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An Assessment of Constructed Wetland Treatment System Cells: Removal of Excess Nutrients and Pollutants from Municipal Wastewater in Lakeland, Florida

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An Assessment of Constructed Wetland Treatment System Cells: Removal of Excess Nutrients and Pollutants from Municipal Wastewater in Lakeland, Florida

by

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Abstract

Wastewater treatment wetlands are proven valuable alternatives to the treatment of wastewater in a more natural environment. These wetlands can be natural or constructed, and come in a variety of types and sizes. The purpose of this study was to determine the efficiency of water treatment for nutrients and pollutants utilized by the City of Lakeland in treating their municipal wastewater by wetland treatment system cells. This study is important in order to ensure the successful use of the wetland, as well as to determine the impacts previous phosphorus mining use may have on the effectiveness of treatment. Following FDEP standard operating procedures, this study monitored various water quality parameters for three consecutive summer months. The wetland as a whole varied in the removal of nutrients. The wetland was best at decreasing concentrations of TN and TP, at eighty-three percent and fifty-four percent, respectively, when compared to other parameters. This study shows how municipal wastewater is beneficially treated by wetland treatment system cells to produce viable water resources that can be reused in order to promote sustainable uses going into the future.

Chapter One:

Introduction

1.1 Wetland Treatment Systems

Wastewater is treated in numerous stages of the treatment process by various types of wetlands around the world. Constructed wetlands are more efficient than natural wetlands since they can be engineered to provide the best environment needed for treatment (Zhang et al., 2015). Constructed wetlands are reliable sources for low cost and efficient treatment systems in treating various types of wastewater. The efficiency of such wetlands are due to an abundance of factors, including vegetative cover, water flow and water column, type of substrate, and other living organisms present (Zhang et al., 2015). Nutrient removal is one of the most important components of the treatment process involved in constructed wetlands when treating wastewater. This removal enhances the potential for water reuse and water bodies receiving the treated wastewater have a decreased potential for eutrophication (Lin et al., 2002).

Since the 1950s, wetlands have been utilized for nutrient removal globally (Verhoeven & Meuleman, 1999). Studies have shown these types of systems to be successful in mountainous, rural, small municipal, and tropical and subtropical regions around the world (Coleman et al, 2001; Gale et al., 1994; Huang et al., 2000; Zhang et al., 2015). Natural wetlands in the United States were first used for ecological treatment of wastewater in the late 1960s to early 1970s. These systems were primarily free water surface constructed treatment wetlands. However, there are currently numerous engineered forms of constructed wetlands that provide different benefits. These include free water surface constructed wetlands (FWS CW), constructed wetlands with horizontal subsurface flow (HF CW), and constructed wetlands with vertical subsurface flow (VF CW) (Vymazal, 2010). These types are utilized individually, but studies have found that constructed wetlands often work best when utilized as a hybrid. Hybrid constructed wetlands are primarily used in the enhanced removal of nitrogen from water (Zhang et al., 2015).

The removal of excess nutrients by constructed wetlands is extremely important to ensure that eutrophication of the wetland does not occur, as well as to make sure that receiving water bodies do not become contaminated with nutrient-rich treated wastewater (Lin et al., 2002). Levels of nitrogen or phosphorus, in the form of limiting nutrients, influence eutrophication due to an excess of nutrients. Nitrogen is an important component of eutrophication and is found in wastewater. A study conducted by Huang et al. (2000) found that when sampling levels of ammonium, nitrate, and total Kjeldahl nitrogen, the presence of vegetation did not have as great an impact as did residence time throughout the wetland.

A second important component of eutrophication is phosphorus, which is also found in wastewater (Gale et al., 1994). The type of soil present has an important influence on the amounts of phosphorus retained throughout the treatment process. Once the amount of adsorption and desorption of soluble phosphorus is determined, plants and aquatic organisms are able to use the remaining phosphorus for nutritional needs (Huang et al., 2000). In most constructed wetlands, either nitrogen or phosphorus acts as the limiting nutrient for the eutrophication process (Verhoeven & Meuleman, 1999).

Other than total nitrogen and total phosphorus concentrations, chlorophyll-a concentrations and water clarity readings are important in determining the trophic state level of a water body. Once levels are determined for each parameter, then a Tropic State Index (TSI) is calculated for surface waters. Various species of algae and cyanobacteria contain chlorophyll-a. When concentrations are high within a body of water, the water contains many algal types. If there is too much found within a body of water, then an algal bloom will likely occur. Chlorophyll-a, in excessive amounts, will also block sunlight from reaching submerged vegetation within the wetland. Water clarity depths are commonly measured using a Secchi disk reading. When chlorophyll-a concentrations are high, Secchi disk readings are typically low. Water clarity helps determine how far light is able to reach, and is important when taking into account the aesthetic quality based on the use of the wetland (FDEP, 2014).

1.2 Phosphorus in Florida

Florida geology has proven to be rich in phosphorus because of sediment deposits from the sea in its early history. With the development of phosphorus-based fertilizers, mining for phosphate exploded throughout Florida, especially within Central Florida. This phosphorus-rich area of Central Florida became known as Bone Valley, and encompassed parts of Polk County and Hillsborough County (Figure 1). Heavily mined throughout the 1900s, this area is still heavily mined in present day (Florida Industrial and Phosphate Institute, 2017). Mulberry, Florida falls within the Bone Valley region, and mining companies are found throughout the city today.

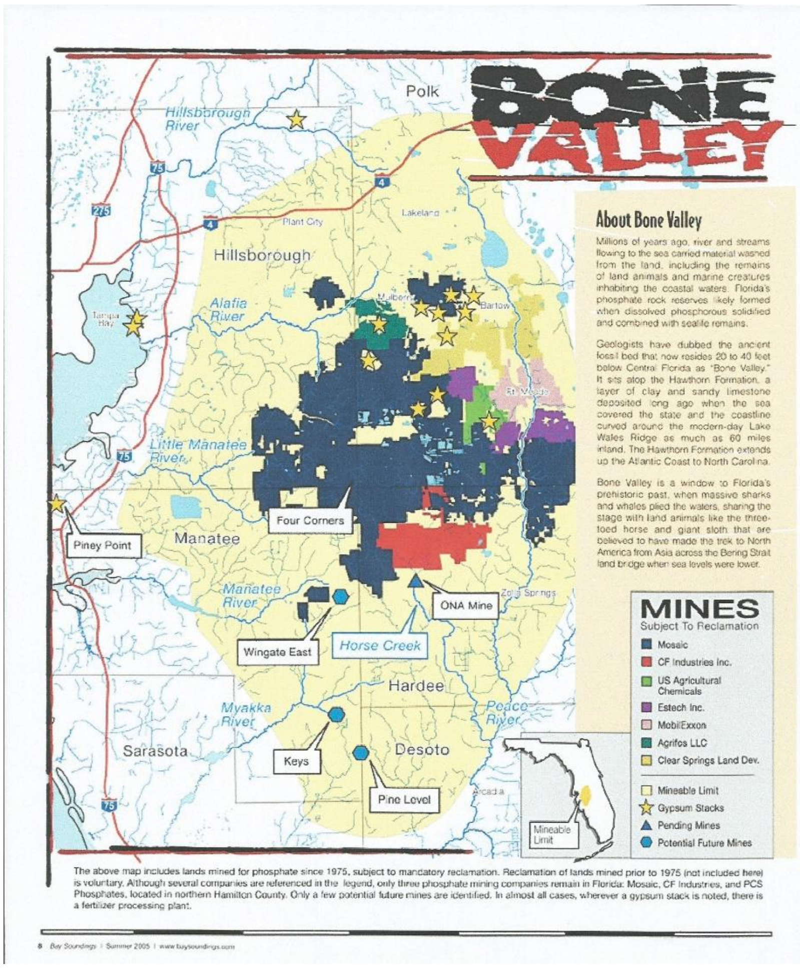

Figure 1: Visual Representation of Bone Valley (www.baysoundings.com, 2005)

The restoration of phosphate mines in Florida began in the 1970s. In order to combat the dominance of phosphate mining's detrimental effects on the environment, some retired phosphate mines have been reclaimed into wetland treatment systems. Phosphate mining occurs using open pit mining with phosphate clay settling areas occupying land not currently mined but owned by the companies. Successful restoration efforts of these areas require the cooperation of many different entities, from ecological engineers, to scientists, to government regulation. In 1975, the state of Florida passed a regulation requiring reclamation of mined lands to as natural of a state as possible when finished. However, this was not a requirement for lands that began their mining operations prior to 1975. Reclaimed phosphate mines are beneficial to the environment because they reintroduce the abiotic and biotic relationships natural landscapes provide. While not entirely restored to their initial states, positive benefits have been shown to come out of these restored lands (Brown, 2005).

1.3 Purpose

The purpose of this study was to determine the efficiency of water treatment for nutrients and pollutants utilized by the City of Lakeland in treating their municipal wastewater by wetland treatment system cells. This specific wetland treatment system impacted temperature, dissolved oxygen (DO), conductivity, pH, water clarity, total nitrogen (TN), total phosphorus (TP), chlorophyll-a, total suspended solids (TSS), and biological oxygen demand (BOD) levels as determined by the treated municipal wastewater quality data. While there has been significant research on the treatment of wastewater by constructed and natural wetland treatment systems, and there has been significant research on phosphate mining in Florida, there is not a large quantity of research on the impacts of reclaimed phosphorus mining lands on wastewater treatment using constructed wetland treatment system cells.

1.4 Working Hypothesis

The working hypothesis for this study is that water quality will improve from the inflow point of the wetland treatment system to the outflow point of the wetland treatment system. Within this hypothesis, the study will determine whether any significant changes are observed between the individual wetland treatment system cells when compared to each other.

Chapter Two:

Literature Review

Wastewater treatment wetlands are useful for the treatment of various types of wastewater in various conditions. The characteristics of the wetland and the characteristics of the surrounding areas are influenced by different water quality parameters. One of the first influences is whether the wetland is natural or constructed. Verhoeven and Meuleman (1999) described how constructed wetlands are usually more efficient at removing pollution because they can be designed for maximum efficiency. Vymazal (2010) classified constructed wetlands using the type of vegetation present, hydrology, and flow direction. This can be further broken down based on the different types of constructed wetlands found. These wetlands can be free water surface constructed wetlands, constructed wetlands with horizontal subsurface flow, constructed wetlands with vertical subsurface flow, infiltration wetlands, or hybrid wetlands (Vymazal 2010; Verhoeven & Meuleman, 1999). Subsurface flow wetlands contain settling basins and compartments with shallow water present. This process takes a minimum of ten days to completely flow throughout the wetland. Subsurface flow constructed wetlands are especially good at removing COD, BOD, and bacterial pollution. Infiltration wetlands contain coarse sediments and water flows vertically into the sediment, which promotes nutrient removal (Verhoeven & Meuleman, 1999). Hybrid wetlands contain different characteristics found within the other specific types of constructed wetlands (Vymazal, 2010).

Constructed wetlands have proven to be successful in treating various types of wastewater in various types of climatic conditions. Zhang et al. (2015) determined the success of constructed wetlands in treating wastewaters found in tropical and subtropical conditions over a thirteen-year period. This review was not complete without taking into account the type of wastewater, stage of treatment, removal performance of different contaminants, and the design and operation of each specific wetland studied. Within tropical and subtropical environments, hybrid constructed wetlands performed the most efficiently in treating wastewater. This proved to be an efficient and cost-effective method for treating various types of wetlands within these types of climatic conditions (Zhang et al., 2015).

While constructed wetlands are used for industrial, municipal, and agricultural wastewaters, they can also be used to treat aquaculture. Lin et al. (2002) set out to determine the efficiency of constructed wetlands in the removal of nitrogen and phosphorus from aquaculture wastewater. After completing a pilot study for eight months using various loading rates, it was determined that constructed wetlands were efficient in the removal process. Loading rates did not have a significant impact in the removal of nitrogen. However, the efficiency of phosphorus removal was inversely related to loading rates. After the aquaculture water was treated, it was suitable for reuse without the threat of creating a eutrophic environment (Lin et al., 2002).

Nitrogen is an important nutrient found within wastewater treatment wetlands. Nitrogen removal is extremely important if there is an excess amount found within the water. Eutrophication is a major cause of pollution within surface waters of the United States. Specifically, excess nitrogen and phosphorus concentrations found because of point and nonpoint sources are detrimental to the health of surface waters (Carpenter et al., 1998). Huang et al.

(2000) found that nitrogen removal was an important factor when related to residence time. Other than residence time, temperature seems to have an important influence on removal rates. It is interesting to note that the type of vegetation present does not seem to have a significant impact on the efficiency of removal of the various types of nitrogen found throughout wastewater treatment wetlands (Huang et al., 2000). In Florida, nitrogen concentrations are not to exceed 1.91 milligrams per liter (FDEP, 2016).

Phosphorus is another important nutrient found within wastewater treatment wetlands. The type of soil found beneath and around the wastewater treatment wetland determines phosphorus retention and release. Constructed wetlands, which contain mineral soils, are more efficient at removing excess phosphorus when compared to natural wetlands, which contain organic soils. Physiochemical properties found within different treatment wetlands help determine the efficiency these wetlands have in removing different pollutants and nutrients from wastewater (Gale et al., 1994). The presence of plants is another important aspect of the amount of phosphorus found within the system. Plants help absorb the nutrients, as well as help determine the erosion rates of sediment, which release stored phosphorus into the aquatic system (Carpenter et al., 1998). In Florida, phosphorus concentrations are not supposed to exceed 0.16 milligrams per liter for surface waters (FDEP, 2016).

Another important water quality parameter within wastewater treatment wetlands is the concentrations of chlorophyll-a found in the water. Chlorophyll-a is also associated with eutrophication, but does not pose as significant threat to surface waters as does nitrogen and phosphorus concentrations. Chlorophyll-a measurements help determine the presence of algae in the water, and an excess of algae shows hyper-nutrient rich waters while low measurements show waters that are low in nutrients. Based on the purpose of the water, either may be detrimental to the use of the water (Rundquist et al., 1996). In Florida, chlorophyll-a levels should not exceed an amount that causes an imbalance of the natural populations of flora and fauna present (FDEP, 2016).

While the state of Florida does not have specific standards set in place for total suspended solids (TSS), it is still an important criteria for determining the health and potential reuse of water bodies. Instead, Florida measures TSS through setting regulations on turbidity measurements, which is determined by the background turbidity levels of the water. Flow rates are important influencers in the abundance of TSS found within a water body. Faster flowing water bodies often have higher concentrations of TSS, as well as bodies of water with higher rates of sediment erosion and vegetation present (US EPA, 2006). For class one surface waters, this amount is not to be greater than five hundred milligrams per liter in a month’s time (FDEP, 2016).

According to the Florida Department of Environmental Protection (2011), BOD is the measurement of the usage of oxygen by microorganisms within a five day time period. High concentrations of BOD in the water can lead to die offs of organisms due to there not being enough oxygen present in the water for the organisms to use. For surface waters in Florida, it is not supposed to reach below the limit of the class designation for the water, and it is not supposed to exceed the limit that causes a nuisance habitat environment (FDEP, 2016).

Macrophytes play an important role in the removal of excess nutrients and pollutants within wastewater treatment wetlands. They provide different contributions to the wetland, with the most important contribution being their physical characteristics. Macrophytes help in stabilizing surface beds, improving conditions for physical filtration, preventing clogging, insulating the surface from cold temperatures, and providing increased surface area for microbial growth (Brix, 1997). Karathanseis et al. (2003) showed how polycultures of macrophytes are more successful in removing nutrients and pollutants when compared to monocultures of macrophytes. Polyculture wastewater treatment wetlands are better able to remove fecal bacteria, reduce BOD, and remove suspended solids, and are not as influenced by seasonal variations (Karathanseis et al., 2003). Three specific plant species, *Juncus effusus*, *Scirpus validus,* and *Typha latifolia*, benefit constructed wetlands. Effluent quality improved when these plants were present and mixed within the wetlands (Coleman et al., 2001). Other than nutrient and pollutant removal benefits to wastewater treatment wetlands, macrophytes also help these wetlands to become more aesthetically pleasing and provide different habitats for wildlife. The presence of macrophytes, especially in polycultures, are an essential component of successful constructed wastewater treatment wetlands (Brix, 1997).

Chapter Three:

Study Area

The City of Lakeland employs a constructed wastewater treatment wetland with seven treatment cells in order to filter its municipal wastewater. This retired phosphate mine site was acquired by the city in 1987 and is used as a tertiary treatment process for the city's municipal wastewater after secondary processing at one of two wastewater treatment plants. The wetland is approximately sixteen hundred acres and is located in Mulberry, Florida, which is approximately twelve miles from Lakeland. Various water quality parameters are monitored in the wetland to ensure that levels stay within the permitted amounts established by the Florida Department of Environmental Protection. A wide variety of ecosystem benefits are provided by the wetland, and a diverse range of plant and animal species can be found residing in the constructed wetland. In the past, water treated in the wetland was sent to the Alafia River, but is currently being utilized by Tampa Electric's (TECO) Polk Power Station (City of Lakeland, 2015).

Prior to the use of the wetland treatment system, the City of Lakeland would discharge its treated wastewater from the Glendale Water Reclamation Facility into a local lake, known as Banana Lake. This began in 1926 and continued for more than sixty-five years. Heavy development along Banana Lake and the many years of discharged wastewater severely degraded water quality in the lake, which led to the Florida Department of Environmental Protection's (FDEP) withdrawal of the City of Lakeland's discharge permit in 1983. Faced with the task of finding an alternative method of discharge to reach compliance levels, the City of

Lakeland determined that the use of an artificial, constructed wastewater treatment wetland would be the most efficient and cost effective method to treat the city's wastewater supplies (United States Environmental Protection Agency's Office of Water, 1993).

The City of Lakeland's Wetland Treatment System is located in Mulberry, Florida, which has a humid subtropical climate. Mulberry resides in Polk County, which is part of the Bone Valley region of Florida (Figures 2 and 3). The wetland treatment system is approximately sixteen hundred acres and was constructed from an old phosphate mine and phosphate clay settling areas. It provides tertiary treatment of the wastewater for all of the City of Lakeland, which has approximately one hundred thousand residents. The City of Lakeland started successfully utilizing this land in 1987 and has been operating it ever since. The treatment system contains an abundance of vegetation and wildlife thanks to the variety of landscape found there. Uplands, hard wood swamps, emergent marshes, and open water lakes make up the land. The primary vegetation found within the parts of the wetland that treat wastewater are cattails (*Typha spp.*) and/or Carolina willow (*Salix caroliniana*). From 1987 until mid-2015, water that traveled throughout the wetland made its way to the north prong of the Alafia River, which eventually traveled to Tampa Bay. Starting in the summer of 2015, the City of Lakeland began sending the treated wastewater to Tampa Electric's (TECO) Polk Power Station via a fifteen-mile pipeline. The current agreement allows TECO to receive approximately five million gallons of water per day, with planned expansion up to seventeen million gallons per day in the future. The agreement is currently set for a thirty-year time frame (City of Lakeland, 2015).

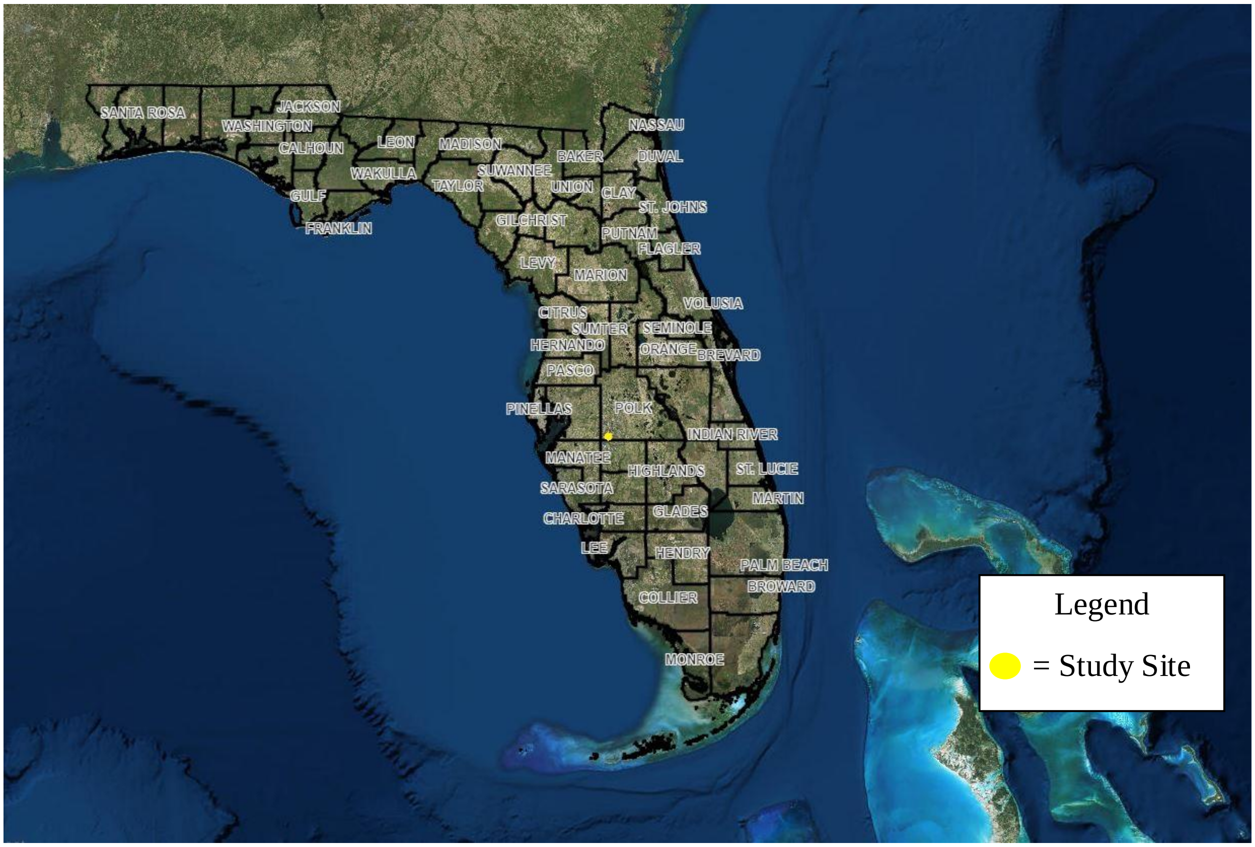

Figure 2: Study Site within Polk County (ArcGIS, 2016)

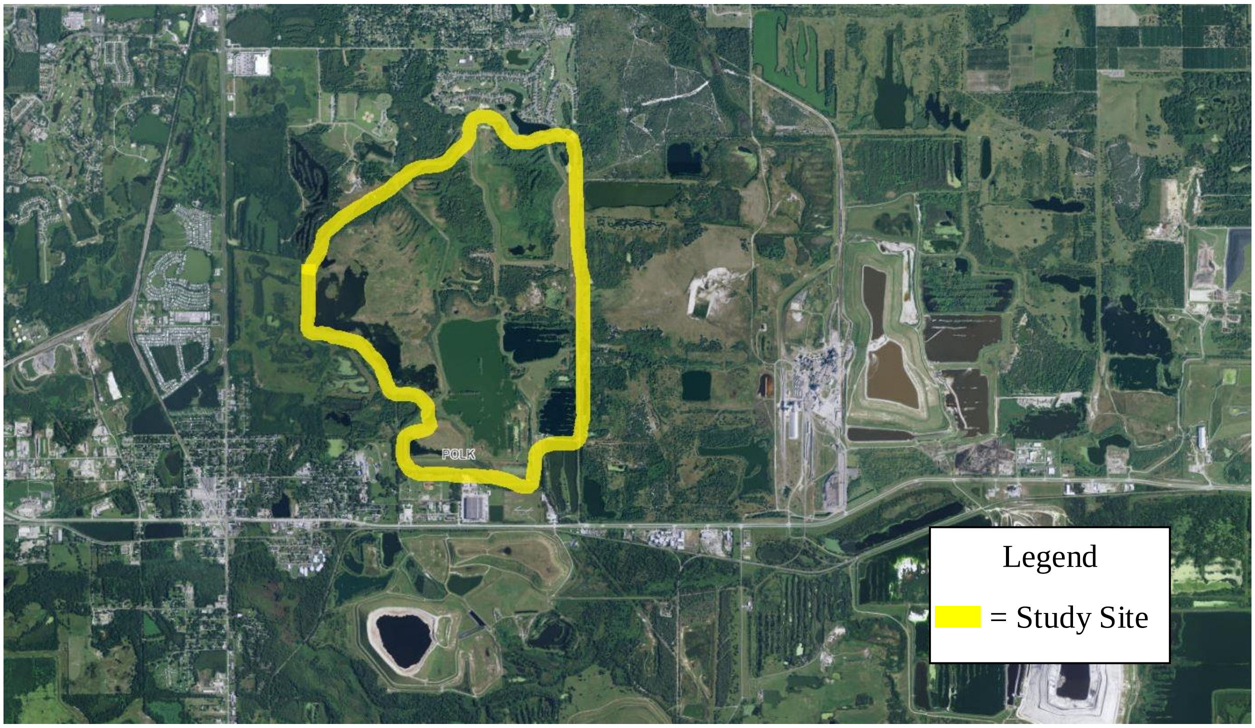

Figure 3: Study Site within Mulberry, Florida (ArcGIS, 2016)

The wetland treatment system comprises seven cells (Figure 4). Cells One to Four and part of Five are characterized as cattail marsh, while the rest of Five through Seven are characterized as open water lakes. Cells One to Three are characterized as having course-grained sands and fine, clayey sediments present while Cells Four through Seven have predominately fine clayey soils. The wetland treatment system is home to various organisms, including alligators, otters, wild boars, varieties of birds, and varieties of freshwater fish. Cell Five's waters house a significant population of alligators and rookeries, which can contribute their own waste to the waters. The wastewater comes into the wetland at the influent structure via a pipe from the City of Lakeland's Glendale Water Reclamation Facility. The amount of water that flows between the cells is determined based on the level of stop logs placed on control structures at each wetland. Gravity induces the flow of water with an approximate eighty-foot elevation gradient throughout the wetland treatment system. The system removes excess nutrients and solids through its vegetation, microorganisms, filtration, and settling of solids. Many different water quality parameters are monitored throughout the wetland based on permitted limits from FDEP. Since the wetland used to be a phosphate clay settling area, there is no permitted limit for total phosphorus annually. Berms separate the wetlands from each other (City of Lakeland, 2015) (Figure 5).

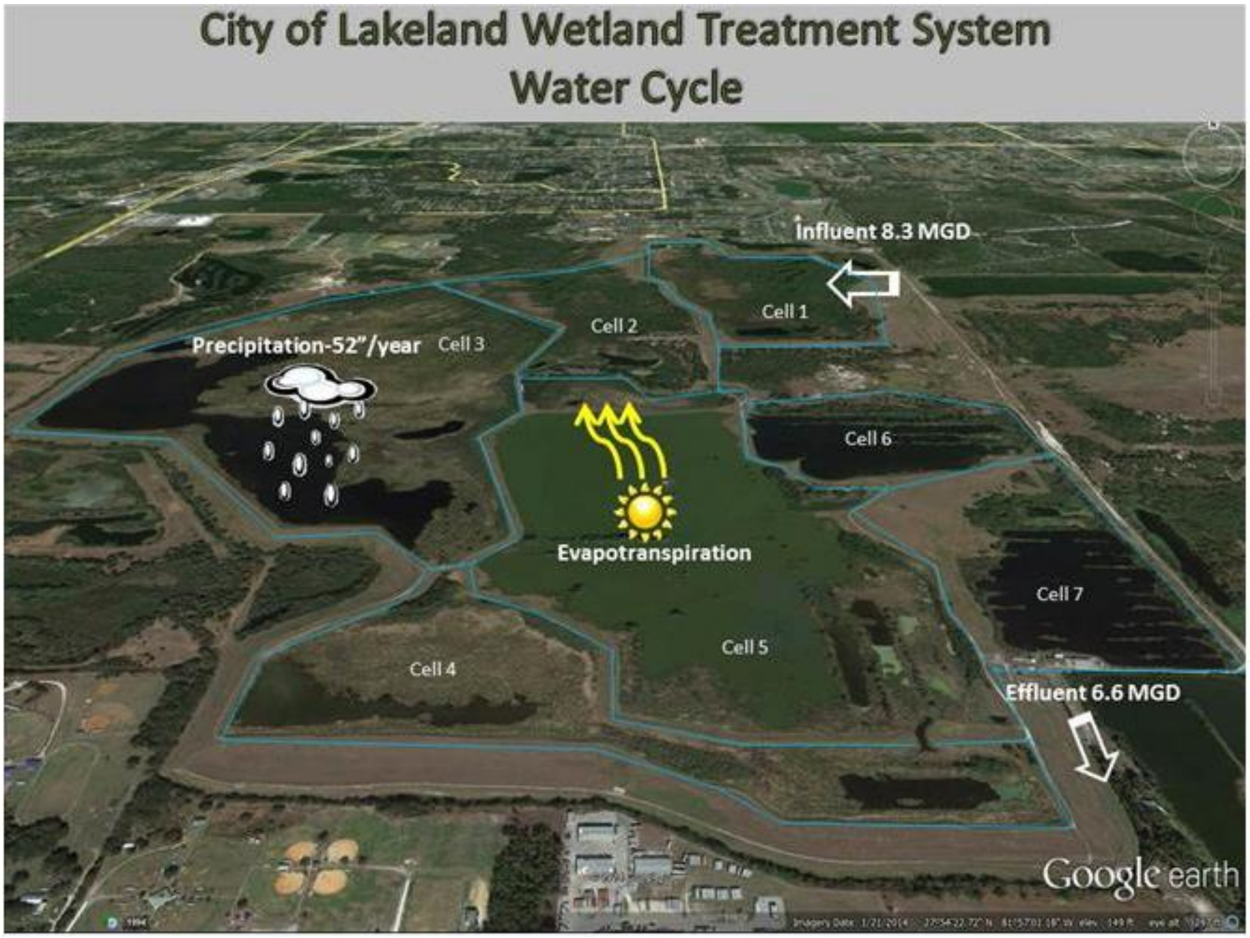

Figure 4: City of Lakeland Wetland Treatment System Water Cycle (www.lakelandgov.net, 2014)

Figure 5: The City of Lakeland's Wetland Treatment System Flow Patterns (City of Lakeland, 2015)

Each cell is unique from the others in their sizes (Figure 6) and amounts of water they are capable of holding. It takes approximately ninety days for the water to completely flow throughout the wetland. A tracer study was conducted by the City of Lakeland that measured the hydraulic residence times for Cells One through Four. The residence time for Cell One was 5.2 days, for Cell Two was 0.6 days, for Cell Three was 34.5 days, and for Cell Four was 5.4 days (Keller & Bays, 2004). At approximately 45.7 days, the remaining three cells account for approximately 44.3 days of hydraulic residence. The volume of each cell could not be obtained, but the volume capacity of each cell was determined by comparing the minimum and maximum water levels (Table 1) (B. Anderson, personal communication, February 6, 2017).

Table 1: Wetland Cell Capacities

	Acres	**Min**	**Max**	**Difference**	**Capacity**	**Capacity**
		(Ft MSL)	**(FT MSL)**	**(FT)**	**(MG)**	**Acre Feet**
Cell 1	200	188.04	192.08	4.04	263.288	808.294
Cell 2	190	158.59	160.00	1.41	87.296	267.997
Cell 3	410	150.40	155.89	5.49	733.459	2251.719
Cell 4	75	147.00	154.00	7.00	171.072	525.191
Cell 5	240	146.50	154.00	7.50	586.533	1800.655
Cell 6	100	146.34	154.45	8.11	264.266	811.295
Cell 7	80	132.50	138.22	5.72	149.110	457.767
				Totals	2255.022	6922.918

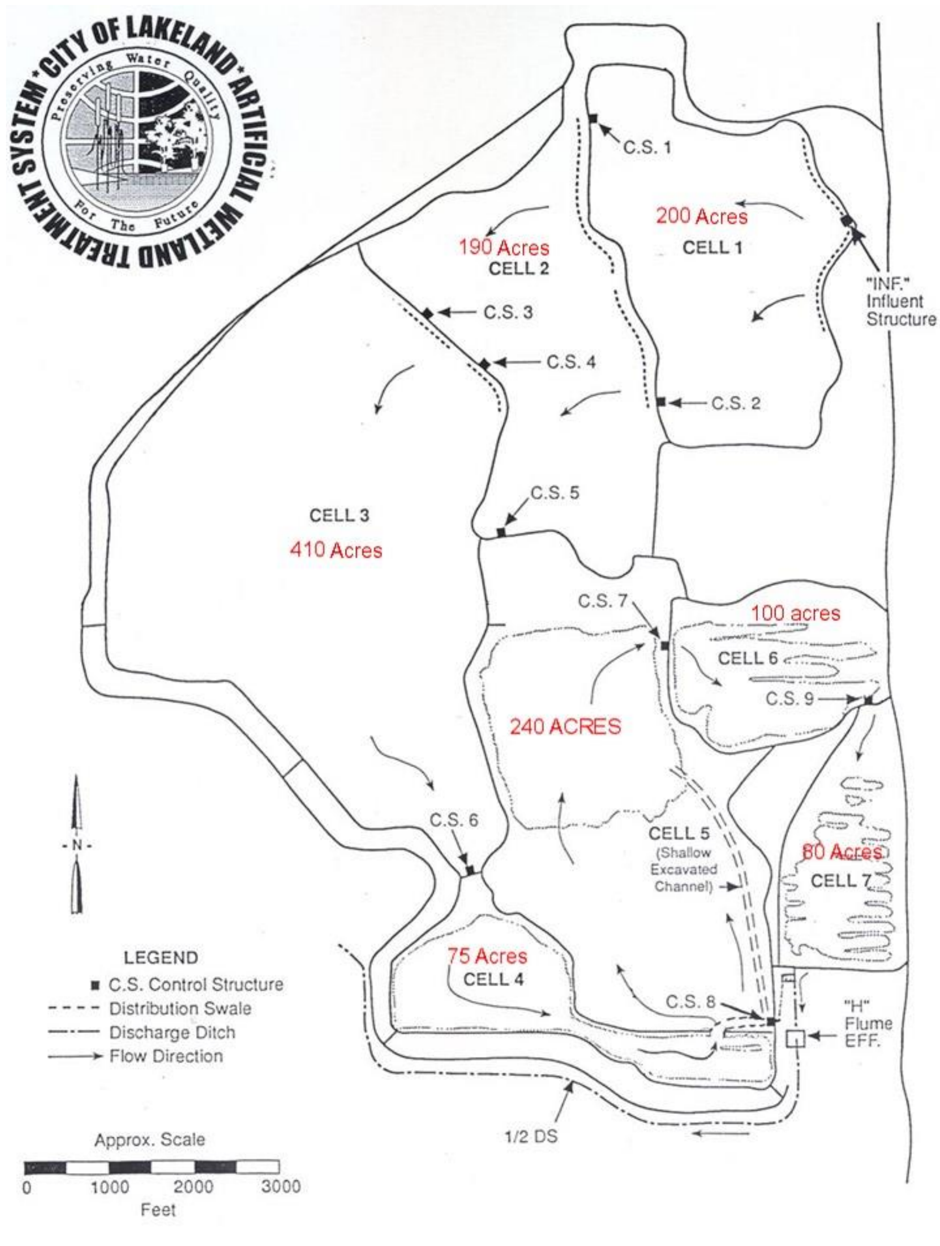

Figure 6: Wetland Map with Acreage (B. Anderson, personal communication, February 6, 2017)

The agreement between the City of Lakeland and TECO shows how constructed wastewater treatment wetlands have the potential of incorporating more environmentally friendly methods by utilizing treated effluent in place of traditional freshwater sources. TECO no longer needs to withdraw groundwater for use at its power station since it is able to use the treated wastewater. Since not as much wastewater will be received by the Alafia River from the treatment wetland, the possibility of polluting the river, and eventually Tampa Bay from this source, is decreased (City of Lakeland, 2015). With the many issues Tampa Bay has, and is currently facing when it comes to its water quality, the decrease in receiving waters will help to exclude some of the potential polluting sources. However, none of this would be possible without the efficiency of the wetland in removing excess nutrients and pollutants from the received wastewater. This study is important in ensuring the success of the treatment wetland for the City of Lakeland to use as an example for other municipalities.

Chapter Four:

Methods

4.1 Sampling

This study focused on different water quality parameters found throughout the wetland. The parameters in consideration are total nitrogen, total phosphorus, chlorophyll-a, water clarity, pH, temperature, TSS, dissolved oxygen, conductivity, and BOD (Coleman et al., 2001). This study used FDEP's water sampling criteria for grab samples of surface waters for water samples. This study took measurements at elbow depth, or approximately thirty centimeters under the water's surface. This study took samples in clear sample bottles, except chlorophyll-a samples were taken in brown sample bottles to inhibit breakdown of chlorophyll-a due to being exposed to sunlight. Two sample points were established within each of the seven wetlands, one sample point near the inflow area, and another sample point near the outflow area (Figures 7 – 20).

Since there were seven wetland treatment cells, fourteen samples were taken each week of sampling. Sampling occurred every two weeks throughout the summertime, for approximately three months between June 2016 and September 2016. Coleman et al. (2001) sampled once a month for a year, but since sampling for this study did not occur for an entire year, sampling occurred every two weeks so that possible differences between the weeks could be determined. Samples were stored in a refrigerator, for no more than three days after collection, in order to preserve quality (FDEP, 2014).

Figure 7: Cell One Inflow

Figure 8: Cell One Outflow

Figure 9: Cell Two Inflow

Figure 10: Cell Two Outflow

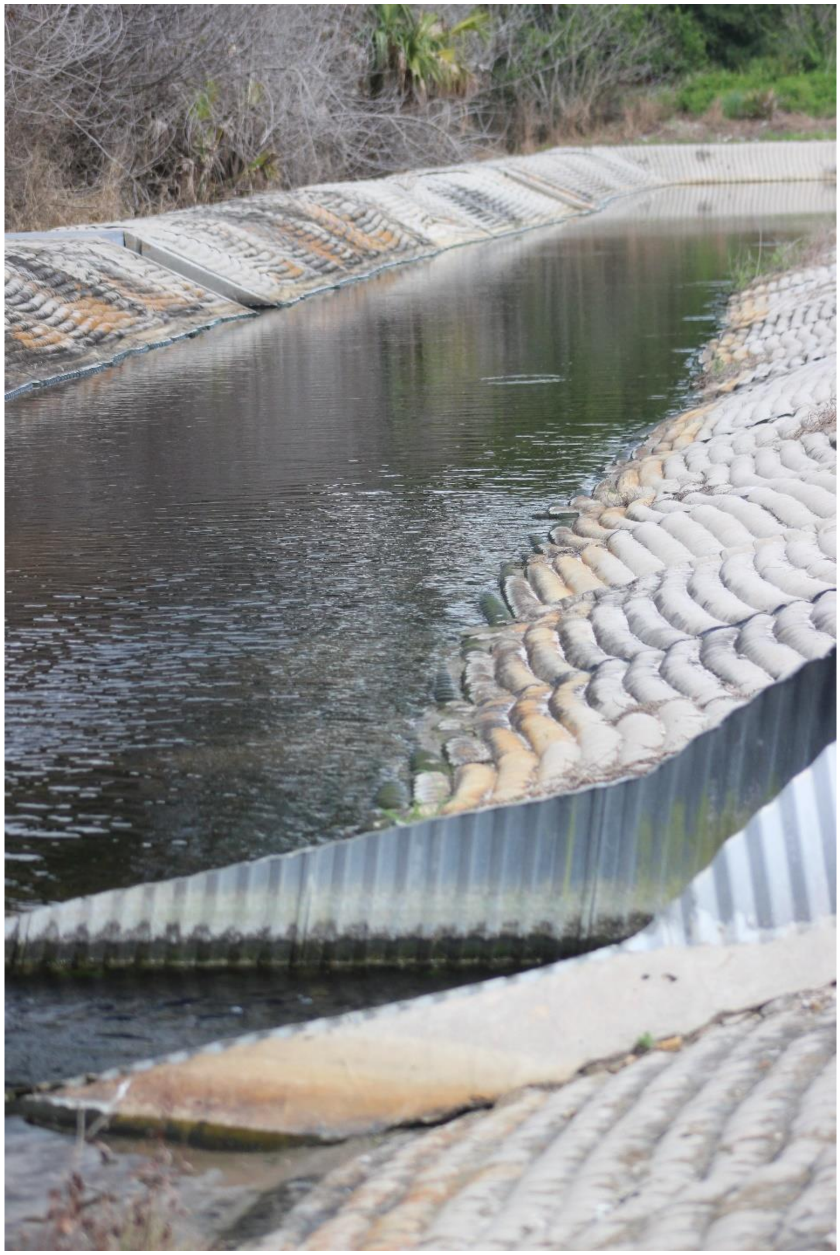

Figure 11: Cell Three Inflow

Figure 12: Cell Three Outflow

Figure 13: Cell Four Inflow

Figure 14: Cell Four Outflow

Figure 15: Cell Five Inflow

Figure 16: Cell Five Outflow

Figure 17: Cell Six Inflow

Figure 18: Cell Six Outflow

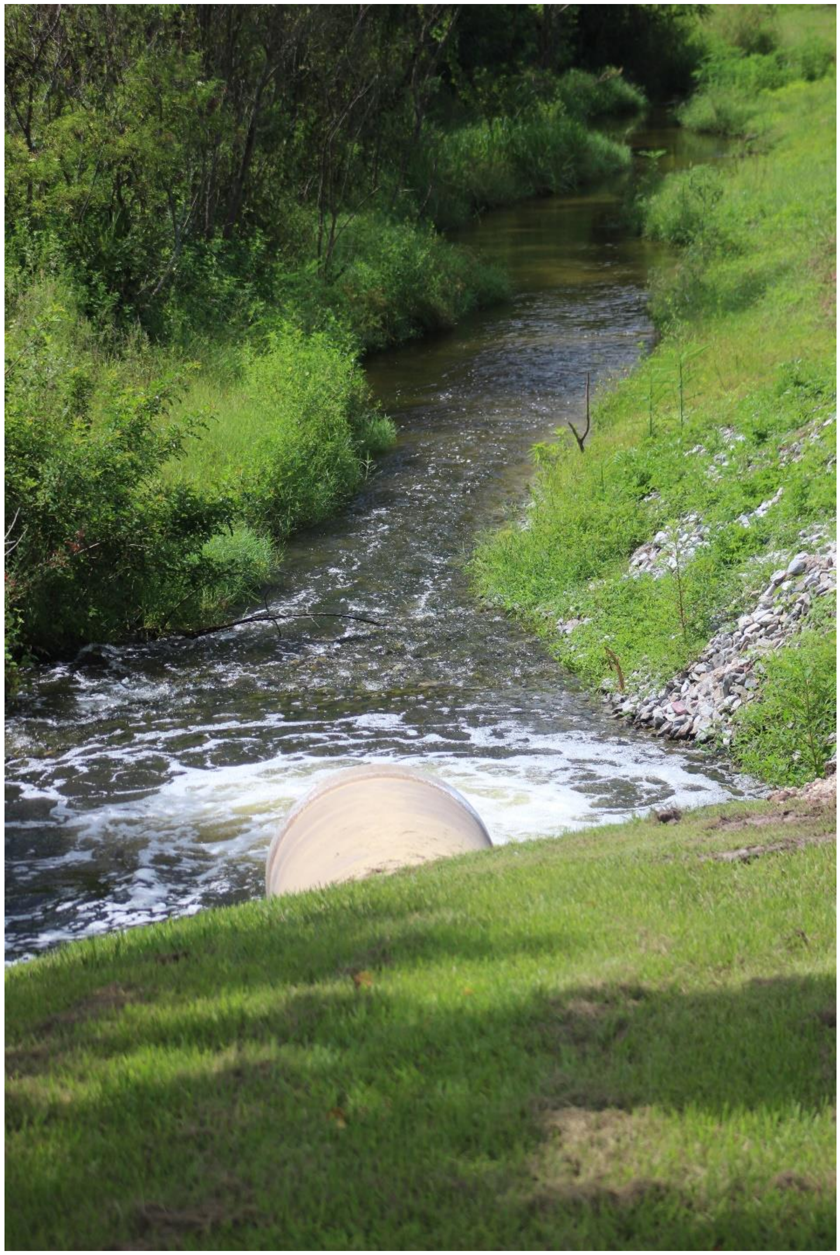

Figure 19: Cell Seven Inflow

Figure 20: Cell Seven Outflow

Water quality parameters were tested using the appropriate test associated with it established by the FDEP. Since the City of Lakeland has to adhere to these parameters, they were deemed appropriate for this study.

Total Nitrogen (FDEP QA Rule, 62-160 F.A.C)

Total nitrogen was determined using FDEP's Quality Assurance Rule 62-160 F.A.C.

Total Phosphorus (FDEP NU-090)

Total phosphorus was determined using FDEP's NU-090.

Chlorophyll-a (FDEP-SAS-002/10)

Chlorophyll-a was determined using FDEP's SAS-002/10.

Water Clarity (FDEP-SOP-001/01)

Water clarity was determined using FDEP's Standard Operating Procedure (SOP) 001/01, involving a secchi disk.

(FDEP, 2014)

pH, Temperature, Dissolved Oxygen, and Conductivity (Specific Conductance)

pH, temperature (°C), dissolved oxygen (mg/L), and conductivity (µs/cm) were determined using a calibrated YSI Professional Plus model.

Total Suspended Solids (TSS) (FDEP QA Rule, 62-160 F.A.C)

TSS was measured using FDEP's Quality Assurance Rule 62-160 F.A.C.

Biochemical Oxygen Demand (FDEP SOP LB-015)

Biochemical oxygen demand (BOD) was determined using FDEP's SOP LB-015.

4.2 Data Analysis

Efficiency

Different statistical tests were performed to analyze effectiveness of the constructed wetland site. Initially, standard statistics were determined. This included the mean, median, standard deviation, minimum reading, maximum reading, and range for each week, as well as for each cell. Efficiency of removal was determined for each individual cell, as well as for the wetland as a whole. Influent and effluent measurements from each wetland determined the percentage of removal within the specific wetlands. Influent from the first wetland and effluent from the last wetland determined the efficiency rate of the wastewater treatment wetland as a whole (Brix, 1997), following Formula 6:

Efficiency removal percentage = $\frac{Influent - Effluent}{Influent}$ x 100

T-tests

Using Excel 2013, t-tests were performed for the inflow and outflow measurement of each cell, as well as for the Cell One inflow point versus the Cell Seven outflow point to determine these parameters for the wetland as a whole. T-tests are important to establish because they show the difference of two measurements that come from a small sample size, without known variances. This is important because it determines whether the two points are related, and if they are statistically significant. If the t-value is close to zero, then that shows that there is not a significant difference between the measured variables. Performing both paired and unpaired statistics were computed for this test because of the residence times of the water in each cell.

Box and Whisker Plots

Using Excel 2013, box and whisker plots were constructed of the distribution and any potential outliers that may be found. By separating plots based on a specific water quality parameter, the distribution of nutrient and pollutant concentrations found throughout the process of the treatment system cells can be visualized.

Chapter Five

Results

5.1 Water Sampling Data

The study collected and analyzed water sampling data by the inputs and outputs of each individual cell throughout the sampling weeks. The standard statistical analysis for each water quality parameter obtained by order of inflow and outflow points of each cell is listed in Tables 2-15. Overall, BOD levels increased and pH levels increased. TSS and chlorophyll-a levels varied, while TN and TP levels decreased. The individual data collected as a whole is in Appendices A – G.

Table 2: Cell One Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
Average	31.24	6.83	1540.43	7.11	N/A	13.01	4.66	3.77	0.39	N/A
Standard Deviation	1.11	1.03	643.53	7.06	N/A	6.46	2.51	1.41	0.01	N/A
Median	31.2	6.93	1767	0.22	N/A	11.2	3.63	3.24	0.39	N/A
Maximum	33.2	8.43	2498	7.52	N/A	25	9.81	6.97	0.41	N/A
Minimum	30	5.42	785	6.87	N/A	7.1	2.35	3.24	0.37	N/A
Range	3.2	3.01	1713	0.65	N/A	17.9	7.46	3.73	0.04	N/A

Table 3: Cell One Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (μs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	28.17	30.31	1567.14	7.00	N/A	6.64	5.23	4.03	0.21	1
Standard Deviation	1.00	46.44	231.79	0.13	N/A	6.10	1.14	1.75	0.02	0
Median	28.7	4.34	1492	7.02	N/A	5.2	5.04	3.24	0.20	1
Maximum	28.9	113.18	1978	7.16	N/A	17.1	7.35	6.99	0.24	1
Minimum	26.4	0.28	1376	6.76	N/A	0.5	3.86	2.26	0.19	1
Range	2.5	112.9	602	0.4	N/A	16.6	3.49	4.73	0.05	0

Table 4: Cell Two Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	28.26	31.79	1540.43	7.31	N/A	7.47	5.17	3.24	0.82	N/A
Standard Deviation	1.04	44.91	346.25	0.11	N/A	5.93	1.19	0.01	0.01	N/A
Median	28.7	6.05	1585	7.31	N/A	5.75	5.13	3.24	0.82	N/A
Maximum	29	112.6	2244	7.48	N/A	18.3	7.36	3.26	0.84	N/A
Minimum	26.1	4.54	1318	7.15	N/A	2.7	3.73	3.24	0.80	N/A
Range	2.9	108.06	926	0.33	N/A	15.6	3.63	0.03	0.04	N/A

Table 5: Cell Two Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	26.39	21.67	1787.57	7.24	N/A	6.27	4.53	3.56	0.62	1
Standard Deviation	0.89	46.72	269.90	0.08	N/A	4.46	0.64	1.10	0.01	0
Median	26.6	3.48	1881	7.21	N/A	6.2	4.78	3.24	0.62	1
Maximum	27.2	127.45	2175	7.37	N/A	13.5	5.34	6.02	0.63	1
Minimum	24.6	1.52	1427	7.14	N/A	0.7	3.44	2.70	0.60	1
Range	2.6	125.93	748	0.23	N/A	12.8	1.9	3.32	0.03	0

Table 6: Cell Three Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	26.71	28.21	1810.71	7.22	N/A	7.36	4.78	3.63	0.48	N/A
Standard Deviation	1.11	40.45	298.13	0.04	N/A	3.97	1.03	1.58	0.03	N/A
Median	26.6	4.54	1892	7.21	N/A	5.6	4.65	3.24	0.48	N/A
Maximum	28.4	88.72	2250	7.29	N/A	12.2	6.53	6.94	0.54	N/A
Minimum	24.9	2.16	1423	7.17	N/A	1.8	3.31	1.78	0.45	N/A
Range	3.5	86.56	827	0.12	N/A	10.4	3.22	5.16	0.09	N/A

Table 7: Cell Three Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD(mg/L)
Average	29.53	29.92	1297.14	7.63	N/A	2.42	3.65	5.54	0.27	2.3
Standard Deviation	1.06	39.71	164.81	0.24	N/A	1.94	0.25	4.36	0.35	1
Median	30.1	3.37	1289	7.6	N/A	1.9	3.74	3.24	0.07	2.5
Maximum	30.6	93.46	1521	8	N/A	5.7	3.92	12.96	0.79	3
Minimum	27.9	2.01	1046	7.35	N/A	0.6	3.27	2.68	0.05	1
Range	2.7	91.45	475	0.65	N/A	5.1	0.65	10.28	0.74	2

Table 8: Cell Four Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	29.17	29.17	1437.43	7.66	N/A	3.84	3.97	3.49	0.47	N/A
Standard Deviation	1.41	42.63	394.73	0.26	N/A	4.69	1.15	1.63	0.10	N/A
Median	29.3	5.34	1292	7.71	N/A	2	3.53	3.24	0.40	N/A
Maximum	30.5	105.51	2250	7.97	N/A	12.2	6.53	6.99	0.61	N/A
Minimum	26.6	2.34	1050	7.17	N/A	1.3	3.22	1.78	0.38	N/A
Range	3.9	103.17	1200	0.8	N/A	10.9	3.31	5.22	0.23	N/A

Table 9: Cell Four Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	29.36	28.26	1303.57	7.17	N/A	3.03	3.11	4.12	0.74	2
Standard Deviation	0.53	43.76	151.34	0.05	N/A	0.62	0.26	1.71	0.01	1
Median	29.5	4.62	1265	7.17	N/A	3.15	3.06	3.24	0.74	2
Maximum	30	105.19	1539	7.23	N/A	3.6	3.4	6.68	0.77	3
Minimum	28.5	0.65	1092	7.07	N/A	2.2	2.68	2.73	0.73	1
Range	1.5	104.54	447	0.16	N/A	1.4	0.72	3.95	0.04	2

Table 10: Cell Five Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	29.37	29.73	1233.43	7.21	N/A	2.33	3.16	6.74	0.58	N/A
Standard Deviation	1.13	44.73	133.31	0.08	N/A	1.23	0.22	5.26	0.01	N/A
Median	29.8	5.44	1196	7.35	N/A	2.25	3.04	3.24	0.58	N/A
Maximum	31.8	109.38	1434	7.2	N/A	3.8	3.5	14.45	0.60	N/A
Minimum	28.6	1.05	1029	7.08	N/A	1	2.97	2.65	0.57	N/A
Range	3.2	108.33	405	0.27	N/A	2.8	0.53	11.80	0.04	N/A

Table 11: Cell Five Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	30.36	27.72	1027.71	7.87	N/A	2.70	2.63	5.30	0.47	4
Standard Deviation	1.29	40.08	87.23	0.20	N/A	1.35	0.28	4.08	0.02	1.9
Median	29.8	6.06	1051	7.93	N/A	2.55	2.6	3.24	0.47	4
Maximum	31.8	98.92	1156	8.12	N/A	4.4	3.1	13.98	0.49	4
Minimum	28.9	2.44	928	7.63	N/A	0.9	2.21	3.19	0.44	1
Range	2.9	96.48	228	0.49	N/A	3.5	0.89	10.80	0.05	2

Table 12: Cell Six Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	31.19	28.20	999.71	8.32	0.73	2.44	2.29	4.16	0.61	N/A
Standard Deviation	0.93	39.25	90.74	0.22	0.12	1.23	0.21	2.91	0.02	N/A
Median	31.8	6.6	992	8.3	0.76	2.4	2.29	3.24	0.61	N/A
Maximum	31.9	98.53	1145	8.63	0.85	4	2.56	10.72	0.63	N/A
Minimum	29.7	3.52	870	8.05	0.56	0.6	1.97	2.70	0.59	N/A
Range	2.2	95.01	275	0.58	0.29	3.4	0.59	8.02	0.04	N/A

Table 13: Cell Six Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	31.06	28.94	1004.86	8.61	0.76	1.74	2.03	3.42	0.10	4.4
Standard Deviation	1.02	39.33	109.76	0.21	0.15	0.87	0.18	1.71	0.01	0.9
Median	31.6	8.05	992	8.68	0.81	2.2	2.04	3.24	0.1	4
Maximum	32	99.81	1191	8.87	0.88	2.5	2.27	6.94	0.12	4
Minimum	29.5	3.8	864	8.26	0.55	0.7	1.69	1.26	0.09	1
Range	2.5	96.01	327	0.61	0.33	1.8	0.58	5.68	0.03	3

Table 14: Cell Seven Inflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (μs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	30.84	28.82	992.86	8.46	0.71	1.56	2.03	3.67	0.07	N/A
Standard Deviation	1.07	39.67	118.71	0.27	0.22	0.63	0.19	1.47	0.02	N/A
Median	31.4	6.66	990	8.5	0.61	1.6	2.04	3.21	0.08	N/A
Maximum	31.9	100.66	1188	8.8	1.11	2.1	2.24	6.99	0.09	N/A
Minimum	29.4	3.2	829	8.04	0.49	0.5	1.73	2.75	0.05	N/A
Range	2.5	97.46	359	0.76	0.62	1.6	0.51	4.24	0.04	N/A

Table 15: Cell Seven Outflow Statistics

	Temperature (°C)	DO (mg/L)	Conductivity (µs/cm)	pH	Water clarity (m)	TN (mg/L)	TP (mg/L)	Chlorophyll-a	TSS (g/L)	BOD (mg/L)
Average	30.63	29.37	963.57	8.43	0.47	2.25	1.81	5.55	0.40	4.3
Standard Deviation	1.29	39.54	85.39	0.60	0.16	0.89	0.52	2.42	0.02	0.5
Median	31.1	8.99	985	8.65	0.50	2.25	1.87	6.97	0.41	4
Maximum	32.2	100.7	1066	8.94	0.73	3.2	2.54	8.74	0.42	4
Minimum	28.6	3.89	830	7.15	0.29	0.8	1.10	2.73	0.38	1
Range	3.6	96.81	236	1.79	0.44	2.4	1.44	6.02	0.04	3

5.2 Removal Efficiency

Another important component was the removal efficiency of various nutrients and pollutants throughout the wetland as a whole and throughout individual cells. The average efficiency of removal for each of the major water quality parameters is in Tables 16-22. Negative numbers indicate the addition of concentrations, while positive numbers indicate the removal of concentrations. The individual data collected as a whole determined these averages, which may be found in the appendix. The greatest change in conductivity was observed in Cell Three and the wetland as a whole. The greatest change in pH was observed in the wetland as a whole. The greatest change in TN concentrations was observed in Cell Five. The greatest change in TP concentrations was observed in the wetland as a whole. The greatest change in chlorophyll-a was observed in the wetland as a whole. The greatest change in TSS was observed in Cell Seven.

Table 16: Conductivity Changes Observed

	Changes Observed (%)
Cell One	-22
Cell Two	-9
Cell Three	27
Cell Four	5
Cell Five	16
Cell Six	0
Cell Seven	3
Whole Wetland	27

Table 17: pH Changes Observed

	Changes Observed (%)
Cell One	1
Cell Two	1
Cell Three	-6
Cell Four	6
Cell Five	-9
Cell Six	-4
Cell Seven	0
Whole Wetland	-19

Table 18: Removal Efficiency of TN

	Removal Efficiency (%)
Cell One	50
Cell Two	-27
Cell Three	74
Cell Four	-7
Cell Five	-98
Cell Six	11
Cell Seven	-79
Whole Wetland	83

Table 19: Removal Efficiency of TP

	Removal Efficiency (%)
Cell One	-29
Cell Two	9
Cell Three	20
Cell Four	17
Cell Five	17
Cell Six	11
Cell Seven	12
Whole Wetland	54

Table 20: Removal Efficiency of Chlorophyll-a

	Removal Efficiency (%)
Cell One	-19
Cell Two	-10
Cell Three	-49
Cell Four	-38
Cell Five	7
Cell Six	-4
Cell Seven	-63
Whole Wetland	-64

Table 21: Removal Efficiency of TSS

	Removal Efficiency (%)
Cell One	46
Cell Two	25
Cell Three	45
Cell Four	-64
Cell Five	19
Cell Six	83
Cell Seven	-467
Whole Wetland	-4

Table 22: Removal Efficiency of BOD

	Removal Efficiency (%)
Whole Wetland	-325

5.3 Box and Whisker Plots

Box and whisker plots are good indicators of distribution shapes and if there are any outliers. They are helpful visual indicators used to gain insights into understanding what the data is revealing. All water parameters monitored showed outliers within their data sets. The differences in quartiles also showed differences among data sets, as well as among each specific wetland. Conductivity showed a general decrease throughout the wetland process, with decreasing amounts of outliers as the data got deeper into the wetland process. PH showed a general increase in basicness throughout the wetland. Outliers were not as significant as other water quality parameters measured. Total nitrogen showed a general decrease throughout the wetland, with greater outliers occurring in the first four cells compared to the last three cells. Total phosphorus also showed a general decrease throughout the wetland. Significant outliers in the first four cells outnumbered those in the last three cells. Chlorophyll-a showed a general linear pattern in its box and whisker plot. Outliers varied throughout the wetland, but there was not any particular shape shown by the data. TSS varied greatly in its visual interpretation through a box and whisker plot. The data were abstract and did not show any type of shape or pattern. Outliers were the greatest for Cell Three Outflow. Box and whisker plots plotted each major water parameter tested in order to show general distributions and any potential outliers, as seen in the color blocks and error bars. These plots are in Figures 21 – 26.

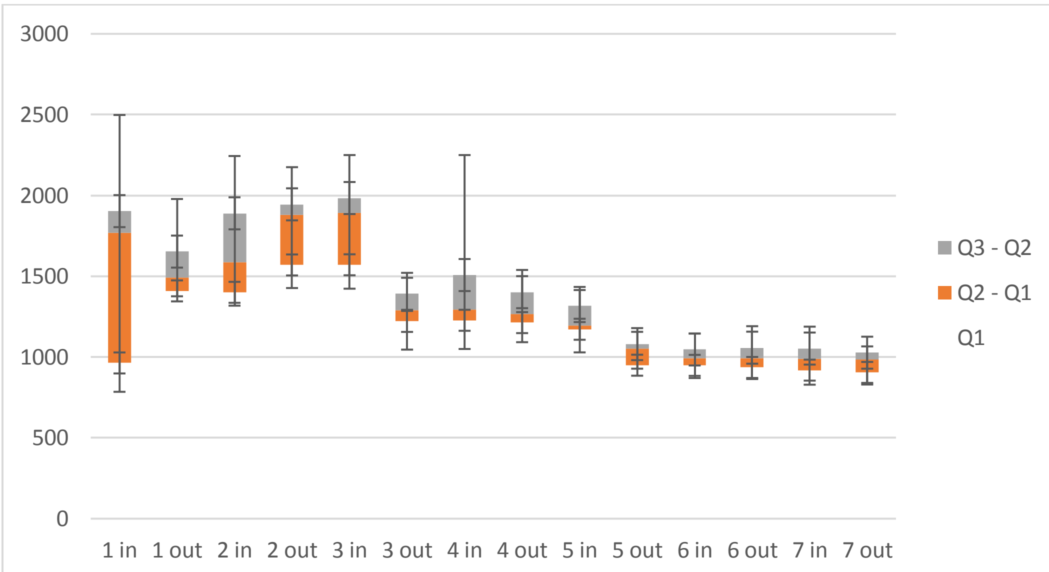

Figure 21: Conductivity Plot (μs/cm)

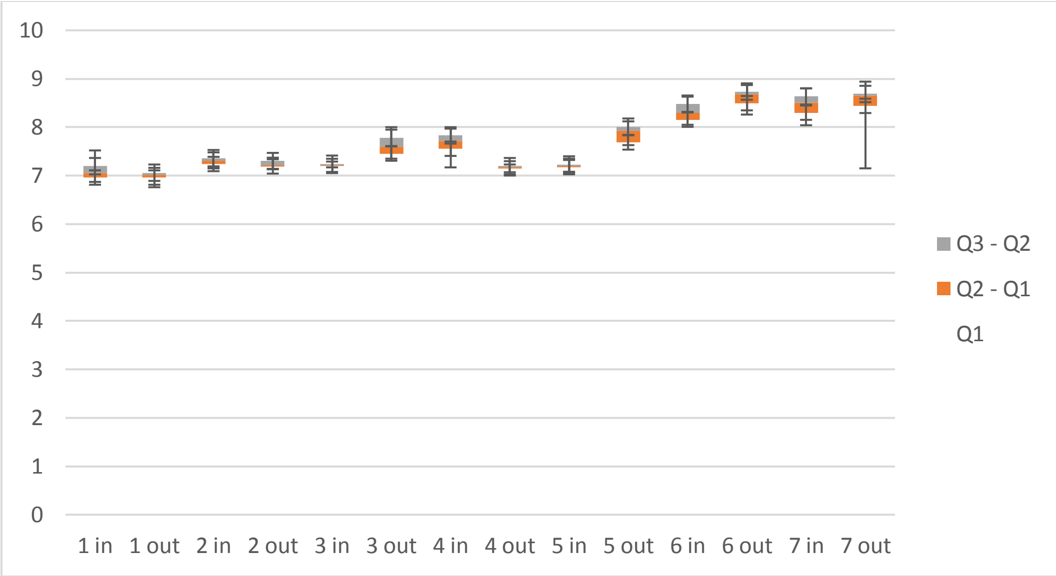

Figure 22: pH Plot

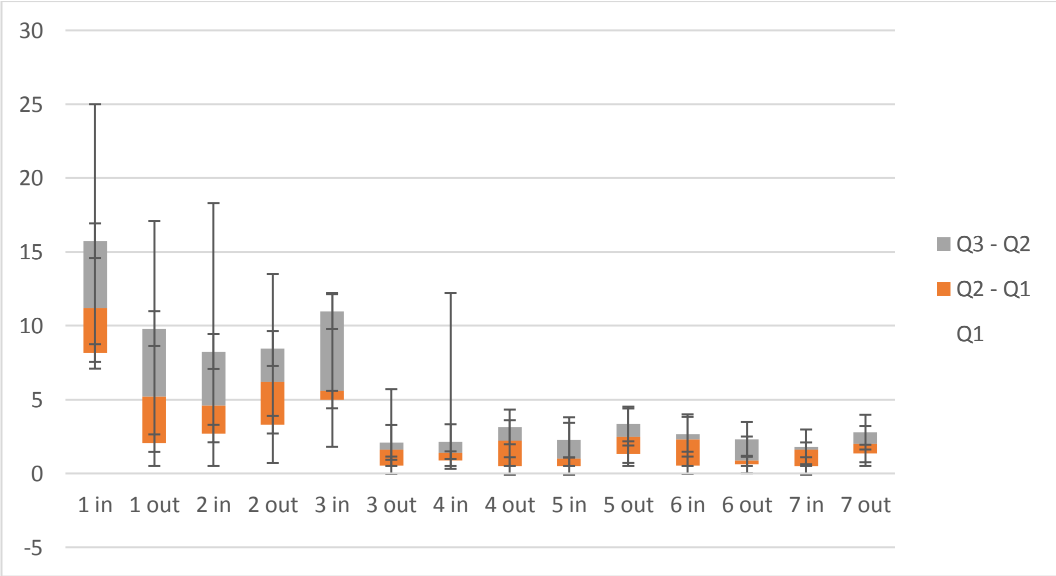

Figure 23: TN Plot (mg/L)

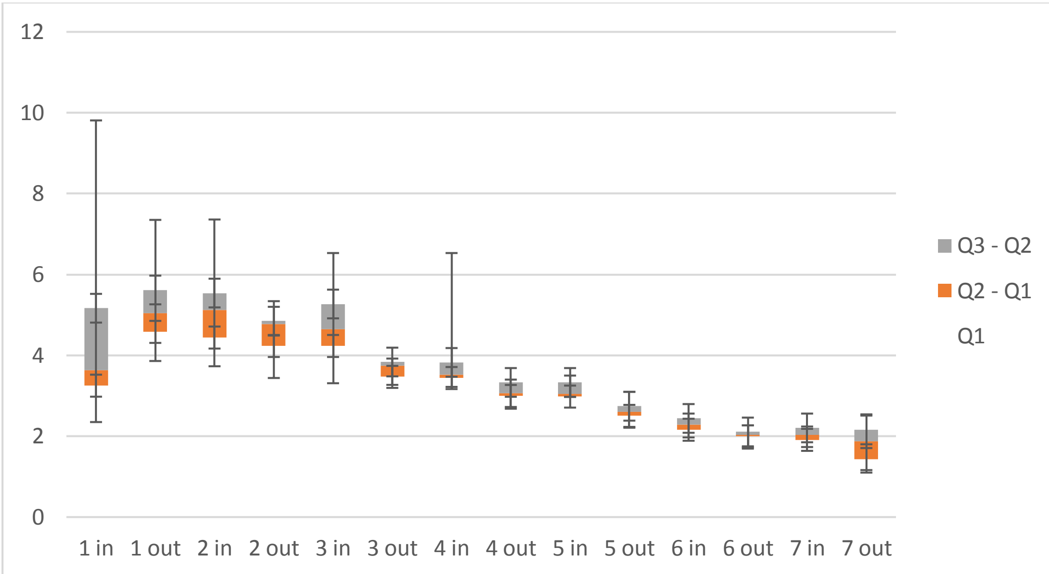

Figure 24: TP Plot (mg/L)

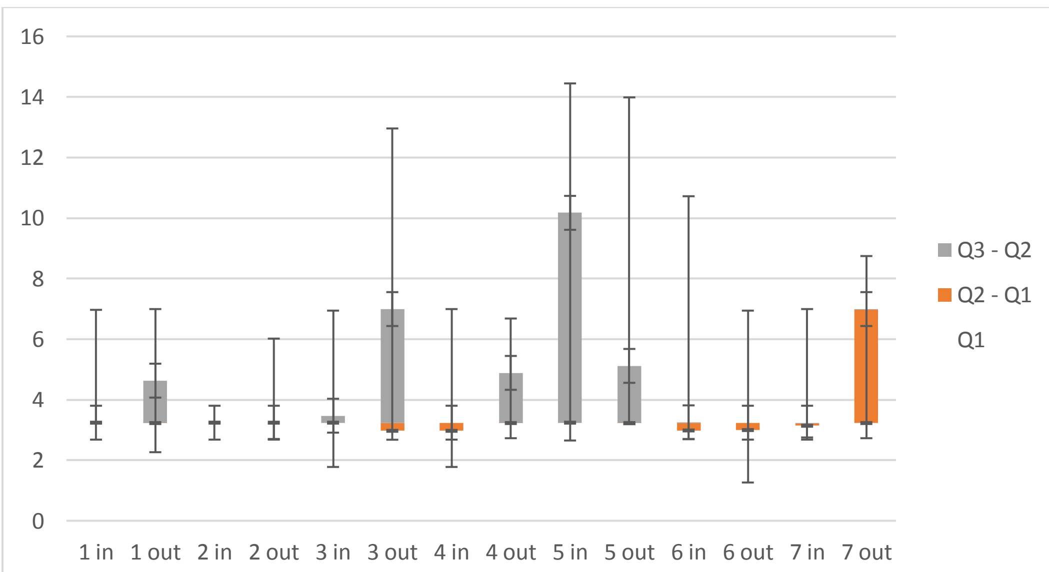

Figure 25: Chlorophyll-a Plot (mg/m^3)

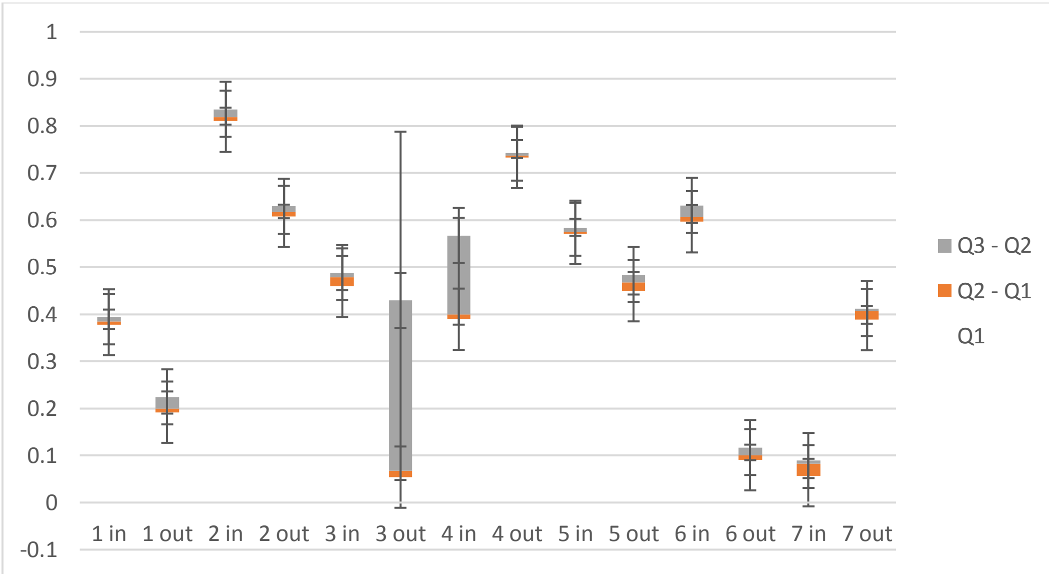

Figure 26: TSS Plot (g/L)

5.4 T-Tests

T-tests compared the data from inflow and outflow points of each cell, using paired parametric tests because of residence times within the wastewater treatment wetland. Two-tailed t-tests are used to determine the possibility of the relationship of the variables from the mean variable to be significantly proportionate in both directions. Two-tailed t-tests are more conservative, with only differences being observed with this data. These were determined for each major water parameter within each individual cell and for the wetland as a whole, as seen in Tables 23 – 30. The null hypothesis states that there is no significant difference between the inflow and outflow water quality parameters for each cell. The acceptance of the hypothesis proves this, while rejecting the hypothesis proves that the parameters are not related from cell to cell.

High p-values signify the acceptance of the null hypothesis with a high probability that the points are related. P-values were highest for conductivity and lowest for TSS in Cell One (Table 23). P-values were highest for TN and lowest for TSS in Cell Two (Table 24). P-values were highest for chlorophyll-a and TSS, and lowest for conductivity and TN in Cell Three (Table 25). P-values were highest for TN and conductivity, and lowest for TSS in Cell Four (Table 26). P-values were highest for chlorophyll-a and lowest for TSS in Cell Five (Table 27). P-values were highest for conductivity and lowest for TSS in Cell Six (Table 28). P-values were highest for pH and lowest for TSS in Cell Seven (Table 29). P-values were highest for chlorophyll-a and TSS, and were lowest for TN and pH within the wetland as a whole (Table 30).

Table 23: Cell One T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	-0.10	0.92	2.45
pH Paired	6	1.16	0.29	2.45
TN Paired	6	3.15	0.02	2.45
TP Paired	6	-0.89	0.41	2.45
Chlorophyll-a Paired	6	-0.25	0.81	2.45
TSS Paired	6	36.71	2.72E-08	2.45

Table 24: Cell Two T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	-1.09	0.32	2.45
pH Paired	6	1.07	0.33	2.45
TN Paired	6	0.13	0.90	2.47
TP Paired	6	1.48	0.19	2.45
Chlorophyll-a Paired	6	-0.76	0.48	2.45
TSS Paired	6	60.94	1.31E-09	2.45

Table 25: Cell Three T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	4.32	0.00	2.45
pH Paired	6	-4.35	0.00	2.45
TN Paired	6	4.30	0.01	2.45
TP Paired	6	2.50	0.05	2.45
Chlorophyll-a Paired	6	-1.50	0.18	2.45
TSS Paired	6	1.63	0.15	2.45

Table 26: Cell Four T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	0.82	0.44	2.45
pH Paired	6	5.70	0.00	2.45
TN Paired	6	0.66	0.53	2.45
TP Paired	6	1.72	0.14	2.45
Chlorophyll-a Paired	6	-0.91	0.40	2.45
TSS Paired	6	-6.90	0.00	2.45

Table 27: Cell Five T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	5.24	0.00	2.45
pH Paired	6	-8.13	0.00	2.45
TN Paired	6	-2.02	0.09	2.45
TP Paired	6	7.19	0.00	2.45
Chlorophyll-a Paired	6	0.92	0.39	2.45
TSS Paired	6	14.49	6.78E-06	2.45

Table 28: Cell Six T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	-0.61	0.56	2.45
pH Paired	6	-2.55	0.04	2.45
TN Paired	6	1.14	0.30	2.45
TP Paired	6	2.70	0.02	2.45
Chlorophyll-a Paired	6	0.56	0.60	2.45
TSS Paired	6	303.78	8.59E-14	2.45

Table 29: Cell Seven T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	1.37	0.22	2.45
pH Paired	6	0.11	0.92	2.45
TN Paired	6	-3.19	0.02	2.45
TP Paired	6	1.53	0.18	2.45
Chlorophyll-a Paired	6	-1.92	0.10	2.45
TSS Paired	6	-93.20	1.03E-10	2.45

Table 30: Whole Wetland T-Tests

	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Conductivity Paired	6	2.39	0.05	2.45
pH Paired	6	-5.51	0.00	2.45
TN Paired	6	4.79	0.00	2.47
TP Paired	6	2.89	0.03	2.45
Chlorophyll-a Paired	6	-1.44	0.20	2.45
TSS Paired	6	-2.77	0.03	2.45

Chapter Six

Discussion

As expected, the wastewater treatment wetland showed efficient removal of excess nutrients and pollutants when studied as a whole. However, each individual cell varied in its ability to remove nutrients and pollutants, with some nutrients and pollutants being better removed than others. Certain nutrients and pollutants were found in increased quantities throughout individual cells, which could be due to many factors, from sediment types, surrounding land uses, animal populations, or a number of other factors (Coleman et al., 2001). The various statistical tests analyzed explain the significance of these removal processes, as discussed below.

6.1 Removal Efficiency

As a whole, the wetland proved to be efficient in the removal of nutrients and pollutants (Verhoeven & Meuleman, 1999). However, not all parameters were efficient, and some were even added back within the individual cells. The variation in conductivity throughout the whole wetland decreased approximately 26.6%. However, Cells One, Two, and Six all added various levels of conductivity back into the system. Cells Three, Four, Five, and Seven all decreased the levels of conductivity, which led to an overall decrease as a whole (Table 16). Cell Three was the best at reducing the amount of conductivity in the water, while Cell One added the most back into the system.

Throughout the wetland became more basic than the water inflowing from the water treatment plant. Levels of pH increased approximately 18.6% from the start to the end of the wetland. Cells One, Two, Four, and Seven all decreased their pH readings while Cells Three, Five, and Six increased their pH readings (Table 17). These cells proved more dominant than the others did, which led to an increased pH reading overall. Cell Five increased its pH reading the most, while Cell Four decreased its pH reading the most significantly (Table 17).

The efficiency of removal of TN varied greatly throughout each individual cell, but as a whole, the wetland was able to decrease its concentration of TN by approximately 83.3%. Cells One, Three, and Six decreased their concentrations individually, while Cells Two, Four, Five, and Seven all increased their concentrations (Table 18). Cell Five had the greatest increase of TN concentrations, at an average of a 98% increase, while Cell Three had the greatest decrease of TN concentrations compared to the other cells. The wetland seems to be especially efficient in removing TN concentrations. Since Cell Three has the greatest residence time, it is not surprising that it was able to remove the greatest concentrations of nitrogen, as Huang et al. (2000) determined this to be an important factor in the removal process for nitrogen.

Since the wetland is a retired clay phosphorus settling area, there are currently no permits in place on the amounts of phosphorus allowed by the FDEP in the wetland (City of Lakeland, 2015). With that in mind, however, the wetland was able to remove approximately 53.7% of TP concentrations as a whole. Cell One was the only cell to add TP concentrations into the system. Cells Two, Three, Four, Five, Six, and Seven all showed decreased concentrations of TP as individual systems (Table 19). Since Cell One was the only cell on average to add TP concentrations back into the system, it had the greatest increase of TP compared to other cells. Cell Three was the most proficient at decreasing TP concentrations when compared to the other cells. The efficiency of TN and TP were not surprising, as outlined by Verhoeven and Meuleman's study (1999), in which concentrations of both parameters were reduced in constructed wetlands by at least fifty percent.

As a whole, the wetland added approximately 63.8% of chlorophyll-a concentrations back into the whole system. Cell Five was the only cell to show a decrease in chlorophyll-a concentrations, thereby making it on average the best at decreasing chlorophyll-a levels. Cells One, Two, Three, Four, Six, and Seven all added chlorophyll-a levels back into the wetland individually (Table 20). On average, Cell Seven added the greatest percentage of chlorophyll-a back into the wetland, almost equaling the percentage of addition of chlorophyll-a into the whole wetland. This was surprising since chlorophyll-a concentrations typically decrease with decreasing concentrations of TN and TP (Huang et al., 2000).

As a whole, the wetland was efficient in removing TSS by approximately 3.6%. Cells One, Two, Three, Five, and Six were all able to decrease their TSS concentrations individually. However, Cells Four and Seven added large amounts of TSS back into their individual cells (Table 21). Cell Seven performed the least efficiently, with an average addition of 467.3% of TSS levels back into the system. This is not completely surprising since TSS is related to turbidity (US EPA, 2006). Cell Seven had approximately 0.3 meters of decreased water readings from the inflow point of the cell to the outflow point of the cell (Tables 14 & 15), which would mean that the water became more turbid as it flowed throughout this specific cell. Cell Six performed the most efficiently compared to the other cells. The wetland as a whole also showed itself to be efficient in adding BOD back into the system as a whole. On average, BOD concentrations increased by approximately 325% (Table 22). The TSS and BOD results were surprising as most studies found that constructed wetlands decreased concentrations of each parameter (Karathanasis et al., 2003; Merlin et al., 2002; Zhang et al., 2015).

TN and TP are major sources of excess nutrient pollution throughout Florida (Carpenter et al., 1998). It is exceptional that the wetland is able to remove those excess concentrations in each respective water parameter. This is most likely due to the various sediment types, vegetation, and microorganisms that find homes throughout the wetland (Vymazal, 2010). As a whole, TSS concentrations decreased, but only by a minute amount. It was surprising how much TSS Cell Seven adds back into the system. After reviewing the individual weekly data, the most significant changes happened during the month of July. It would be beneficial to perform additional research to understand why this happened, and how the cell could better mimic its other cell counterparts. Chlorophyll-a and BOD concentrations increased throughout the wetland as a whole. This is not especially surprising considering the number of organisms found throughout the wetland, especially with the addition of much larger and more numerous organisms in the last few cells of the wetland treatment process.

Although no statistical analyses were performed for temperature and DO readings, it is still important to note the changes observed in these specific parameters throughout the wetland. The average temperature of the treated wastewater coming into the wetland was approximately 31.2°C, while the average temperature of the water once it finished flowing throughout the wetland was approximately 30.6°C. These readings on average showed a 1.9% decrease in temperature for the system as a whole. The average DO of the water coming into the wetland was 6.83 mg/L, while the average DO of water leaving the wetland was 7.32 mg/L. These readings showed an average increase of 7.2% of DO concentrations throughout the wetland as a whole.

6.2 Box and Whisker Plot

The box and whisker plot showed that for the majority of water quality parameters tested, the largest changes occurred between Cells One to Four. Changes still occurred after Cell Four, but they did not appear to be as great or have as much of a difference in shape as the previous cells. With that in mind, Cells One to Four also seemed to have the largest differences and ranges in outliers. While these cells seemed to have a greater change in water quality, they also were more likely to have skewed data. The opposite is true when it comes to pH. The cells with the greatest changes seem to occur at Cell Five and beyond. This is when the wetland's water starts to become more basic, but overall does not have a large change in pH levels. Chlorophyll-a and TSS had the most random shapes and did not seem to have a distinct pattern within the wetland where there was an obvious change compared to the rest of the wetland (Figures 21 – 26).

The figure, tables, and statistical analyses tell an interesting story of the wetland treatment system. There seems to be a change that occurs to the water during the flow throughout Cell Three. When referencing the box and whisker plots, many parameters drastically change between Cells Three and Four. Cell Three is the largest cell (Figure 6) with the longest residence time (Keller & Bays, 2004), so it is not necessarily surprising that drastic changes occur throughout this flow time. Conductivity, TN, and TP change the most within Cell Three. Other than being the largest size and longest residence time, the water within this cell may be coming in contact with groundwater. The treated wastewater coming in contact with groundwater would explain why conductivity has such a drastic drop throughout Cell Three. Groundwater is more pure than the treated wastewater, and therefore does not have as high conductivity readings (approximately 100 μs/cm). The mixing of these waters would lower the conductivity readings throughout the cell. This would also help explain why conductivity is much lower in the last few cells when compared to the first few cells (Figure 21). Groundwater is also more basic than treated wastewater, so the change in pH observed could also be explained by coming in contact with this different type of water. While the change is not as drastic in Cell Three as it is for other cells, this could be a factor in the increasing pH concentrations as the water flows throughout the wetland (Florida Geological Survey, 1992).

From the inflow point of Cell Three to the outflow point of Cell Three, TN levels take a dramatic dip in concentration (Figure 23). Instead of necessarily being due to contact with groundwater, this could be more in part because of the long residence time and the large size of the wetland cell (Lin et al., 2002). This would also most likely explain the large change from the inflow point of Cell Three to the outflow point in Cell Three observed for TP levels (Figure 24).

The variability when it comes to chlorophyll-a and TSS is ever changing from the inflow points of cells to the outflow points of cells. This is especially surprising with such different changes observed from the outflow point of one cell to the inflow point of the adjacent cell. While not much distance is covered in these areas, the changes may be due in part to the changes in vegetation and water levels, as well as the distance the samples were collected to shore (Rundquist et al., 1996; US EPA, 2006; Coleman et al., 2001). These two parameters are more affected by particulate matter found within the water, so these changes may be due in part to this. Since the summer months of Florida are typically rainy months, the runoff from the surrounding wetland may increase the amount of particulates found within the water. The animals found throughout the wetland may also contribute to these changes (Brix, 1997).

6.3 T-Tests

The study used two-tailed t-tests to determine if there were any significant differences between each individual cell sampled and the wetland as a whole. T-tests are good to use with a small sample size that has an unknown variance. Since this research contained small sample sizes, paired t-tests were determined to be beneficial to the understanding of the data. The closer the t-test is to zero, the less of a significant difference there is between the two data sets. In this case, the inflow of a cell versus the outflow of that same cell are being compared, as well as the inflow of Cell One versus the outflow of Cell Seven, representing the wetland as whole. The p-values within the t-tests show whether the null hypothesis should be rejected or accepted, with a confidence level of 0.05. The null hypothesis shows that the two water sampling locations are related.

Each individual cell shows varied statistics in comparison to each water quality parameter tested. Within Cell One, conductivity, TP, and chlorophyll-a all have t-values close to zero. The parameter with the highest t-value is TSS. P-values were highest for conductivity, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 23).

Cell Two shows varied statistics when looking at each individual water quality parameter tested. Conductivity, TN, and chlorophyll-a all also had t-values close to zero, while TSS had the highest t-values. P-values were highest for TN, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 24).

Cell Three was different from the previous two cells. There were not any parameters with t-values below one, but TSS did have the lowest t-values observed, while conductivity, pH, and TN had the highest t-values from zero. P-values were highest for chlorophyll-a and TSS, which means that the data obtained have a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for conductivity and TN, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 25).

Cell Four was similar to the first two cells. The parameters with the lowest t-values were conductivity, TN, and chlorophyll-a, while TSS had the highest t-values. P-values were highest for TN and conductivity, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 26).

Cell Five was unique in that chlorophyll-a had the lowest t-values, while TSS had the highest t-values. P-values were highest for chlorophyll-a, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 27).

Cell Six was similar to Cells One, Two, and Four in that conductivity, TN, and chlorophyll-a had the lowest t-values, while TSS had the highest t-values. P-values were highest for conductivity, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 28).

Cell Seven was unique in that pH had the lowest t-values, while TSS had the highest t-values. P-values were highest for pH, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TSS, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected (Table 29).

When it comes to the wetland as a whole, none of the t-values were close to zero, but the lowest-values were found in chlorophyll-a and TSS parameters. The highest t-values were observed for pH. P-values were highest for chlorophyll-a and TSS, which means that the data obtained has a high probability of occurring based on the null hypothesis that the sample points are related. P-values were the lowest for TN and pH, which means that the data collected showed a low probability of occurring based on the null hypothesis that the sample points were related, which means that this would be rejected.

6.4 Discussion

Statistical analyses highlighted the variability of the wetland from one cell to another. No two cells are alike, whether in relation to size or residence times or flora and fauna present, and this is seen through the various statistical analyses performed (Verhoeven & Meuleman, 1999; Brix, 1997). The greatest changes seem to occur when the water passes through Cell Three. As previously speculated, this could be in fact due to the size of the cell and the possible contact with groundwater experienced. The soil type present and the type of vegetation present are similar to other cells within the wetland, with the only significant difference being the residence time of the water and the acreage of the cell. It takes the longest amount of time for water to flow through this cell, which exposes it to many possible changes throughout its time there (Lin et al., 2002). This study is related to other studies done on wastewater treatment wetlands because it showed the effectiveness of constructed wetlands for treatment of wastewater (Verhoeven & Meuleman, 1999). While it was similar, it is hard to compare this study to other tests because of the specific background of the reclaimed lands used for the wetland by Lakeland. The City of Lakeland does have to follow permitted limits enforced by FDEP, so this study helps to show if the waters stayed within those limits during this specific time period (City of Lakeland, 2015).

Even though the water seems to have the most drastic changes in Cell Three, it appears that all cells are important in the efficiency of the wetland in the removal, or change, of parameters measured. The wetland would not be as efficient if it did not have all cells present and if all cells were not utilized as a whole. Each cell contributes some change, and the qualities do not level off after flowing through a certain part of the wetland. It is beneficial for the City of Lakeland to continue using all parts of the wetland, especially with the use of Cell Three.

Chapter Seven

Conclusion

7.1 Future Recommendations

This research project leaves room for improvements and further investigations in the future regarding to the efficiency of the wastewater treatment wetland. First, since this research took place during the summertime, it would be beneficial to carry this study out throughout the whole year in order to understand the differences Florida's seasons have on water quality. This would most likely impact the results observed. It would also be beneficial to look more closely into the specific parts of the wetland and how they affect water quality. This would include the vegetation, soil makeup, and organisms present. Since these are the significant reasons the wetland is able to treat the wastewater so well, it would be important to better understand the specific implications each trait has when compared with specific water parameters. Since TECO does not currently take all water they are permitted to take, it would be beneficial to do a long-term study on water quality parameters to better understand if the amount of water they are taking has impacts on water quality. While this would not necessarily influence water quality in the initial cells, it might have impacts to the health and ecology of the last cells as more water is taken. Lastly, since the wetland is a retired phosphate clay settling area, it would be beneficial to do a comparison on a similar type of wastewater treatment wetland that does not have the same origins in order to better understand how its previous mining activity might have affected the wetland's efficiency.

7.2 Conclusion

It was determined that the wetland acted as a beneficial resource to the City of Lakeland as an alternative treatment process in order to further enhance water health before it is used by TECO as an environmentally friendly alternative water source. This research provided evidence that the wetland is appropriately treating its waters from start to finish. While some quantities of nutrients were greater at the end of the wetland compared to the inflow water qualities, the wetland remained healthy. The findings of this study are important because they show the abilities of restored phosphate mine systems into wetlands as successful environmental restoration projects. Since not all phosphate mines are required to restore their lands once they retire, this study helps show the promising environmental results that may occur if lands are restored properly to help offset the negative consequences (Brown, 2005). Since no permits are currently in place by the FDEP for regulation of phosphorus within the wetland, it is important to establish how the wetland responds without such limitations that other nutrients face (City of Lakeland, 2015).

While not all findings proved to be significant once statistical analyses were completed, the information obtained still proved to be valuable in understanding the mechanisms behind the wetland treatment system and how seasonality potentially impacts water quality parameters. These findings were especially important considering the size and makeup of the wetland compared with traditional wetland treatment systems. While the system could be considered a FWS wetland, it does not encompass the traditional makeup of ones often-studied (Vymazal, 2010). With the utilization of channels and lake-like cells, the various types of cells prove to work cohesively together to reach the common goal of treating the wastewater. Vegetation also proves to be a beneficial tool to the wetland's treatment process. The presence of predominately cattails and Carolina willows influences the uptake of nutrients throughout the wetland. Vegetation have shown to be a valuable asset to wastewater treatment wetlands throughout numerous studies when compared to wetland treatment systems that have monoculture varieties of vegetation present (Brix, 1997; Coleman et al., 2001; Karathanseis et al., 2003).

The working hypothesis was acknowledged throughout the research, even though not all of the parameters were proven efficient. It was proven that the wetland treatment system was efficient in removing certain nutrients and pollutants, but not as efficient at removing others. As a whole, the wetland became more basic from start to end, and added back various concentrations of chlorophyll-a, TSS, and BOD. The wetland also reduced its conductivity, and concentrations of TN, and TP as a whole. However, it did not seem as if one wetland type had a more significant impact on water quality as a whole compared to the other wetland types. All cells varied in their efficiencies dependent on the type of parameter observed. With that in mind, the cells seemed to all work harmoniously with each other throughout the wetland, with positive impacts from each of their unique traits.

This study is important for all parties involved in the successful running and maintenance of the wetland. In regards to the summer months, it shows the strengths and weaknesses throughout the wetland in treating its waters. This is important for the FDEP, City of Lakeland, City of Mulberry, and TECO. Not only is this study beneficial to these listed parties, it also acts as a good example for the encouraged growth and development of other wastewater treatment wetlands. With so many different design options available, it is important to show the benefits of all types in order to help determine which type would be best for new development. There is not a one size fits all mentality when it comes to these wetlands, so the more understanding we have of the different types, the better we can help restoration acts and the environment. Restored mined areas are used by municipalities, and they can further promote sustainability through companies reusing treated wastewater for various purposes instead of pulling fresh groundwater out of the aquifer. Sustainability is especially important going into the future in order to preserve water supplies for coming generations. The City of Lakeland's wastewater treatment wetland and its cells promote health and sustainability of water supplies with proper monitoring and upkeep standards going into the future.

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Appendices

Appendix A: Cell One Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (µs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30	113	8.43	1767	7.18	N/A	9.1	3.63	3.24	0.41	N/A
20-Jun	30.2	93.3	6.93	1985	7.06	N/A	17.2	3.26	3.24	0.40	N/A
5-Jul	30.7	92.2	6.95	920	7.52	N/A	7.2	2.35	6.97	0.39	N/A
18-Jul	33.2	76.5	5.42	2498	6.89	N/A	25	9.81	3.24	0.38	N/A
1-Aug	32	105	7.62	1821	7.03	N/A	14.3	4.81	3.24	0.37	N/A
15-Aug	31.4	78.1	5.73	1007	6.87	N/A	11.2	5.52	3.24	0.37	N/A
30-Aug	31.2	76.4	6.7	785	7.21	N/A	7.1	3.24	3.24	0.39	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (µs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	27.1	122	9.62	1376	6.76	N/A	0.5	5.69	6.99	0.23	1
20-Jun	26.4	57	4.34	1385	7.05	N/A	1.5	4.23	3.24	0.22	N/A
5-Jul	28.9	48.6	3.74	1492	7	N/A	2.6	5.04	2.26	0.24	N/A
18-Jul	28.8	1037	80.23	1501	6.92	N/A	17.1	7.35	3.24	0.19	1
1-Aug	28.7	1479	113.18	1978	7.07	N/A	7.4	5.54	3.24	0.20	1
15-Aug	28.7	11	0.8	1434	7.02	N/A	12.2	4.93	3.21	0.19	1
30-Aug	28.6	3.7	0.28	1804	7.16	N/A	5.2	3.86	6.02	0.19	1

Appendix B: Cell Two Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	27.7	120	9.32	1318	7.22	N/A	under 0.5	5.65	3.26	0.83	N/A
20-Jun	26.1	74.6	6.05	1372	7.48	N/A	2.7	4.06	3.24	0.84	N/A
5-Jul	28.6	73.8	5.71	1585	7.41	N/A	2.7	5.13	3.24	0.84	N/A
18-Jul	29	1031	79.33	2244	7.15	N/A	18.3	7.36	3.24	0.82	N/A
1-Aug	28.8	1470	112.6	1978	7.31	N/A	6.9	5.43	3.24	0.81	N/A
15-Aug	28.9	64.7	4.95	1429	7.26	N/A	9.6	4.82	3.24	0.80	N/A
30-Aug	28.7	59.5	4.54	1801	7.31	N/A	4.6	3.73	3.24	0.81	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	27.1	122	9.61	1427	7.19	N/A	0.7	3.96	3.24	0.63	1
20-Jun	24.6	41.7	3.48	1612	7.14	N/A	8.4	3.44	3.24	0.63	N/A
5-Jul	26.8	54.5	4.32	2175	7.19	N/A	6.2	4.80	2.70	0.63	N/A
18-Jul	26.4	42.8	3.38	1960	7.21	N/A	13.5	4.89	3.24	0.61	1
1-Aug	26	1560	127.45	1881	7.37	N/A	8.5	5.34	3.24	0.60	1
15-Aug	27.2	19.4	1.52	1528	7.26	N/A	5.4	4.50	3.24	0.61	1
30-Aug	26.6	25.2	1.96	1930	7.34	N/A	1.2	4.78	6.02	0.62	1

Appendix C: Cell Three Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (µs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	27.3	121	9.48	1423	7.21	N/A	1.80	4.12	3.24	0.48	N/A
20-Jun	24.9	53.2	4.45	1611	7.22	N/A	11.00	3.31	3.24	0.50	N/A
5-Jul	26.6	56.6	4.54	2250	7.17	N/A	12.20	6.53	1.78	0.54	N/A
18-Jul	26.5	1071	88.72	2035	7.19	N/A	10.90	5.33	3.24	0.45	N/A
1-Aug	26	1150	85.89	1892	7.29	N/A	5.10	5.21	3.24	0.46	N/A
15-Aug	27.3	28	2.2	1531	7.21	N/A	5.60	4.34	6.94	0.46	N/A
30-Aug	28.4	27	2.16	1933	7.27	N/A	4.90	4.65	3.70	0.48	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (µs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30.4	114	8.29	1301	8.00	N/A	under 0.5	3.51	3.19	0.77	3
20-Jun	27.9	35.2	2.82	1046	7.43	N/A	1.60	3.92	3.24	0.79	N/A
5-Jul	30.6	45.1	3.37	1264	7.35	N/A	5.70	3.42	2.75	0.09	N/A
18-Jul	30.2	998	75.49	1177	7.87	N/A	0.60	3.27	3.24	0.05	3
1-Aug	30.1	1234	93.46	1482	7.48	N/A	1.90	3.79	10.74	0.05	2
15-Aug	29.1	39	2.97	1289	7.69	N/A	2.30	3.88	12.96	0.06	1
30-Aug	28.4	26.1	2.01	1521	7.60	N/A	under 0.5	3.74	2.68	0.07	1

Appendix D: Cell Four Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30.5	111	8.22	1292	7.84	N/A	under 0.5	3.42	3.19	0.61	N/A
20-Jun	28.4	65.9	5.34	1050	7.82	N/A	2.30	3.46	6.99	0.60	N/A
5-Jul	26.6	56.6	4.54	2250	7.17	N/A	12.20	6.53	1.78	0.54	N/A
18-Jul	30.4	992	74.79	1177	7.97	N/A	1.30	3.22	3.24	0.40	N/A
1-Aug	30.3	1411	105.51	1496	7.55	N/A	2.00	3.75	3.24	0.38	N/A
15-Aug	29.3	45.4	3.44	1278	7.71	N/A	1.40	3.90	2.75	0.38	N/A
30-Aug	28.7	30.7	2.34	1519	7.56	N/A	under 0.5	3.53	3.24	0.40	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30		6.34	1539	7.19	N/A	under 0.5	3.06	3.24	0.73	N/A
20-Jun	29.5		4.62	1265	7.23	N/A	3.40	3.27	6.68	0.73	N/A
5-Jul	29.7	42.1	3.18	1204	7.07	N/A	2.90	2.68	6.53	0.77	N/A
18-Jul	29.7	1011	77.09	1092	7.15	N/A	under 0.5	2.97	3.24	0.74	3
1-Aug	29.3	1385	105.19	1400	7.17	N/A	3.60	3.39	3.24	0.73	1
15-Aug	28.5	8.6	0.65	1222	7.2	N/A	2.20	3.40	3.21	0.74	2
30-Aug	28.8	10.2	0.77	1403	7.15	N/A	under 0.5	3.02	2.73	0.75	2

Appendix E: Cell Five Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	28.7		7.77	1286	7.15	N/A	under 0.5	2.98	3.24	0.57	N/A
20-Jun	28.9		3.54	1187	7.2	N/A	1.70	3.37	6.33	0.58	N/A
5-Jul	31.8	71.9	5.44	1196	7.08	N/A	3.80	2.98	14.01	0.59	N/A
18-Jul	29.4	1019	78.2	1029	7.2	N/A	under 0.5	2.97	3.24	0.57	N/A
1-Aug	29.5	1441	109.38	1345	7.25	N/A	2.80	3.50	14.45	0.58	N/A
15-Aug	28.6	13.7	1.05	1157	7.21	N/A	1.00	3.29	2.65	0.57	N/A
30-Aug	28.7	35.9	2.70	1434	7.35	N/A	under 0.5	3.04	3.24	0.60	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	28.9	116	8.86	1156	7.64	N/A	under 0.5	2.45	3.19	0.49	7
20-Jun	29.1	52.1	3.99	967	7.73	N/A	2.50	3.10	6.99	0.48	N/A
5-Jul	31.8	80.9	6.06	1094	8.12	N/A	4.40	2.60	3.24	0.49	N/A
18-Jul	31.5	964	71.35	928	7.93	N/A	1.70	2.21	3.24	0.45	4
1-Aug	31.8	1356	98.92	1066	8.06	N/A	2.60	2.68	13.98	0.45	2
15-Aug	29.8	31.3	2.44	932	7.63	N/A	4.10	2.80	3.21	0.44	3
30-Aug	29.6	31.3	2.44	1051	7.96	N/A	0.90	2.56	3.24	0.47	4

Appendix F: Cell Six Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi, m)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30.9	110	8.08	1145	8.30	0.56	under 0.5	2.15	3.26	0.63	N/A
20-Jun	29.7	69.8	5.78	992	8.52	0.56	2.90	2.56	3.24	0.63	N/A
5-Jul	31.9	63.7	4.68	1059	8.05	0.73	4.00	2.50	3.24	0.63	N/A
18-Jul	31.8	954	70.18	922	8.08	0.85	0.60	2.17	3.24	0.60	N/A
1-Aug	31.9	1352	98.53	1035	8.63	0.83	2.40	1.97	10.72	0.60	N/A
15-Aug	30.2	47.2	3.52	870	8.23	0.76	2.30	2.29	2.70	0.59	N/A
30-Aug	31.9	92	6.60	975	8.45	0.79	under 0.5	2.38	2.73	0.61	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi, m)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30.6	111	8.22	1191	8.87	0.55	under 0.5	1.69	1.26	0.12	6
20-Jun	29.5	64.7	5.01	992	8.46	0.55	2.50	2.09	3.24	0.12	N/A
5-Jul	32	111	8.05	1084	8.77	0.81	0.90	1.96	3.24	0.12	N/A
18-Jul	31.8	956	70.42	913	8.53	0.84	0.70	2.03	3.24	0.09	4
1-Aug	31.6	1363	99.81	1032	8.70	0.81	2.20	2.04	3.24	0.09	4
15-Aug	30	51.3	3.8	864	8.26	0.88	2.40	2.12	6.94	0.09	4
30-Aug	31.9	103	7.3	958	8.68	0.87	under 0.5	2.27	2.75	0.10	4

Appendix G: Cell Seven Data

IN	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi, m)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	30.1	112	8.41	1188	8.80	0.61	under 0.5	1.73	2.75	0.09	N/A
20-Jun	29.4	82.7	6.37	990	8.37	0.61	1.60	2.21	6.99	0.09	N/A
5-Jul	31.8	89.4	6.66	1080	8.73	0.49	2.00	1.91	3.24	0.09	N/A
18-Jul	31.9	953	70.15	913	8.50	1.11	0.50	2.04	3.14	0.06	N/A
1-Aug	31.4	1370	100.66	1025	8.54	0.91	2.10	1.91	3.14	0.05	N/A
15-Aug	29.7	38.5	3.20	829	8.04	0.55	1.60	2.24	3.21	0.05	N/A
30-Aug	31.6	87.1	6.32	925	8.23	0.68	under 0.5	2.20	3.24	0.08	N/A

OUT	temperature (°C)	% DO	DO (mg/L)	conductivity (μs/cm)	pH	water clarity (secchi, m)	TN (mg/L)	TP (mg/L)	chlorophyll-a (mg/m^3)	TSS (g/L)	BOD (mg/L)
6-Jun	28.6	117	8.99	1032	7.15	0.29	under 0.5	1.10	8.74	0.41	N/A
20-Jun	29.6	62.2	4.76	985	8.65	0.29	3.10	1.87	6.99	0.41	N/A
5-Jul	31.1	74.1	5.57	1066	8.68	0.40	2.50	1.40	3.21	0.42	N/A
18-Jul	31.6	961	70.80	906	8.69	0.73	2.00	1.47	3.24	0.38	4
1-Aug	31.4	1369	100.70	1022	8.64	0.59	3.20	2.02	6.99	0.39	5
15-Aug	29.9	52.8	3.89	830	8.24	0.52	1.90	2.29	6.97	0.39	4
30-Aug	32.2	154	10.91	904	8.94	0.50	0.80	2.54	2.73	0.42	4

Appendix H: Permission to use Lakeland Data

7/20/2017 Gmail - Questions

Gmail Molly Klinepeter <mklinepeter58@gmail.com>

Questions

7 messages

Molly Klinepeter <mklinepeter58@gmail.com> Mon, Feb 6, 2017 at 9:07 AM
To: "Anderson, Bill" <[redacted]>

Hi Bill,

[redacted]

2) I was hoping to use a few maps from documents you've given me during my internships of the wetland and wanted to ask if I had permission to use them? They would be sourced appropriately.

[redacted]

Thank you,
Molly Klinepeter

Anderson, Bi[redacted] Mon, Feb 6, 2017 at 9:55 AM
To: Molly Klinepeter <mklinepeter58@gmail.com>

Molly,

[redacted]

2) Yes, you can use any maps. If you need any more, just let me know and I'll see what I can find.

[redacted]

https://mail.google.com/mail/u/0/?ui=2&ik=dfd2dc0133&jsver=VK6E92h7KU4.en.&view=pt&q=Bill.Anderson%40lakelandgov.net&qs=true&search=que... 1/4

Appendix I: Permission to Use Bone Valley Image

Gmail

Molly Klinepeter <mklinepeter58@gmail.com>

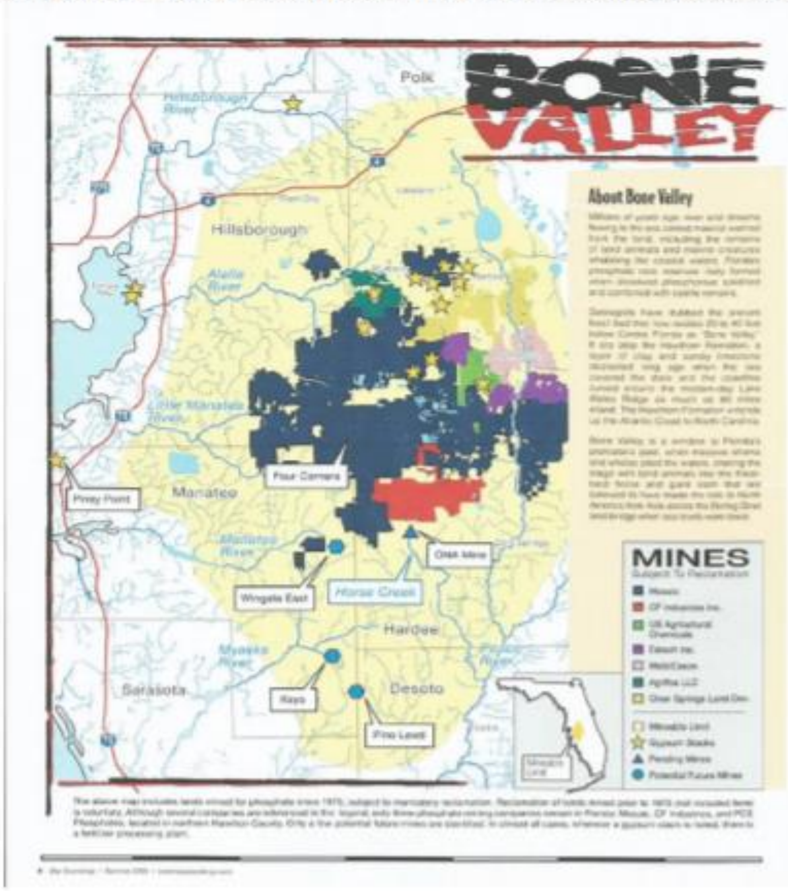
Permission to use picture

3 messages

Molly Klinepeter <mklinepeter58@gmail.com> Thu, Jul 20, 2017 at 6:30 PM
To: editor@baysoundings.com

To whom it may concern,

I am currently working on my thesis project for graduate school at USF and I was wondering if I had permission to use your picture of the Bone Valley region in my thesis manuscript? It would be cited appropriately.



Thank you,
Molly Klinepeter

Vicki Parsons <editor@baysoundings.com> Fri, Jul 21, 2017 at 4:26 AM
Reply-To: editor@baysoundings.com
To: Molly Klinepeter <mklinepeter58@gmail.com>

Please help yourself, and I'd love to see a copy of the thesis when you finish it.

Vicki Parsons
editor@baysoundings.com