.31	3.26	2	1	2			
9/8/2011	Deep 50 mL	50	7.97	6.22	1.75	0.49	0.167		3.82	1.66	0.43
9/8/2011	Deep 150 mL	150	7.16	3.15	4.01	2.75	0.500	5.5			
9/8/2011	Deep 200 mL	200	6.38	2.61	3.77	2.51	0.667	3.765			
9/8/2011	Deep 300 mL	300	5.05	1.6	3.45	2.19	1	2.19			

APPENDIX C

Raw excel data calculations for total solids.

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/13/2010	Deep	48.3443	48.3538	25	0.0095	380			
7/13/2010	Deep	41.8214	42.8273	25	1.0059	40236			
7/13/2010	Deep	70.7388	70.7586	25	0.0198	792	13803	22893	1.66
7/13/2010	Shallow	44.0927	44.0983	25	0.0056	224			
7/13/2010	Shallow	42.9667	42.9708	25	0.0041	164			
7/13/2010	Shallow	66.6502	66.6556	50	0.0054	108	165	58.0	0.351

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/27/2010	Deep	44.0930	48.3548	25	4.2618	170472			
7/27/2010	Deep	41.8209	44.0983	25	2.2774	91096			
7/27/2010	Deep	70.7483	70.76	50	0.0117	234	87267	85184	0.976
7/27/2010	Shallow	41.8209	41.8277	25	0.0068	272			
7/27/2010	Shallow	42.9657	42.9712	25	0.0055	220			
7/27/2010	Shallow	66.6455	66.6565	50	0.011	220	237	30.0	0.126

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/3/2010	Deep	48.3506	48.3524	25	0.0018	72			
8/3/2010	Deep	44.0935	44.098	25	0.0045	180			
8/3/2010	Deep	70.7499	70.7591	50	0.0092	184	145	63.5	0.437
8/3/2010	Shallow	41.8234	41.828	25	0.0046	184			
8/3/2010	Shallow	42.9671	42.9709	25	0.0038	152			
8/3/2010	Shallow	66.6499	66.6571	50	0.0072	144	160	21.2	0.132

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/18/2010	Deep	48.3498	48.3501	25	0.0003	12			
8/18/2010	Deep	44.0946	44.0974	25	0.0028	112			
8/18/2010	Deep	70.7515	70.757	50	0.0055	110	78	57.2	0.733
8/18/2010	Shallow	41.8242	41.8259	25	0.0017	68			
8/18/2010	Shallow	42.9676	42.9691	25	0.0015	60			
8/18/2010	Shallow	66.65	66.6548	50	0.0048	96	75	18.9	0.253

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
9/8/2010	Deep	48.3497	48.3553	25	0.0056	224			
9/8/2010	Deep	44.0958	44.0987	25	0.0029	116			
9/8/2010	Deep	70.7535	70.7588	50	0.0053	106	149	65.4	0.440
9/8/2010	Shallow	41.823	41.8277	25	0.0047	188			
9/8/2010	Shallow	42.9676	42.9708	25	0.0032	128			
9/8/2010	Shallow	66.6507	66.6573	50	0.0066	132	149	33.5	0.225

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
4/3/2011	Deep	48.348	48.3522	25	0.0042	168			
4/3/2011	Deep	44.0944	44.0992	25	0.0048	192			
4/3/2011	Deep	70.7478	70.762	50	0.0142	284	215	61.2	0.285
4/3/2011	Shallow	41.8223	41.8267	25	0.0044	176			
4/3/2011	Shallow	42.966	42.9711	25	0.0051	204			
4/3/2011	Shallow	66.6466	66.6592	50	0.0126	252	211	38.4	0.182

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
4/24/2011	Deep	48.3488	48.3527	25	0.0039	156			
4/24/2011	Deep	44.0956	44.0985	25	0.0029	116			
4/24/2011	Deep	70.7536	70.7616	50	0.008	160	144	24.3	0.169
4/24/2011	Shallow	41.8228	41.8285	25	0.0057	228			
4/24/2011	Shallow	42.9676	42.9722	25	0.0046	184			
4/24/2011	Shallow	66.6518	66.6616	50	0.0098	196	203	22.7	0.112

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/7/2011	Deep	48.3501	48.3532	25	0.0031	124			
7/7/2011	Deep	44.095	44.0998	25	0.0048	192			
7/7/2011	Deep	70.7546	70.7627	50	0.0081	162	159	34.1	0.214
7/7/2011	Shallow	41.8239	41.8273	25	0.0034	136			
7/7/2011	Shallow	42.968	42.9719	25	0.0039	156			
7/7/2011	Shallow	66.6525	66.6611	50	0.0086	172	155	18.0	0.117

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/13/2011	Deep	48.3513	48.3532	25	0.0019	76			
7/13/2011	Deep	44.098	44.1003	25	0.0023	92			
7/13/2011	Deep	70.7566	70.7629	50	0.0063	126	98	25.5	0.261
7/13/2011	Shallow	41.8234	41.8277	25	0.0043	172			
7/13/2011	Shallow	42.9702	42.9729	25	0.0027	108			
7/13/2011	Shallow	66.6566	66.663	50	0.0064	128	136	32.7	0.241

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/27/2011	Deep	48.3516	48.3544	25	0.0028	112			
7/27/2011	Deep	44.0979	44.1014	25	0.0035	140			
7/27/2011	Deep	70.7579	70.7651	50	0.0072	144	132	17.4	0.132
7/27/2011	Shallow	41.8249	41.8286	25	0.0037	148			
7/27/2011	Shallow	42.9702	42.9737	25	0.0035	140			
7/27/2011	Shallow	66.657	66.6649	50	0.0079	158	149	9.0	0.0607

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/3/2011	Deep	48.3508	48.3555	25	0.0047	188			
8/3/2011	Deep	44.0988	44.102	25	0.0032	128			
8/3/2011	Deep	70.7559	70.7636	50	0.0077	154	157	30.1	0.192
8/3/2011	Shallow	41.8251	41.8282	25	0.0031	124			
8/3/2011	Shallow	42.9713	42.974	25	0.0027	108			
8/3/2011	Shallow	66.6576	66.6664	50	0.0088	176	136	35.6	0.261

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/18/2011	Deep	48.3512	48.3555	25	0.0043	172			
8/18/2011	Deep	44.099	44.1022	25	0.0032	128			
8/18/2011	Deep	70.756	70.7649	50	0.0089	178	159	27.3	0.171
8/18/2011	Shallow	41.8248	41.8287	25	0.0039	156			
8/18/2011	Shallow	42.9711	42.9743	25	0.0032	128			
8/18/2011	Shallow	66.6581	66.6665	50	0.0084	168	151	20.5	0.136

Date	Location	Crucible Before (g)	Crucible After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
9/8/2011	Deep	48.3517	48.3557	25	0.004	160			
9/8/2011	Deep	44.0999	44.1036	25	0.0037	148			
9/8/2011	Deep	70.7588	70.7667	50	0.0079	158	155	6.43	0.0414
9/8/2011	Shallow	41.825	41.8294	25	0.0044	176			
9/8/2011	Shallow	42.9717	42.9757	25	0.004	160			
9/8/2011	Shallow	66.6578	66.6687	50	0.0109	218	185	30.0	0.162

APPENDIX D

Raw excel data calculations for total suspended solids.

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/7/2010	Deep	0.1083	0.109	200	0.0007	3.5			
7/7/2010	Deep	0.1079	0.1092	300	0.0013	4.33			
7/7/2010	Deep	0.1098	0.1119	270	0.0021	7.78	5.20	2.27	0.436
7/7/2010	Shallow	0.1091	0.1101	200	0.001	5			
7/7/2010	Shallow	0.1091	0.11	300	0.0009	3			
7/7/2010	Shallow	0.1127	0.1136	270	0.0009	3.33	3.78	1.07	0.284

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/13/2010	Deep	0.1077	0.109	250	0.0013	5.2			
7/13/2010	Deep	0.1082	0.1097	300	0.0015	5.00			
7/13/2010	Deep	0.1092	0.1114	500	0.0022	4.40	4.87	0.416	0.086
7/13/2010	Shallow	0.1082	0.1097	250	0.0015	6			
7/13/2010	Shallow	0.1082	0.1099	300	0.0017	5.67			
7/13/2010	Shallow	0.1081	0.1108	500	0.0027	5.40	5.69	0.301	0.053

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/27/2010	Deep	0.1078	0.1103	250	0.0025	10			
7/27/2010	Deep	0.1092	0.1116	300	0.0024	8.00			
7/27/2010	Deep	0.1084	0.1106	300	0.0022	7.33	8.44	1.39	0.164
7/27/2010	Shallow	0.1096	0.1124	250	0.0028	11.2			
7/27/2010	Shallow	0.1085	0.1106	300	0.0021	7.00			
7/27/2010	Shallow	0.1096	0.1118	300	0.0022	7.33	8.51	2.33	0.274

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/3/2010	Deep	0.109	0.1096	250	0.0006	2.4			
8/3/2010	Deep	0.1095	0.1112	300	0.0017	5.67			
8/3/2010	Deep	0.1072	0.1097	500	0.0025	5.00	4.36	1.73	0.396
8/3/2010	Shallow	0.1107	0.1114	250	0.0007	2.8			
8/3/2010	Shallow	0.1101	0.1114	300	0.0013	4.33			
8/3/2010	Shallow	0.1072	0.1093	500	0.0021	4.20	3.78	0.849	0.225

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/18/2010	Deep	0.1089	0.1109	250	0.002	8			
8/18/2010	Deep	0.1091	0.1118	300	0.0027	9.00			
8/18/2010	Deep	0.1107	0.1146	500	0.0039	7.80	8.27	0.643	0.0778
8/18/2010	Shallow	0.1121	0.1143	250	0.0022	8.8			
8/18/2010	Shallow	0.1097	0.1121	300	0.0024	8.00			
8/18/2010	Shallow	0.1105	0.1149	500	0.0044	8.80	8.53	0.462	0.0541

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
9/8/2010	Deep	0.1072	0.1093	250	0.0021	8.4			
9/8/2010	Deep	0.1074	0.1094	300	0.002	6.67			
9/8/2010	Deep	0.1099	0.114	500	0.0041	8.20	7.76	0.948	0.122
9/8/2010	Shallow	0.1079	0.1101	250	0.0022	8.8			
9/8/2010	Shallow	0.1113	0.1137	300	0.0024	8.00			
9/8/2010	Shallow	0.1113	0.1141	500	0.0028	5.60	7.47	1.67	0.223

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
4/3/2011	Deep	0.1078	0.1087	250	0.0009	3.6			
4/3/2011	Deep	0.1102	0.111	300	0.0008	2.67			
4/3/2011	Deep	0.1092	0.111	500	0.0018	3.60	3.29	0.539	0.164
4/3/2011	Shallow	0.1072	0.1078	250	0.0006	2.4			
4/3/2011	Shallow	0.1082	0.109	300	0.0008	2.67			
4/3/2011	Shallow	0.1103	0.1117	500	0.0014	2.80	2.62	0.204	0.0777

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
4/24/2011	Deep	0.1113	0.1178	250	0.0065	26			
4/24/2011	Deep	0.11	0.1184	300	0.0084	28.00			
4/24/2011	Deep	0.1088	0.1214	500	0.0126	25.20	26.40	1.44	0.0546
4/24/2011	Shallow	0.1106	0.1159	250	0.0053	21.2			
4/24/2011	Shallow	0.109	0.116	300	0.007	23.33			
4/24/2011	Shallow	0.1063	0.1184	500	0.0121	24.20	22.91	1.54	0.0674

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/7/2011	Deep	0.1075	0.1086	250	0.0011	4.4			
7/7/2011	Deep	0.1102	0.1115	300	0.0013	4.33			
7/7/2011	Deep	0.1091	0.1106	500	0.0015	3.00	3.91	0.790	0.202
7/7/2011	Shallow	0.109	0.1101	250	0.0011	4.4			
7/7/2011	Shallow	0.1088	0.11	300	0.0012	4.00			
7/7/2011	Shallow	0.1081	0.1096	500	0.0015	3.00	3.80	0.721	0.190

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/13/2011	Deep	0.1095	0.1108	250	0.0013	5.2			
7/13/2011	Deep	0.1121	0.1137	300	0.0016	5.33			
7/13/2011	Deep	0.1111	0.1132	500	0.0021	4.20	4.91	0.619	0.126
7/13/2011	Shallow	0.1079	0.1092	250	0.0013	5.2			
7/13/2011	Shallow	0.1104	0.1116	300	0.0012	4.00			
7/13/2011	Shallow	0.1117	0.1133	500	0.0016	3.20	4.13	1.01	0.244

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
7/27/2011	Deep	0.1101	0.1111	250	0.001	4			
7/27/2011	Deep	0.1113	0.1129	300	0.0016	5.33			
7/27/2011	Deep	0.1111	0.1132	500	0.0021	4.20	4.51	0.719	0.159
7/27/2011	Shallow	0.1067	0.1078	250	0.0011	4.4			
7/27/2011	Shallow	0.1082	0.1092	300	0.001	3.33			
7/27/2011	Shallow	0.108	0.1095	500	0.0015	3.00	3.58	0.731	0.204

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/3/2011	Deep	0.109	0.1094	250	0.0004	1.6			
8/3/2011	Deep	0.109	0.1106	300	0.0016	5.33			
8/3/2011	Deep	0.11	0.1105	500	0.0005	1.00	2.64	2.35	0.888
8/3/2011	Shallow	0.1073	0.1081	250	0.0008	3.2			
8/3/2011	Shallow	0.1073	0.1102	300	0.0029	9.67			
8/3/2011	Shallow	0.11	0.1124	500	0.0024	4.80	5.89	3.37	0.572

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
8/18/2011	Deep	0.1089	0.109	250	0.0001	0.4			
8/18/2011	Deep	0.1097	0.11	300	0.0003	1.00			
8/18/2011	Deep	0.1102	0.1106	500	0.0004	0.80	0.73	0.306	0.417
8/18/2011	Shallow	0.1086	0.109	250	0.0004	1.6			
8/18/2011	Shallow	0.108	0.1087	300	0.0007	2.33			
8/18/2011	Shallow	0.1098	0.1109	500	0.0011	2.20	2.04	0.391	0.191

Date	Location	Filter Before (g)	Filter After (g)	Sample Volume	Final (g)	mg/L	Average	Stdev	Coef Variation
9/8/2011	Deep	0.1071	0.109	250	0.0019	7.6			
9/8/2011	Deep	0.1074	0.1104	300	0.003	10.00			
9/8/2011	Deep	0.1078	0.1122	500	0.0044	8.80	8.80	1.20	0.136
9/8/2011	Shallow	0.108	0.1092	250	0.0012	4.8			
9/8/2011	Shallow	0.1081	0.1102	300	0.0021	7.00			
9/8/2011	Shallow	0.1088	0.1139	500	0.0051	10.20	7.33	2.72	0.370

APPENDIX E

Raw excel data calculations for total coliform plates. Standard deviation and coefficient variation data was not calculated for some of the values because they were single numbers and cannot be divided by zero.

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
8/10/2010	Deep	30	61	203	105	57.5	0.55
8/10/2010	Deep	30	21	70			
8/10/2010	Deep	50	51	102			
8/10/2010	Deep	50	71	142			
8/10/2010	Shallow	30	19	63	57	9.43	0.166
8/10/2010	Shallow	50	25	50			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
4/3/2011	Deep	50	18	27	64	NA	NA
4/3/2011	Deep	50	9				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/7/2010	Deep	1	1	100	100	NA	NA
7/7/2010	Deep	1	1				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/13/2010	Deep	1	2	50	50	NA	NA
7/13/2010	Deep	1	1				
7/13/2010	Deep	5	2				
7/13/2010	Deep	5	1				
7/13/2010	Shallow	5	3	40	40	NA	NA
7/13/2010	Shallow	5	1				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/27/2010	Deep	10	12	47	47	NA	NA
7/27/2010	Deep	10	10				
7/27/2010	Deep	25	17				
7/27/2010	Deep	50	6				
7/27/2010	Shallow	10	6	56	56	NA	NA
7/27/2010	Shallow	10	6				
7/27/2010	Shallow	25	14				
7/27/2010	Shallow	25	13				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
8/3/2010	Deep	5	1	13	19	NA	NA
8/3/2010	Deep	10	1				
8/3/2010	Shallow	5	1	24	24	NA	NA
8/3/2010	Shallow	10	3				
8/3/2010	Shallow	10	2				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
8/18/2010	Deep	10	1	16	16	NA	NA
8/18/2010	Deep	20	8				
8/18/2010	Deep	20	4				
8/18/2010	Deep	30	6				
8/18/2010	Deep	30	2				
8/18/2010	Deep	50	5				
8/18/2010	Deep	50	7				
8/18/2010	Shallow	5	1	43	47	NA	NA
8/18/2010	Shallow	10	1				
8/18/2010	Shallow	10	3				
8/18/2010	Shallow	20	10				
8/18/2010	Shallow	20	13				
8/18/2010	Shallow	30	19				
8/18/2010	Shallow	30	14				
8/18/2010	Shallow	50	15				
8/18/2010	Shallow	50	25	50			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
9/8/2010	Deep	15	2	21	17	NA	NA
9/8/2010	Deep	15	3				
9/8/2010	Deep	20	4				
9/8/2010	Deep	20	4				
9/8/2010	Deep	30	6				
9/8/2010	Deep	30	3				
9/8/2010	Deep	50	18				
9/8/2010	Deep	50	9				
9/8/2010	Shallow	15	3	13	13	NA	NA
9/8/2010	Shallow	20	6				
9/8/2010	Shallow	30	2				
9/8/2010	Shallow	30	4				
9/8/2010	Shallow	50	4				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
4/3/2011	Deep	20	1	2	5	NA	NA
4/3/2011	Deep	60	1				
4/3/2011	Deep	80	1				
4/3/2011	Deep	80	2				
4/3/2011	Deep	100	1				
4/3/2011	Shallow	40	1	8	8	NA	NA
4/3/2011	Shallow	40	1				
4/3/2011	Shallow	60	17				
4/3/2011	Shallow	60	2				
4/3/2011	Shallow	100	3				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
4/24/2011	Deep	1	9	750	714	300.9	0.421
4/24/2011	Deep	1	6				
4/24/2011	Deep	5	60	1200			
4/24/2011	Deep	5	31	620			
4/24/2011	Deep	10	39	390			
4/24/2011	Deep	10	61	610			
4/24/2011	Shallow	1	3	400	626	163	0.260
4/24/2011	Shallow	1	5				
4/24/2011	Shallow	5	43	860			
4/24/2011	Shallow	5	31	620			
4/24/2011	Shallow	10	62	620			
4/24/2011	Shallow	10	63	630			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/7/2011	Deep	25	3	13	13	NA	NA
7/7/2011	Deep	25	3				
7/7/2011	Deep	50	14				
7/7/2011	Deep	50	3				
7/7/2011	Deep	75	8				
7/7/2011	Deep	75	12				
7/7/2011	Deep	100	8				
7/7/2011	Deep	100	13				
7/7/2011	Shallow	25	8	12	16	NA	NA
7/7/2011	Shallow	25	3				
7/7/2011	Shallow	50	7				
7/7/2011	Shallow	50	4				
7/7/2011	Shallow	75	8				
7/7/2011	Shallow	75	9				
7/7/2011	Shallow	100	20	20			
7/7/2011	Shallow	100	9				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/13/2011	Deep	25	4	15	16	1	0.0665
7/13/2011	Deep	25	1				
7/13/2011	Deep	50	8				
7/13/2011	Deep	50	10				
7/13/2011	Deep	75	9				
7/13/2011	Deep	75	12				
7/13/2011	Deep	100	17				
7/13/2011	Deep	100	19				
7/13/2011	Deep	125	19				
7/13/2011	Deep	125	15				
7/13/2011	Deep	150	26	17			
7/13/2011	Deep	150	25	17			
7/13/2011	Shallow	25	4	15	20	6.09	0.298
7/13/2011	Shallow	25	5				
7/13/2011	Shallow	50	11				
7/13/2011	Shallow	50	8				
7/13/2011	Shallow	75	14				
7/13/2011	Shallow	75	23	31			
7/13/2011	Shallow	100	21	21			
7/13/2011	Shallow	100	17				
7/13/2011	Shallow	125	22	18			
7/13/2011	Shallow	125	14				
7/13/2011	Shallow	150	17				
7/13/2011	Shallow	150	27	18			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
7/27/2011	Deep	75	25	33	24	5.22	0.215
7/27/2011	Deep	75	17	23			
7/27/2011	Deep	100	20	20			
7/27/2011	Deep	100	24	24			
7/27/2011	Deep	125	26	21			
7/27/2011	Deep	125	35	28			
7/27/2011	Deep	150	26	17			
7/27/2011	Deep	150	42	28			
7/27/2011	Shallow	75	18	23	29	6.22	0.213
7/27/2011	Shallow	75	16	33			
7/27/2011	Shallow	100	41	41			
7/27/2011	Shallow	100	31	31			
7/27/2011	Shallow	125	35	28			
7/27/2011	Shallow	125	37	30			
7/27/2011	Shallow	150	43	29			
7/27/2011	Shallow	150	31	21			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
8/3/2011	Deep	75	6	10	14	4.85	0.343
8/3/2011	Deep	75	8				
8/3/2011	Deep	100	10				
8/3/2011	Deep	100	8				
8/3/2011	Deep	125	16				
8/3/2011	Deep	125	12				
8/3/2011	Deep	150	28	19			
8/3/2011	Deep	150	12				
8/3/2011	Shallow	75	4	11	16	3.95	0.253
8/3/2011	Shallow	75	14				
8/3/2011	Shallow	100	12				
8/3/2011	Shallow	100	9				
8/3/2011	Shallow	125	27	22			
8/3/2011	Shallow	125	19	15			
8/3/2011	Shallow	150	25	17			
8/3/2011	Shallow	150	20	13			

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
8/18/2011	Deep	100	1	1	1	NA	NA
8/18/2011	Deep	100	1				
8/18/2011	Deep	125	1				
8/18/2011	Deep	125	3				
8/18/2011	Deep	150	1				
8/18/2011	Shallow	125	5	2	2	NA	NA
8/18/2011	Shallow	125	1				
8/18/2011	Shallow	150	2				
8/18/2011	Shallow	150	1				

Date	Location	Volume of Water (mL)	Number of Colonies	Total Coliform per 100 mL	Average	Stdev	Coef Variation
9/8/2011	Deep	75	44	59	63	13.5	0.215
9/8/2011	Deep	75	61	81			
9/8/2011	Deep	100	71	71			
9/8/2011	Deep	100	58	58			
9/8/2011	Deep	125	63	50			
9/8/2011	Deep	125	103	82			
9/8/2011	Deep	150	73	49			
9/8/2011	Deep	150	80	53			
9/8/2011	Shallow	75	28	37	43	5.14	0.119
9/8/2011	Shallow	75	34	45			
9/8/2011	Shallow	100	37	37			
9/8/2011	Shallow	100	45	45			
9/8/2011	Shallow	125	51	41			
9/8/2011	Shallow	125	57	46			
9/8/2011	Shallow	150	62	41			
9/8/2011	Shallow	150	79	53			

APPENDIX F

Raw excel data calculations for dissolved oxygen and temperature.

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/7/2010	Deep	2	4.58	26.7	2.59	20.1	3.67	1.42
7/7/2010	Deep	3	8.15	24.4				
7/7/2010	Deep	5	0.09	19.2				
7/7/2010	Deep	7	0.06	15.5				
7/7/2010	Deep	9	0.06	14.8				
7/7/2010	Shallow	2	4	26.2	2.65	25.0	1.97	0.743
7/7/2010	Shallow	3	3.55	25.2				
7/7/2010	Shallow	4	0.39	23.7				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/13/2010	Deep	2	3.05	25.5	1.06	20.7	1.403734	1 .32
7/13/2010	Deep	3	2.05	25.1				
7/13/2010	Deep	5	0.06	23.5				
7/13/2010	Deep	7	0.1	16.2				
7/13/2010	Deep	9	0.05	13.2				
7/13/2010	Shallow	2	2.65	25.5	1.83	25.1	0.862	0.472
7/13/2010	Shallow	3	1.9	25.1				
7/13/2010	Shallow	4	0.93	24.7				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/27/2010	Deep	1	3.4	26.8	1.10	22.5	1.37	1.25
7/27/2010	Deep	2	1.8	25.7				
7/27/2010	Deep	3	1.35	25.7				
7/27/2010	Deep	5	0.01	23.4				
7/27/2010	Deep	7	0.01	18.5				
7/27/2010	Deep	9	0.01	15				
7/27/2010	Shallow	2	1.88	25.5	1.25	25.1	0.591	0.474
7/27/2010	Shallow	3	1.15	25.1				
7/27/2010	Shallow	4	0.71	24.7				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
8/3/2010	Deep	1	2.8	25.8	1.06	21.5	1.29	1.23
8/3/2010	Deep	2	2.85	24.5				
8/3/2010	Deep	3	2.1	24.6				
8/3/2010	Deep	4	1.75	24.5				
8/3/2010	Deep	5	0	23.2				
8/3/2010	Deep	6	0	20.2				
8/3/2010	Deep	7	0	18.2				
8/3/2010	Deep	8	0	16.9				
8/3/2010	Deep	9	0	15.9				
8/3/2010	Shallow	1	2.6	24.6	1.11	24.5	1.25	1.13
8/3/2010	Shallow	2	2.3	24.8				
8/3/2010	Shallow	3	0.65	24.6				
8/3/2010	Shallow	4	0.01	24.5				
8/3/2010	Shallow	5	0	23.8				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
8/18/2010	Deep	1	3.67	24.6	1.39	21.9	1.72	1.24
8/18/2010	Deep	2	3.4	24.6				
8/18/2010	Deep	3	3.55	24.5				
8/18/2010	Deep	4	1.9	24.5				
8/18/2010	Deep	5	0.01	24.4				
8/18/2010	Deep	6	0.01	21.7				
8/18/2010	Deep	7	0.01	19.3				
8/18/2010	Deep	8	0	17.3				
8/18/2010	Deep	9	0	16				
8/18/2010	Shallow	1	2.8	24.6	2.01	24.5	1.87	0.929
8/18/2010	Shallow	2	3.5	24.6				
8/18/2010	Shallow	3	3.75	24.5				
8/18/2010	Shallow	4	0	24.4				
8/18/2010	Shallow	5	0	24.2				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
9/8/2010	Deep	1	8.38	20.3	2.89	19.0	3.42	1.18
9/8/2010	Deep	2	7.05	20.5				
9/8/2010	Deep	3	5.85	19.5				
9/8/2010	Deep	4	3.75	19.4				
9/8/2010	Deep	5	0.79	19.2				
9/8/2010	Deep	6	0.11	19				
9/8/2010	Deep	7	0.05	18.6				
9/8/2010	Deep	8	0.02	18.2				
9/8/2010	Deep	9	0.01	16.1				
9/8/2010	Shallow	1	6.6	20	3.31	19.8	2.93	0.885
9/8/2010	Shallow	2	6.07	20.1				
9/8/2010	Shallow	3	2.73	19.8				
9/8/2010	Shallow	4	1.15	19.5				
9/8/2010	Shallow	5	0.01	19.4				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
4/3/2011	Deep	1	11.87	6.6	11.6	6.0	0.287	0.0248
4/3/2011	Deep	2	11.48	6.3				
4/3/2011	Deep	3	11.3	6.1				
4/3/2011	Deep	4	11.95	6				
4/3/2011	Deep	5	11.5	6				
4/3/2011	Deep	6	11.5	5.6				
4/3/2011	Deep	7	11.1	5.8				
4/3/2011	Deep	8	11.75	5.5				
4/3/2011	Shallow	1	12.9	6.8	12.2	6.26	0.503	0.0414
4/3/2011	Shallow	2	11.9	6.2				
4/3/2011	Shallow	3	12.4	6.1				
4/3/2011	Shallow	4	11.6	6.1				
4/3/2011	Shallow	4.5	12	6.1				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
4/24/2011	Deep	1	5.7	12.3	5.27	9.84	0.480	0.0911
4/24/2011	Deep	2	5.67	10.8				
4/24/2011	Deep	3	5.65	9.6				
4/24/2011	Deep	4	5.4	9.4				
4/24/2011	Deep	5	5.3	9.2				
4/24/2011	Deep	6	5.3	9.2				
4/24/2011	Deep	7	4.8	9.1				
4/24/2011	Deep	8	4.33	9.1				
4/24/2011	Shallow	1	5.45	12.2	5.33	10.6	0.236	0.0442
4/24/2011	Shallow	2	5.6	10.8				
4/24/2011	Shallow	3	5.2	9.8				
4/24/2011	Shallow	4	5.08	9.4				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/7/2011	Deep	1	5.7	25.1	2.70	22.5	2.97	1.10
7/7/2011	Deep	2	6.4	25.1				
7/7/2011	Deep	3	5.65	25				
7/7/2011	Deep	4	3.85	24.5				
7/7/2011	Deep	5	0	23.5				
7/7/2011	Deep	6	0	21.8				
7/7/2011	Deep	7	0	18.6				
7/7/2011	Deep	8	0	16.5				
7/7/2011	Shallow	1	5.6	25.4	4.37	25.0	2.22	0.508
7/7/2011	Shallow	2	5.9	25.1				
7/7/2011	Shallow	3	4.88	25				
7/7/2011	Shallow	4	1.1	24.5				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/13/2011	Deep	1	7	25.9	2.99	23.0	3.37	1.13
7/13/2011	Deep	2	7.03	25.8				
7/13/2011	Deep	3	6.35	25.8				
7/13/2011	Deep	4	3.5	25.3				
7/13/2011	Deep	5	0	24.1				
7/13/2011	Deep	6	0	21.4				
7/13/2011	Deep	7	0	18.9				
7/13/2011	Deep	8	0.01	16.8				
7/13/2011	Shallow	1	6	25.8	5.05	25.6	2.19	0.434
7/13/2011	Shallow	2	6.6	25.6				
7/13/2011	Shallow	3	5.8	25.6				
7/13/2011	Shallow	4	1.8	25.5				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
7/27/2011	Deep	1	4.6	26.7	1.71	24.1	2.28	1.34
7/27/2011	Deep	2	4.47	26.8				
7/27/2011	Deep	3	4.3	26.6				
7/27/2011	Deep	4	0.03	26.6				
7/27/2011	Deep	5	0.05	25.1				
7/27/2011	Deep	6	0.14	22.5				
7/27/2011	Deep	7	0.03	20.5				
7/27/2011	Deep	8	0.03	18.2				
7/27/2011	Shallow	1	6.21	26.9	5.31	26.6	0.798	0.150
7/27/2011	Shallow	2	5.74	26.7				
7/27/2011	Shallow	3	4.67	26.3				
7/27/2011	Shallow	4	4.6	26.4				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
8/3/2011	Deep	1	4.36	26.5	1.39	24.1	1.92	1.39
8/3/2011	Deep	2	4.16	26.5				
8/3/2011	Deep	3	2.19	26.7				
8/3/2011	Deep	4	0.35	25.6				
8/3/2011	Deep	5	0	24.6				
8/3/2011	Deep	6	0.02	23.7				
8/3/2011	Deep	7	0	20.8				
8/3/2011	Deep	8	0	18.5				
8/3/2011	Shallow	1	4.3	26.4	2.29	26.2	1.88	0.820
8/3/2011	Shallow	2	3.25	26.5				
8/3/2011	Shallow	3	1.6	26.1				
8/3/2011	Shallow	4	0.02	25.6				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
8/18/2011	Deep	1	0.57	23.1	0.284	21.8	0.253	0.891
8/18/2011	Deep	2	0.53	22.9				
8/18/2011	Deep	3	0.47	22.5				
8/18/2011	Deep	4	0.45	22.5				
8/18/2011	Deep	5	0.25	22.2				
8/18/2011	Deep	6	0	21.6				
8/18/2011	Deep	7	0	20.5				
8/18/2011	Deep	8	0	19				
8/18/2011	Shallow	1	0.51	22.9	0.540	22.7	0.0258	0.0478
8/18/2011	Shallow	2	0.57	22.9				
8/18/2011	Shallow	3	0.53	22.5				
8/18/2011	Shallow	4	0.55	22.5				

Date	Location	Depth (ft)	D.O. (mg/L)	Temperature (°C)	Average D.O. (mg/L)	Average Temperature (°C)	Stdev	Coef Variation
9/8/2011	Deep	1	0	19.2	0.00	19.0	0.00707	2.83
9/8/2011	Deep	2	0	19.2				
9/8/2011	Deep	3	0	19.2				
9/8/2011	Deep	4	0	19.1				
9/8/2011	Deep	5	0	19.1				
9/8/2011	Deep	6	0	19				
9/8/2011	Deep	7	0	18.5				
9/8/2011	Deep	8	0.02	18.5				
9/8/2011	Shallow	1	0	19.2	0.00	19.2	0.000	Can't divide by zero
9/8/2011	Shallow	2	0	19.2				
9/8/2011	Shallow	3	0	19.2				
9/8/2011	Shallow	4	0	19.2				