Armand Bayou Water Quality Improvement Grant: UHCL Created Stormwater Treatment Wetland

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Executive Summary

By all measures the UHCL created wetland has been an overwhelming success. Although we were only able to collect a small suite of indicator variables due to the limited budget for monitoring, the results to date suggest that the system which includes the various wetland cells and associated retention pond are very effective for the removal of phosphorus and indicator bacteria depending on flow regime and bank stability. As the wetland continues to mature, additional plant growth will stabilize bottom sediments. In addition, more extensive plant growth will lead to increase nitrogen and phosphorus removal. In addition, the “pre-polishing’ effect of the wetland has likely lead to the reduction in eutrophic conditions (e.g. algal mats) in Alligator Pond and the receiving water body, Horsepen Bayou. The water which discharges from Alligator Pond to Horsepen Bayou is now cleaner due to in-situ biological and mechanical treatment of the discharge water.

Our limited data suggest that after construction of the wetlands the levels of phosphorus and indicator bacteria have declined leading to reduced frequency of algal blooms which the overall level of dissolved oxygen increased. Supplementary studies utilizing controlled water releases of golf course irrigation water from the Clear Lake City Water Authority treatment facility provided us with an ideal controlled source of pollutants (nutrients) to examine the efficacy of the wetland treatment system. Using estimated time of travel data we were able to track a “slug” of water to evaluate nutrient removal. We observed a clear decreasing spatial trend in nutrient levels extending from upstream to downstream, when the only source of water was the wastewater irrigation system. Decreases in nutrient concentrations were observed and in some cases by three orders of magnitude. Supporting sediment nitrogen and phosphorus data indicated that nitrogen levels generally declined through time, but phosphorus levels increased suggesting that the wetland was sequestering phosphorus into the sediment under anoxic surface water conditions. This pattern was consistent with the general decline in phosphorus levels within the water column as discussed earlier.

Enterococci and *E. coli* bacteria showed significant declines in density during dry weather sampling at the Alligator pond following construction of the wetland. This patter did not occur during all wet weather events. The wetland was effective in reducing levels from 100-880 MPN/100 ml down to less than 50 MPN/100 of *E. col*i and/or Enterococci indicator bacteria.

Part of our project included the evaluation of a solar powered intake pump to irrigate our wetland during low rainfall periods or to supplement runoff. Unfortunately this approach did not appear to be logistically feasible in the long term due to the natural salinity of Horsepen Bayou and the tendency for the intake to become clogged by floating vegetation. We did consider the feasibility of using more salt tolerant plants. However, during many periods the conductivity would be so low as to eventually lead to the establishment of a predominantly freshwater system. The bottom line is it is much easier to maintain a freshwater system given the local meteorology and hydrology then an estuarine wetland. However, based on this pilot feasibility study, the use of solar power to provide energy necessary to pump water and provide tertiary water quality treatment would be feasible in more favorable freshwater systems. Using a solar pump and created wetland complex to provide tertiary water quality treatment would be feasible in smaller freshwater streams. The greatest utility of the solar pump system would be in the treatment of freshwater where perched wetlands can only be built along the river banks and no other option is available. We would also recommend the incorporation of a screen to remove large debris and careful design of the streambank to reduce obstruction of the intake line. In addition, the inclusion of storage batteries to prolong operation during evening hours and overcast days would be useful. Other automated systems using wind power to generate electricity for battery storage should also be explored.

The plant community in the wetland established itself rapidly. Both species composition and richness changed pre and post construction, with a total of 41 species observed during pre-construction sampling, and a total of 122 species observed one year post construction. A total of 113 of the 122 species of plants observed one year post construction, naturally recruited to the site. The wetland site has attracted numerous terrestrial and aquatic wildlife species. It is also utilized by students and faculty of classes and as a rest stop during the day. Over 1000 individuals have been documented visiting the site and more than 300 students have used the wetland as a natural classroom. The wetland complex will continue to serve as a multifunction asset to the University of Houston Clear Lake campus providing water quality improvement, wildlife habitat, aesthetically pleasing areas to rest and a unique teaching and research tool.

Based on data collected during this study we conclude that the construction of wetlands similar to the design used in this project that are associated with detention basins or borrow pits are a viable option in many urban watersheds along the Gulf coast. The design of the primarily surface flow treatment wetland is both practical, provides effective treatment for common pollutants (e.g. bacteria, sediment, nutrients), is cost effective and aesthetically pleasing. Very often these urban waterways in Texas have been channelized and are separated from the riparian zone by elevated berms and levees. The primary connection with them is through below ground overflow drains. However, the remaining oxbows and man-made depressions provide an ideal location for construction of an intercept surface flow wetland. This type of wetland represents best management practices for construction of riparian wetlands in heavily developed urban areas within the Galveston Bay watershed. The promotion of this technology will both reduce pollutant loading and provide additional green space and natural surroundings in an urban landscape and also expand habitat for fish and wildlife. Improvements in water quality would occur with the wider adoption of these types of constructed wetlands by large landowners and as neighborhood/subdivision projects. Schools, universities, and regional parks are also excellent sites that provide opportunities for educational outreach.

INTRODUCTION

Problem Statement

The Galveston Bay Estuary is a unique and productive biological system that is located in Southeast Texas adjacent to the Houston Galveston metropolis. The shores of the estuary are bordered by urban, industrial and agricultural land uses (Lester and Gonzalez 2011) (HCFCD 2013). Bay waters support productive commercial and recreational fishing industries, industrial and municipal water uses, shipping, and recreational activities. The health of bay resources depends upon suitable habitat including riparian habitat and the associated functions including water quality improvement.

The Armand Bayou watershed is situated in the 4,238 square-mile Lower Galveston Bay watershed. Armand Bayou is listed as impaired in the 2012 Texas Integrated Report 303(d) List (TCEQ 2013) due to elevated levels of bacteria and depressed levels of dissolved oxygen. The bayou is currently being evaluated to determine if a bacteria total maximum daily load (TMDL) is warranted from an initial listing in 1998 (HGAC 2013). A dissolved oxygen study was initiated in 1998 following an impairment listing in 1996, but it could not be determined (based on the data collected and watershed modeling) if the suppressed dissolved oxygen was from pollutant loadings or a naturally occurring hydrologic problem.

The Armand Bayou water quality improvement grant project was developed to attempt to address these identified problems by implementing two structural best management practices (BMPs) and by enhancing the function of these habitats by creating additional riparian wetland habitat that will serve several purposes, including water quality improvement, providing critical habitat for fish and wildlife and providing a long term educational and research tool for UHCL.

Study Objective

The goal of the Armand Bayou water quality improvement project is to construct a riparian wetland on the campus of the University of Houston-Clear Lake (UHCL) that will provide:

1) Water quality treatment for runoff from the campus prior to discharge into the Horsepen Bayou, a major tributary of Armand Bayou,
2) A pilot scale demonstration project to evaluate the feasibility of the use of solar powered pump systems to enhance water quality in Horsepen Bayou,
3) High quality wetland habitat for wildlife that can be maintained during drought periods.

The project took place adjacent to Horsepen Bayou, a major tributary of the Armand Bayou Watershed (59 square miles), located in southeast Harris County, Texas. Armand Bayou watershed covers about 60 square miles (HCFCD 2013) (Figure 1). Current consumptive and non-consumptive uses in the Armand Bayou Watershed include residential, commercial, and industrial land development; oil and gas production; and recreational uses such as fishing, nature viewing, canoeing, and kayaking. The Armand Bayou Watershed is heavily urbanized and multi-jurisdictional, including portions of the cities of Houston, Pasadena, Deer Park, La Porte, and Taylor Lake Village (HCFCD 2013). The watershed’s intense suburban development and its many human uses serve as major stressors for the Watershed. Horsepen Bayou is composed primarily suburban neighborhoods with mixed light industrial use. Armand Bayou is currently listed as impaired due to elevated levels of bacteria and suppressed levels of dissolved oxygen. The bayou is currently being evaluated to determine if a bacteria TMDL is warranted from the initial listing in 1998.

To address these identified problems, this project used two structural best management practices (BMPs): 1) a constructed wetland to treat stormwater runoff from part of the UHCL campus, and 2) a feasibility study of a solar water pump wetland system that will be used to treat water withdrawn from an impaired water body. The construction of treatment wetlands on property owned by UHCL was designed to improve water quality due to impairments from elevated bacteria and decreased dissolved oxygen concentrations in Horsepen Bayou. Runoff from approximately 21.5 acres of university property (including heavily used parking lots, roads and university buildings) was routed through a newly constructed wetland. The primary focus of these treatment wetlands was on removal of nutrients and bacteria before entry into Horsepen Bayou.

The second structural BMP, a solar powered pump, was a feasibility study to determine the effectiveness of improving the quality of water entering Horsepen Bayou. A solar pump was used to pump water from Horsepen Bayou (drawn upstream of the treatment wetland) through the wetland prior to returning to the bayou downstream. This second system was considered an experimental pilot scale structure and was also intended as a system to reduce the probability that the wetland would dry up during drought periods.

Prior to construction, the original pond was fairly deep, extending down to approximately 8 feet in the center, with steeply sloping sides. Consequently, there was little habitat for wading birds, shoreline fishes, and emergent vegetation. Past unpublished surveys by the principal investigator of this study have shown that fish populations are limited due to low amounts of habitat and cover in the pond. Additionally, primary productivity was limited to floating algae and phytoplankton, reducing the potential levels of dissolved oxygen within the habitat. In addition to treating stormwater runoff and ambient water, this treatment wetland system provides additional habitat for native plants, fish and wildlife, including, wading birds, amphibians, freshwater fish, macroinvertebrates, and aquatic reptiles.

EIH at UHCL, over a 4 year phased period, designed, constructed, and evaluated the effectiveness of a new demonstration wetland treatment system on the campus of UHCL. Critical steps in this project included wetland design, permitting, construction, monitoring and applied research. The monitoring and research was conducted over a 4 year period to document anticipated improvements in effluent water quality due to the wetland treatment system as it discharges into Horsepen Bayou. The primary project water quality goal was to reduce influent concentrations of pollutants, including nutrients, indicator bacteria, and suspended sediments. Statistical analyses were used to estimate loading rates and wetland treatment efficiency.

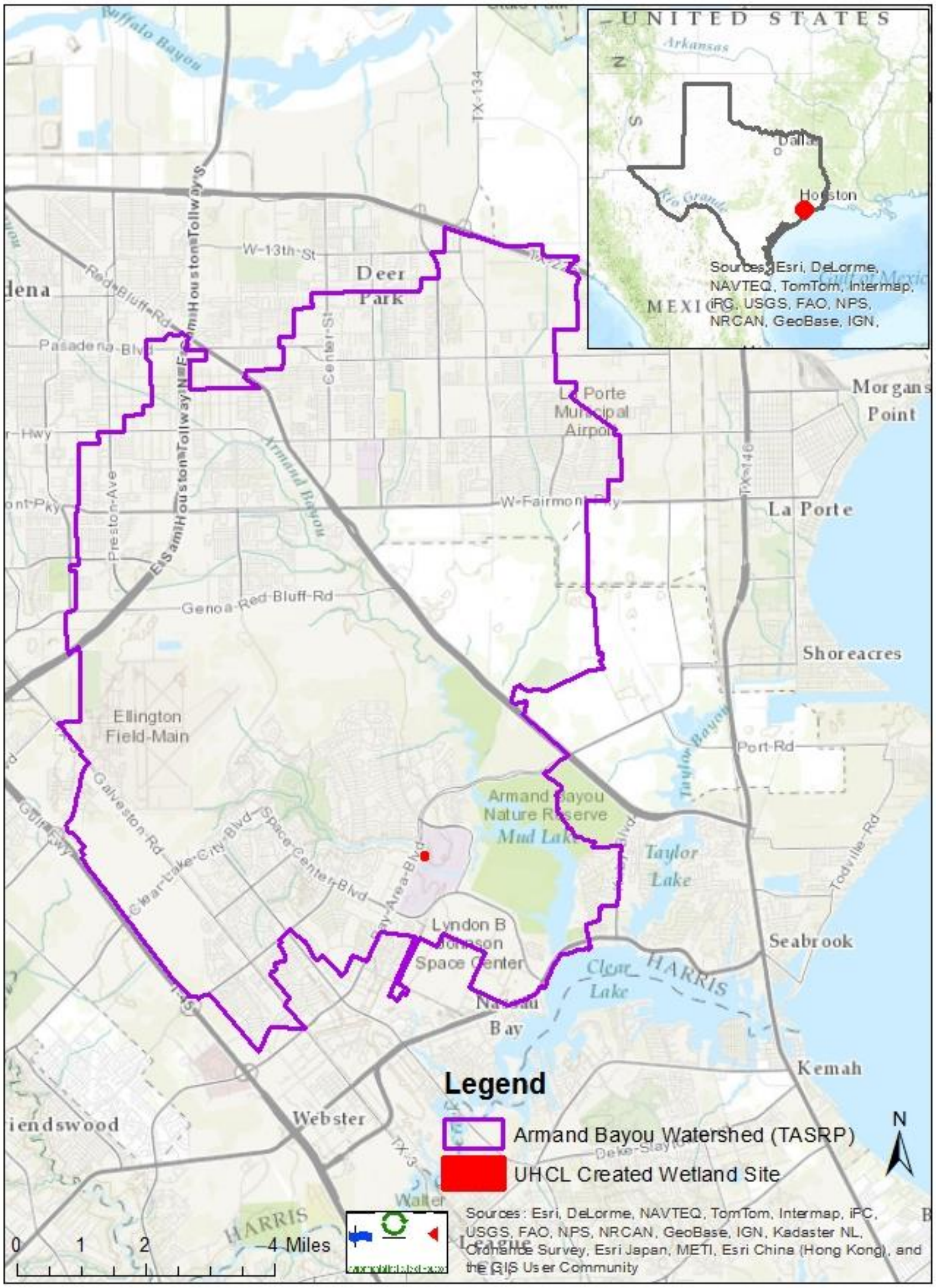

Figure 1. Armand Bayou Watershed (watershed data from the Tropical Storm Allison Recovery Program), showing the location of the UHCL created wetland site.

Wetland Construction

One of the central guiding principles of our project was to design a project that was self sustaining that worked with natural hydrological gradients and the existing landscape (Marble 1992). We wanted to utilize the natural functions of wetlands that help reduce water pollution including mechanical removal, biochemical processes and biological treatment (Kadlec and Wallace 2009). EIH subcontracted with KBA EnviroScience, Ltd. (KBA) to design, assist in permitting, engineer and construct the treatment wetland system. Dr. Margaret Forbes was the lead scientist representing KBA who worked closely with EIH during the design phase. Pre-construction, the site consisted of a single retention pond named Alligator Pond, that was most likely the result of a borrow pit that expanded on an existing abandoned oxbow when the university was constructed. Leading to the pond were grass-lined ditches that were mowed and maintained and only held water immediately after a rain event. Alligator Pond possesses a standpipe which regulated water flow out of the pond and into Horsepen Bayou. Based on historical imagery the project site and adjoining area consisted of forested riparian habitat, stream meanders and possibly oxbow lakes (Figure 2). In recent years, the landscape has been highly modified (Figure 3 and 4). During the 1940's and 1950's federal funding was provided to the Harris County Flood Control District (HCFCD) to conduct various flood control projects. These projects involved channelization of bayous which resulted in deeper, straighter streams (Sipes and Zeve 2012). This resulted in a reduction in instream and riparian vegetation and connectivity to oxbow lakes and associated wetlands.

The site was designed to increase the retention time of stormwater. An additional 0.56 acres of wetland was created and 0.25 acres of the original borrow pond (Alligator Pond) and drainage ditches were modified. The design incorporated a flow pattern where stormwater enters the wetland treatment system at point (A) in Figure 5. It travels through the primary wetland and under Bayou Blvd. There it mixes with water from Horsepen Bayou, which is pumped into the system using solar energy (B). The water flows through the secondary wetland and eventually discharges over a weir (C) into Alligator Pond (D). The treated water flows from Alligator Pond into Horsepen Bayou through an overflow underground pipe (E). Stormwater runoff from precipitation is the primary source of water to the created wetland complex, which can be augmented manually by the lawn irrigation system at the UHCL campus.

The final engineered created wetland involved excavating a pool-run complex out of the previously grass-lined ditch, and the upland area located to the east of the pre-existing Alligator Pond (Figure 5). The excavated dirt was used to fill the deepest parts of Alligator Pond, creating lesser sloped banks and reducing the overall depth of the pond. This increased the potential for vegetative growth (which now serves as new habitat) whereas, before construction, it could not grow due to the deep, steep banks. In addition, during construction, three large cypress trees were removed, and their trunks were used to build the three check dams that were installed in the primary wetland. These check dams function to slow water and allow for sedimentation of suspended solids into the wetland. Finally, a boardwalk, complete with a covered arbor and informational placards, was installed at the secondary wetland leading visitors through the pool-run complex ending at the weir over-fall into Alligator Pond (Figure 6). The design specification for the system is provided in Figure 7.

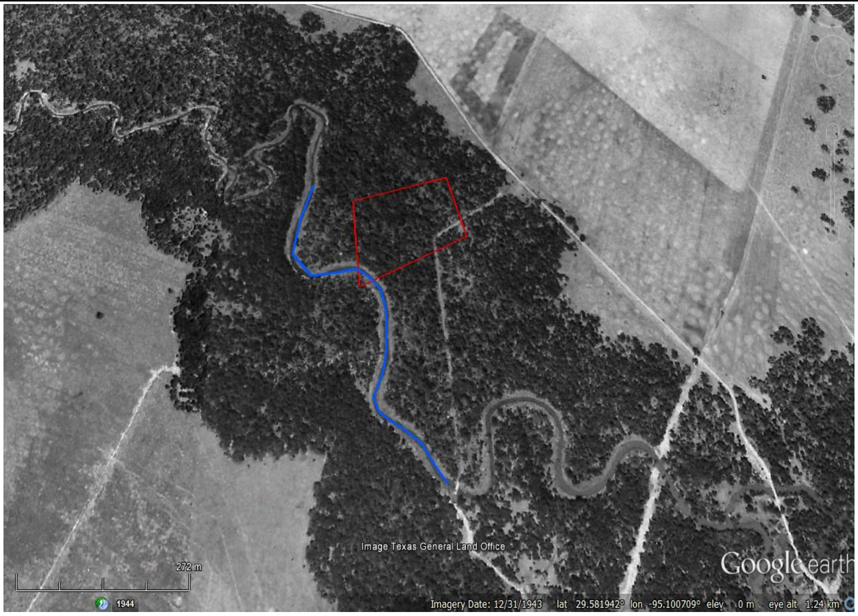

Figure 2. Historical Horsepen Bayou watershed 12/31/1943. Source: Google Earth and Texas General Land Office. Red square shows project area and blue line highlights Horsepen Bayou. Note the extensive riparian forested area and meandering geomorphology.

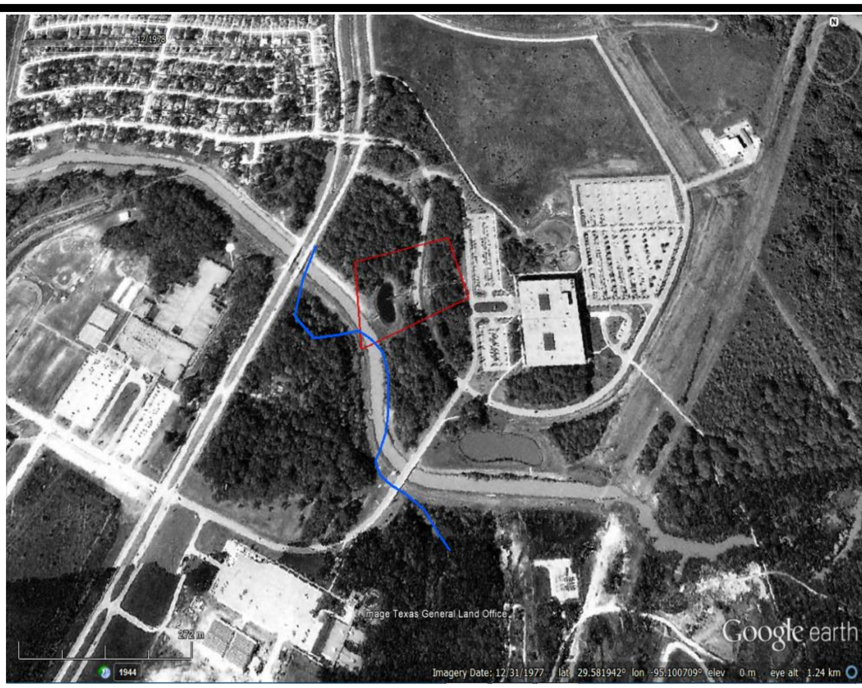

Figure 3. Historical Horsepen Bayou watershed circa 12/1978. Source: Google Earth and Texas General Land Office. Red square shows project area and blue line highlights historical Horsepen Bayou drainage. Note the reduction in riparian forested area and meandering geomorphology and widening of channel.

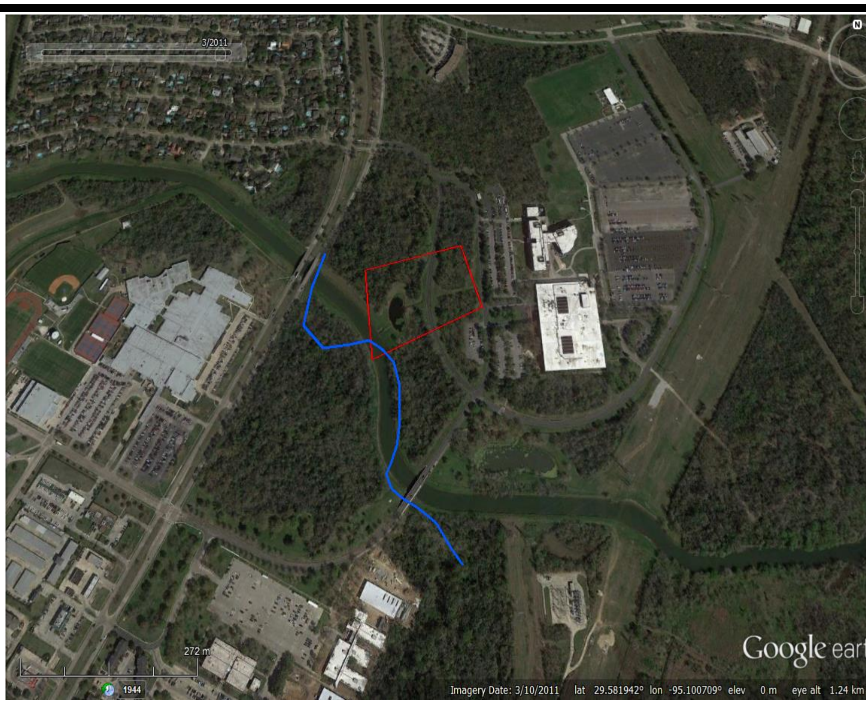

Figure 4. Historical Horsepen Bayou watershed circa 3/2011. Source: Google Earth and Texas General Land Office. Red square shows project area and blue line highlights historical Horsepen Bayou drainage. Note the reduction in riparian forested area and meandering geomorphology and widening of channel.

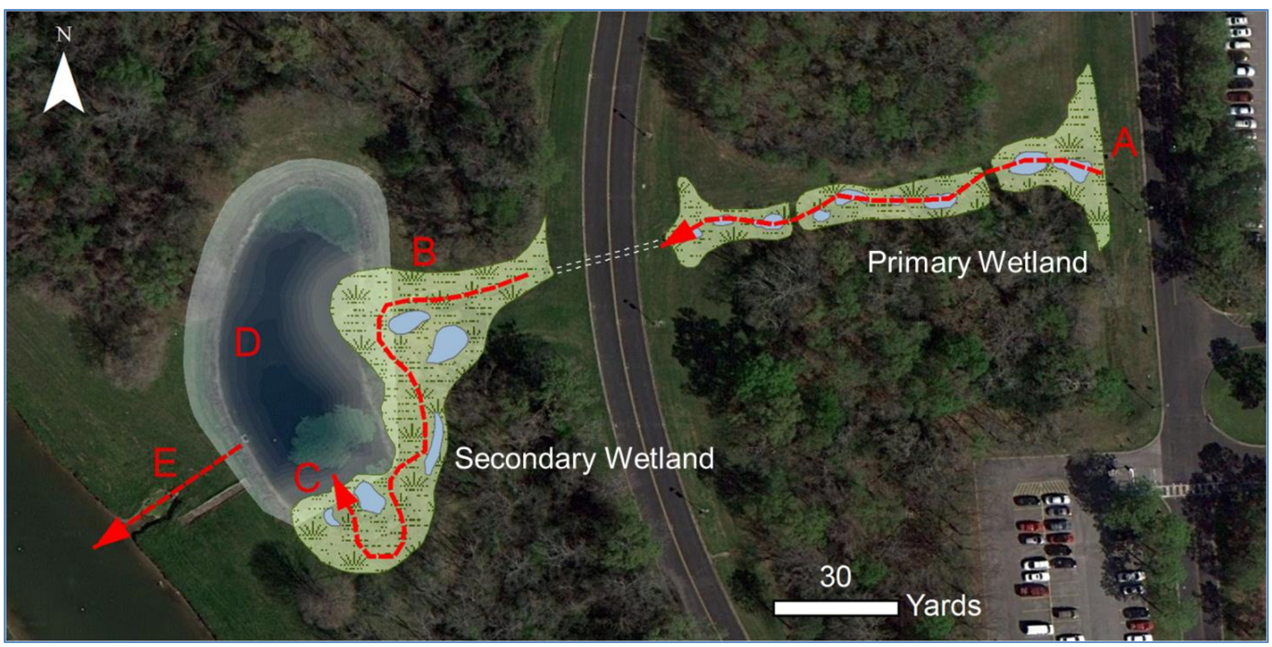

Figure 5. Conceptual design of the created wetland on the UHCL campus at the Alligator Pond site.

Figure 6. The Arbor at the end of the boardwalk at the secondary wetland on the UHCL campus. Note the benches with storage for dip nets, boots, and sorting trays for class visits to the site. Alligator Pond is located to the right.

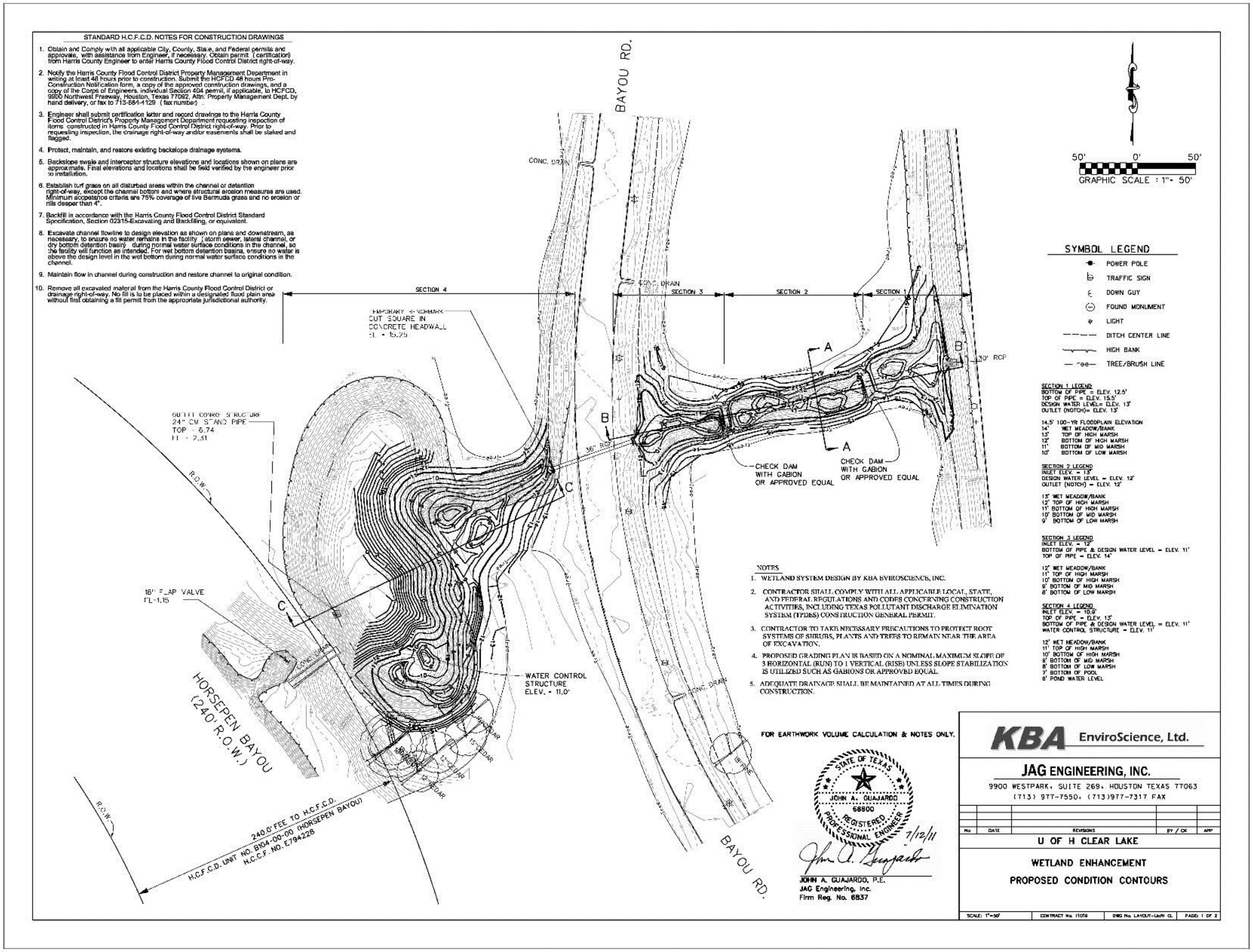

Figure 7. Final engineering drawing of construction plans for the UHCL created wetland.

Prior to any construction numerous permits were obtained including 1) a nationwide permit 27 through the section 404 program from the Army Corps of Engineers, 2) a TCEQ temporary water rights permit for the solar pump, 3) and notification of net gain in flood storage to the City of Pasadena and the HCFCD. The construction schedule was less than two months and this process began with draining the existing Alligator Pond (Figure 8). This pond draining event allowed EIH to quantify the existing nekton community of the pond and compare its contents to previous sampling techniques used to measure fish populations prior to the draining.

During construction, efforts were made to minimize environmental impacts by installing sediment booms, and restricting runoff from the construction site into Horsepen Bayou. Near the end of construction a volunteer community planting day was coordinated with local master naturalists to plant and seed the wetland (Figure 9).

Post construction the area experienced an extreme rainfall event, and the newly constructed levee at the secondary wetland was breached (Figure 10). Part of the levee near the arbor at the end of the walkway and the weir from the secondary wetland into Alligator Pond had eroded, and required repair and slight modification to the construction design. The levee was reinforced, and an overflow low point was constructed allowing for a 100 year flood to overflow directly into Horsepen Bayou to alleviate the pressure on the constructed levee.

In 2013, a v-notched weir was installed at the top of the secondary wetland (Figure 11). This weir was installed with a pressure sensor in order to produce a calibrated continuous flow curve for the wetland.

Time series photographs were taken to show the progress of the created wetland before, during, and after construction. The primary wetland includes a pool and run complex between two campus roads that also had three check dams to aid in sedimentation of stormwater (Figure 12). The secondary wetland complex was constructed as a continuation of the pool-run complexes with a boardwalk feature ending at the weir and arbor at the outfall to Alligator Pond (Figure 13). Educational signs were installed throughout the boardwalk to explain the project background, define what a wetland is, describe how wetlands naturally treat water, and indicate common biota found in a wetland.

Figure 8. Time-lapse of the pond draining pre-construction at the UHCL created wetland site (Alligator Pond). Draining occurred over a 2 day period during July 2011.

Figure 9. Volunteer community planting day held on August, 27, 2011.

Figure 10. Photo of the Levee breach and erosion experienced by an extreme rain event post-construction at the UHCL wetland into Alligator Pond

Figure 11. V-notched weir installed at the most upstream point of the secondary wetland, UHCL created wetland site. The weir is used to monitor water flow.

Figure 12. Time series photographs of the primary wetland complex showing pre-construction, during construction, and post-construction conditions.

Figure 13. Time-series photographs of the secondary wetland complex showing pre-construction, during construction, and post-construction conditions.

METHODOLOGY

Monitoring Site Selection

Fourteen sample sites were identified for this study (Table 1 and Figure 14 - 16). Sites one and two are located on Duck Pond, a detention pond also located on the UHCL campus, which drains into Horsepen Bayou downstream of the Created Wetland Project (Figure 15). These sites were used as a control to compare to the created wetland project sites. Sites 5, 9, and 11 were used only for wet weather sampling and were equipped with first flush stormwater samplers (Figure 16). With this sampling site design, all potential water inputs to the created wetland system could be monitored and enumerated during both dry and wet weather water sampling events.

Table 1 UHCL Created Wetland Monitoring Sample Sites. Sites correspond to Figure 14.

Site #	Site Description	Latitude	Longitude
1	Inlet Control (Duck) Pond	29.580693	-95.099416
2	Outlet Control (Duck) Pond	29.580222	-95.099218
3	Sheet runoff from forested land to Horsepen Bayou	29.583451	-95.103158
4	Primary Treatment wetland Inlet - primary wetland complex	29.583039	-95.100146
5	Primary Treatment wetland Inlet - primary wetland complex *first flush sampler*	29.583033	-95.100189
6	Treatment wetland road ditch inlet - Inlet to secondary wetland	29.582852	-95.101213
7	Solar powered Inlet from Horsepen Bayou - *dry weather only*	29.582817	-95.101271
8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7	29.582828	-95.101201
9	Secondary Treatment Wetland inlet *first flush sampler*	29.582812	-95.101246
10	Secondary Treatment wetland outlet- at weir overfall	29.582389	-95.101622
11	Secondary Treatement wetland outlet *first flush sampler*	29.582373	-95.101601
12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou	29.582495	-95.101804
13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409	29.583279	-95.103385
14	Precipitation and Dry Deposition Collector at EIH building	29.587165	-95.097384

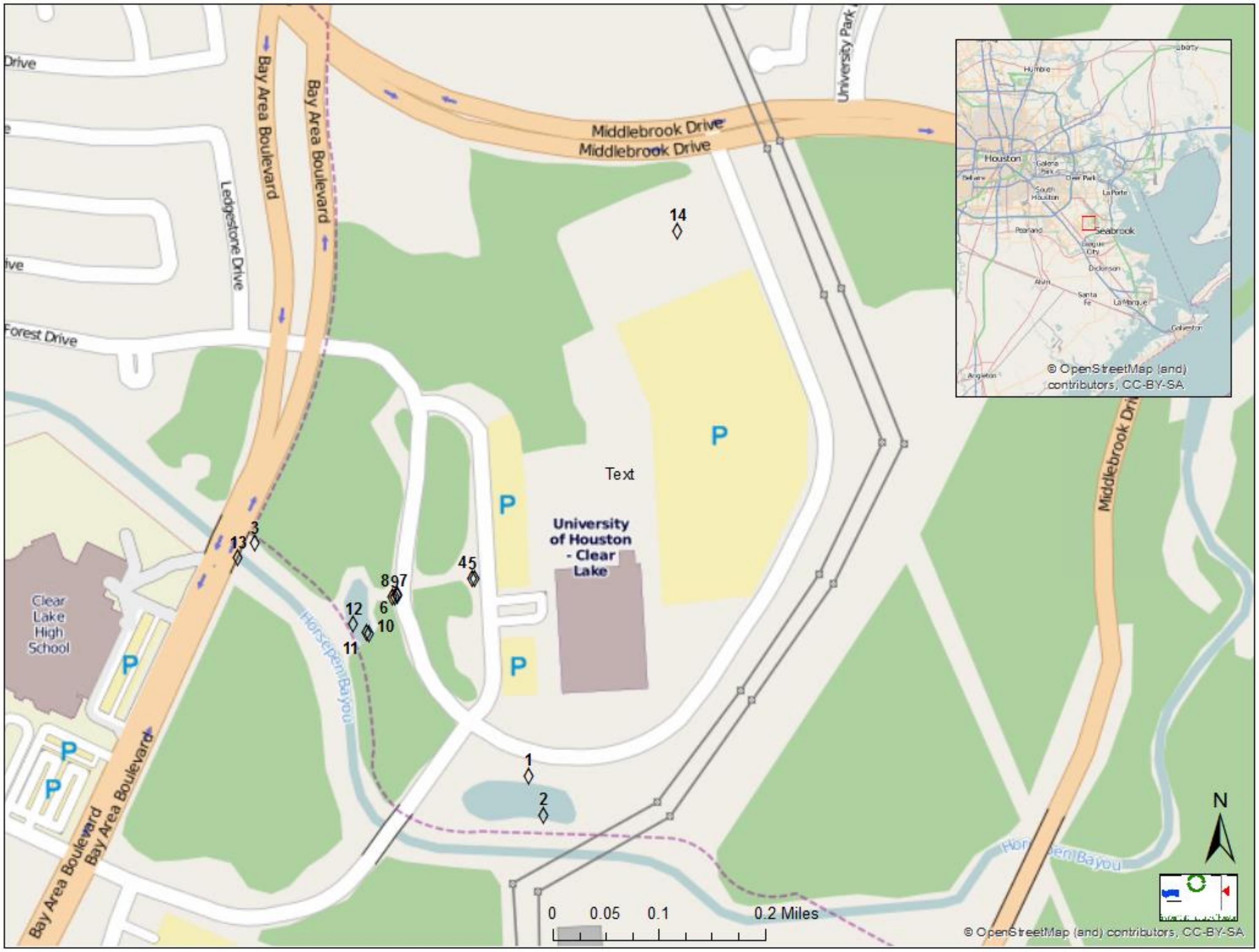

Figure 14. UHCL Created Wetland Monitoring Sample Sites. Numbers correspond to sites correspond in Table 1. Sites 1 and 2 are located at Duck Pond, which served as a control lake.

Figure 15. Control sample sites one and two located at Duck Pond on the UHCL campus. Sites Correspond to Figure 14.

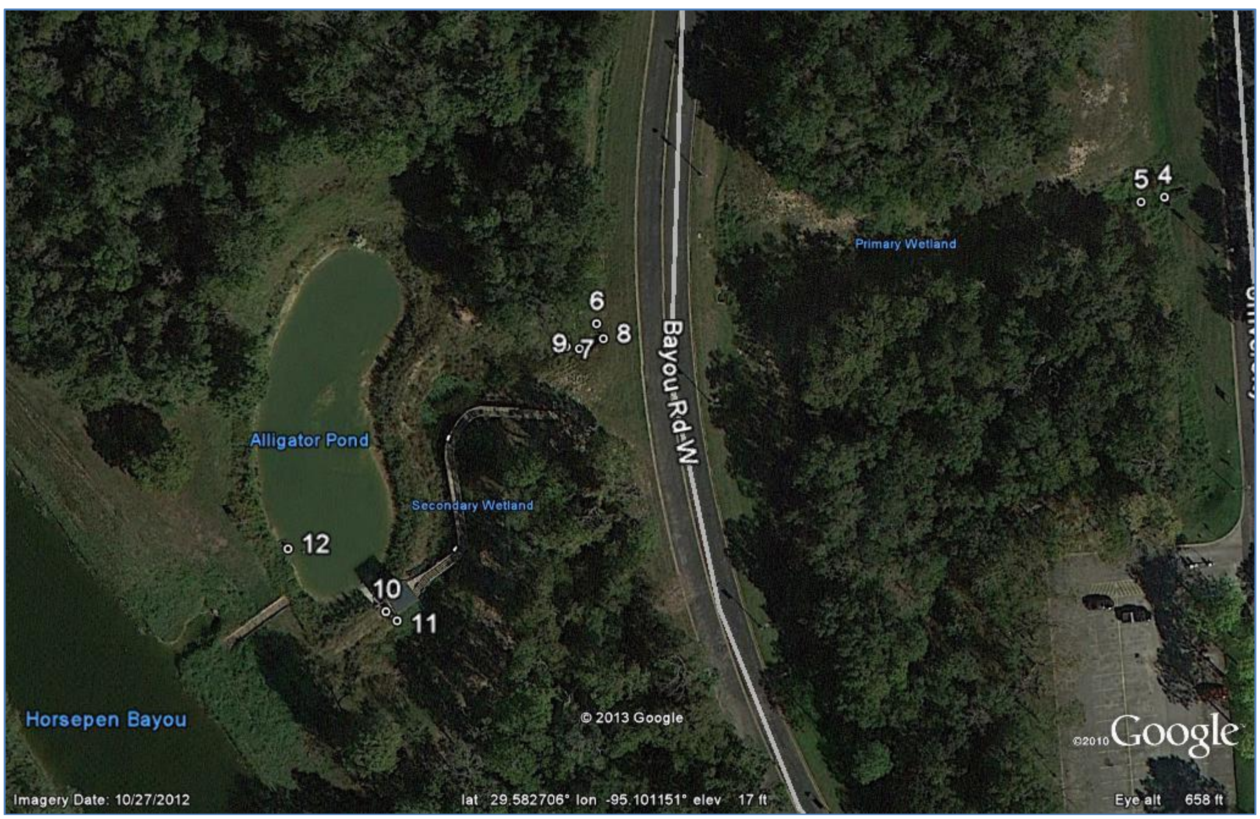

Figure 16. Created treatment wetland sample sites. Sites correspond to Figure 14.

Water Quality Sampling

EIH characterized the concentrations of selected chemicals in ambient and stormwater samples collected on site and in adjacent Horsepen Bayou. In addition, rainfall and flow was measured for calculation of loading rates of various measured chemicals including nutrients, sediments, selected heavy metals and bacteria (Table 2). In addition, an estimated time of travel using in-situ fluorometers and rhodamine dye was conducted according to USGS methods (Wilson et al. 1986, Kilpatrick and Wilson 1989).

Eastex Environmental Laboratory (EEL) was the primary contract lab supporting this project. EEL is certified for the analyses of parameters that require certification for UHCL and this project through the the National Environmental Laboratory Accreditation Program (NELAP). EEL subcontracted some of the analyses the Lower Colorado River Authority (LCRA) Environmental Laboratory Services. The LCRA is a NELAP certified lab for their respective analyses. Measurements of sediment and tissue chemical constituents were used to evaluate the various mechanisms of removal of pollutants from the water. EIH followed the field sampling procedures listed in the TCEQ *Surface Water Quality Monitoring Procedures, Volumes 1 and 2* for all field sampling techniques (TCEQ 2007, 2008).

Continuous Water Quality Monitoring

A continuous monitoring datasonde (YSI 6920) was deployed at each pond (Sites 2 and 12) and at the secondary wetland weir (Site 10). These sondes were placed in the upper 1 meter of water to monitor diel fluctuations in various parameters including water temperature, pH, dissolved oxygen, and specific conductivity every 15 minutes. The sonde at site 2 was installed only during year three (post-construction). Each month the datasondes were retrieved, downloaded, post-calibrated and re-calibrated prior to reinstallation. Relative fluorescent units (RFU) in equivalent µg/L of chlorophyll-*a* were monitored along with turbidity (NTU) using some of these units.

Dry and Wet Weather Water Quality Sampling

Measurements of water, dry atmospheric deposition, and rainfall constituents were used to evaluate the success of the constructed wetland in terms of providing water treatment. Reductions in nutrients, suspended solids, and indicator bacteria in water at the treatment pond discharge point will be the primary indicator of project success. UHCL followed the field sampling procedures listed in the *TCEQ Surface Water Quality Monitoring Procedures* (TCEQ 2007, 2008). Furthermore, all measurements consisted of replicate (field duplicate) measurements.

Table 2. Laboratory parameters sampled as part of the UHCL wetland study.

Matrix	Parameter	Method
Water	TSS	SM 2540 D
	VSS	EPA 160.4
	TDS	SM 2540C
	Sulfate	ASTM D516
	Chloride	SM 4500 Cl^- C
	Alkalinity	SM 2320 B
	Chlorophyll-a	EPA 446.0
	E. coli IDEXX	SM 9223-B
	Enterococcus IDEXX	ASTM D-6503-99
	TKN	SM 4500 C
	Ammonia N, Total	SM 4500 NH3-G
	Nitrate, Nitrite Total	SM 4500-NO3 F
	Total P	SM 4500-P E
	O-Phosphate-P, field filtered	SM 4500-P E
	CBOD (Matching BOD done at UHCL) -3	SM 5210B
	TOC	SM 5310 C
Sediment	Total Organic Carbon	EPA 9060
	Grain Size	Standard sieve
	Nitrate, Nitrite Total	EPA 300.0
	Total Phosphorus	EPA 365.2
	TKN	EPA 351.2
	Total Mercury	SW846 7471
	Total Lead	SW846 6010
	Total Cadmium	SW846 6010
Rainfall and Dry Deposition	Ammonia N, Total	SM 4500 NH3-G
	Nitrate, Nitrite Total	SM 4500-NO3 F
	Sulfate	ASTM D516
Plant Tissue	Total Mercury	EPA 6020A
	Total Lead	EPA 6020A
	Total Cadmium	EPA 6020A

Water quality sampling was conducted twice a year (winter and summer), at most monitoring sites, during pre-construction year 1 and post construction years 2 and 3. During each season, at least one dry and one wet weather sampling event were attempted. During these events, field sampling was conducted at each monitoring site with the exception of selected inflow locations that may not have been flowing. In addition to grab samples, automated first flush stormwater samplers were deployed at three sites and used to collect first flush runoff during each sampled storm event.

In addition, experimental precipitation and dry atmospheric deposition samples for nutrient analysis (total nitrogen) were collected at site 14, nearby in an open field on the UHCL campus (Figure 14 and 17). Precipitation data prior to and during sampling was obtained from the League City National Weather Service (NWS) Station and/or the Harris County Flood Control District gage at Bay Area Blvd and Horsepen Bayou. Relative water level (gage height) was measured at the ponds with a previously installed and leveled staff gage. In addition, water levels were monitored using datasondes or stand-alone pressure transducer depth sensors (YSI or In-Situ). Channel flow into the wetland complex was measured using a SonTek FlowTracker® Acoustic Doppler Velocimeter (ADV).

Figure 17. Dry deposition and precipitation samplers deployed in the field near the N.O.A. building on the UHCL campus.

Time of Travel and Reclaimed Wastewater Sampling

EIH conducted a residence time study using the fluorescent dye method (Rhodamine) (Wilson et al. 1986, Kilpatrick and Wilson 1989). During controlled flow events, dye was released at the most upstream site of the primary wetland, and the presence of the dye was measured by deployed datasondes equipped with fluorometers throughout the complex (Table 3 and Figure 18). The UHCL campus receives recycled wastewater from the Clear Lake City Water Authority Municipal Water Treatment Plant located on Middlebrook Drive near the UHCL campus. The wastewater has been treated with the exception of final dechlorination. The university uses this reclaimed water for irrigation throughout the campus.

Table 3. Reclaimed water special study sampling sites

Site #	Site Description	Latitude	Longitude
S	Spigot of reclaimed water	29.581802	-95.100189
8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7	29.582828	-95.101201
10	Secondary Treatment wetland outlet- at weir overfall	29.582389	-95.101622
12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou	29.582495	-95.101804

Figure 18. Rhodamine Dye release at the top of the primary wetland complex (Site 4).

A spigot for this reclaimed water is located just above the top of the primary wetland complex and provided a unique chance to control inflow into the wetland system in order to measure residence time and time of travel through the complex. Using discharge measurements and measurements of dye release time and the detection times throughout the complex, residence time of stormwater can be calculated. Once average time of travel was determined, multiple controlled water release events were studied to estimate trends in water quality parameters spatially from the same parcel of water as it traveled through the created wetland complex.

Periphyton

Periphyton is defined as the assemblage of microorganisms growing on stones, sticks, aquatic plants, and other submerged surfaces. This includes zoogleal and filamentous bacteria, protozoa, rotifers, algae and free-living microorganisms. This assemblage has been proven useful in assessing the effects of pollutants on waterbodies (Sabater and Admiraal 2005). However, the use of periphyton in assessing water quality often can be hindered by the lack of suitable natural substrates at a sampling site, especially in systems dominated by soft substrate (American Public Health Association et al. 1998). The UHCL created wetland was largely lacking hard substrate. We therefore deployed standardized artificial floating periphyton samplers with glass slides for 7 days using three replicates at each sample location using standard methods (American Public Health Association et al. 1998)(Figure 19 and 20). Periphyton samples were collected at sites 2, 4, 10, and 12 in years 2 and 3 of the study (post-construction). The glass slides were then transported to the laboratory. Both chlorophyll-*a* and total biomass were measured on each slide (Figure 20). At the time of periphyton sampler deployment and retrieval, nutrient samples were collected and analyzed in-house.

Figure 19. Floating artificial substrate used to monitor periphyton during the project.

Figure 20. Periphyton samplers deployed at site 4, primary wetland complex at the UHCL created wetland.

Sediment Sampling

Measurements of sediment chemical constituents were used to evaluate potential mechanisms of contaminant removal and transformation from water overlying water column to soil. This provides a mechanism to measure potential pollutant sequestration. Increases in nutrients and heavy metals were considered to be the primary indicator of project success. UHCL followed the field sampling procedures listed in the TCEQ Surface Water Quality Monitoring Procedures, Volumes 1 and 2 Table B2.2 (TCEQ 2007, 2008). A petite ponar benthic grab was used to collect the most recently deposited sediment, by carefully scraping the top 3 cm of sediment off the top of the sediment grab (Figure 21). Multiple grabs were taken in order to gather a large enough composite sample sufficient for all of the lab analyses.

Figure 21. EIH staff sampling sediment using a petite ponar at the primary wetland site 4.

Plant Tissue Sampling

Measurements of plant tissue constituents were used to evaluate potential mechanisms of contaminant sequestration and removal in the constructed wetland. Increases in nutrients and heavy metals in plant tissues were the primary indicators of project success. It is important to note that there was not background information on contaminant levels at the project site. Plants were sampled at sites 4 and 10 and replicate samples were taken of two species: *Schoenoplectus californicus* and *Sagittaria sp*. EIH measured in-vivo plant chlorophyll-*a* in the field using a SPAD 502 Plus chlorophyll meter (Spectrum Technologies, Inc.) and extracted chlorophyll-*a* in the lab using a Thermo Spectronic Aquamate spectrophotometer. Tissue samples were submitted to the EEL for metal and nutrient analysis.

Solar Pump Study

A solar pump was installed to pump water from Horsepen Bayou up to the top of the secondary wetland complex in order to provide additional water quality treatment of Horsepen Bayou water through the created wetland complex. The pump intake is located near the outfall pipe from Alligator pond, in order to protect it from high flow events in the bayou. The solar panel that powers the pump is located on the berm between Alligator Pond and Horsepen Bayou (Figure 22). A feasibility study was completed to evaluate the use of a solar pump to treat water from Horsepen Bayou. Flow discharge from the pump outfall pipe was compared to solar radiation readings from a LI-COR photosynthetically active radiation (PAR) meter to study the effectiveness of this design. Due to the tidal nature of Horsepen Bayou, an Onset HOBO conductivity data logger was installed at the pump inlet to measure salinity. Water was only pumped into the wetland system when conductivity levels were below 1000 μS/cm specific conductivity to reduce the likelihood of damage/stress to the freshwater wetland plant community.

Figure 22. Solar panel that powers a pump which conveys water from Horsepen Bayou uphill to the top of the secondary wetland complex for additional water quality treatment through the created wetland.

Habitat and Wildlife Sampling

Vegetation Surveys

Pre-construction, vegetation surveys were conducted along random transects to document the vegetation composition around Alligator Pond in the summer of 2011. Post-construction, a volunteer planting day was coordinated to plant the site (August 27, 2011), and subsequent volunteer work days were held to help remove invasive plants, and plant additional species after the initial, natural recruitment occurred. A subsequent vegetation survey was completed nearly one year after construction (summer of 2012) to measure the post-construction vegetation composition and recruitment. This allowed EIH to measure natural recruitment, and planting success to a newly created wetland. The vegetation survey post-construction was an intensive survey consisting of one transect every 25 feet along the primary and secondary wetland complex and along the perimeter of Alligator Pond. Along each transect, 1 square meter (m^2) quadrat plots were assessed from bank full to bank full, and all species present were identified, enumerated as percent cover, and grouped by height class. Additional ground surface attributes were recorded at each quadrat plot including water depth, % exposed soil, % macrophytes present, etc.

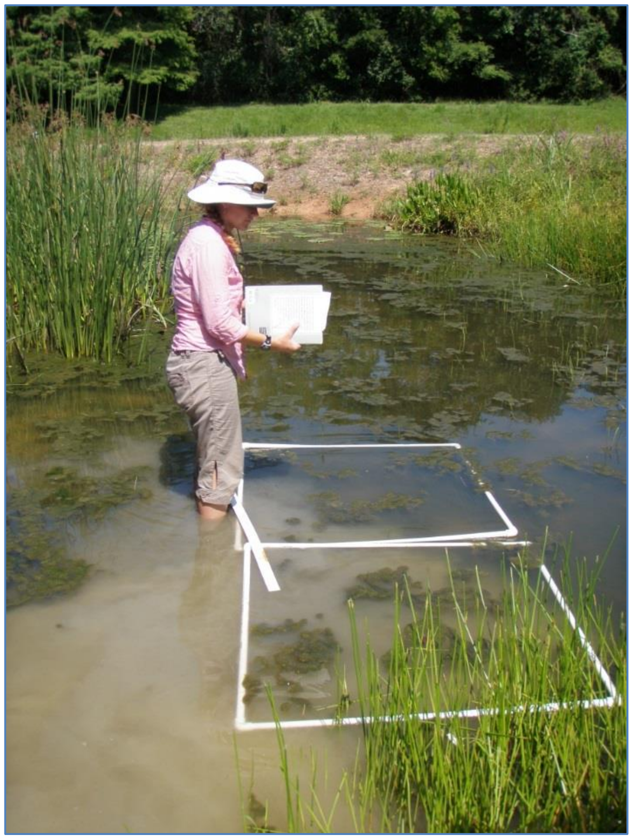

Figure 23. EIH staff completing post-construction vegetation survey at the secondary wetland complex.

Nekton

Nekton sampling was conducted at Alligator pond pre-construction and post-construction to evaluate the community structure. In addition, post-construction nekton sampling was conducted at the primary and secondary wetland complexes. Nekton was also sampled at Duck Pond to serve as a reference site throughout the course of this study. Sampling techniques included backpack electroshocking (Figure 24), seining, gillnets, and minnow traps, all following the field sampling procedures outlined in the TCEQ *Surface Water Quality Monitoring Procedures, Volume 2 (TCEQ 2007).* During construction, Alligator Pond was drained, and EIH staff enumerated and identified all fish, invertebrates, and reptiles that were removed from the pond. All biota was relocated to either Duck Pond on campus or into Horsepen Bayou.

Figure 24. EIH staff sampling for nekton using a backpack electroshocker in the Secondary Wetland complex at the UHCL created wetlands.

Benthic Organisms

Benthic macroinvertebrate samples were collected at sites 2, 4, 10, and 12. Samples were collected using two sampling techniques: petite ponar grabs and D-frame kick-net (Table 4). Kick-net and petite ponar samples were composited in the lab prior to sampling in 2013. Sampling occurred pre and post-construction, and all macroinvertebrates were identified and enumerated for calculation of an Index of Biotic Integrity following procedures outlined in the TCEQ *Surface Water Quality Monitoring Procedures, Volume 2* (TCEQ 2007).

Table 4 Dates and types of benthic samples collected. All sites were sampled in replicates of 2. *Composited samples include both kick-net and PONAR collected samples.

Site #	Date	Sample Type
2	12/8/2010	Kick-net
	7/22/2011	Kick-net
	9/7/2012	PONAR
	5/30/2013	Composite*
4	6/8/2012	Kick-net
	9/5/2012	PONAR
	5/29/2013	Composite*
10	6/7/2012	Kick-net
	9/6/2012	PONAR
	5/29/2013	Composite*
12	12/8/2010	Kick-net
	5/25/2011	Kick-net
	7/22/2011	Kick-net
	6/8/2012	Kick-net
	9/7/2012	PONAR
	5/29/2013	Composite*

Zooplankton

Zooplankton tows were completed at sites 2 and 12 in post-construction years 2 and 3. All zooplankton were identified and enumerated following procedures outlined in the TCEQ *Surface Water Quality Monitoring Procedures, Volume 2* (TCEQ 2007). The zooplankton net used was a Wisconsin sampler (approx. 23" in length, 363µm nitex mesh with 5" diameter mouth and 7" diameter ring). This net was towed across the pond using kayaks, and then released and pulled across the pond at a steady rate to the shore, keeping the net just below the surface of the water (Figure 25). The distance and time pulled was recorded.

Figure 25. EIH staff pulling a zooplankton tow at Duck Pond (Site 2), UHCL campus.

Birds

Bird surveys were conducted monthly at three sites (duck pond, primary wetland, and secondary wetland) post-construction. All sites were surveyed on the same day at the same location per site, with the site survey order being chosen at random each month. All surveys began approximately 30 minutes after sunrise in an attempt to capture higher bird activity.

A ten minute survey was conducted per survey site. All birds seen and heard were identified and enumerated after a two minute cool down period which allowed the birds to acclimate to the observer. Two five minute intervals were sampled, ten minutes total, at each site. Relative distance of the bird from the observer was recorded.

Game Cameras

Three Acorn LTL-5 210mm game cameras were deployed in and around the secondary wetland complex post construction to monitor wildlife usage. Cameras were set up around Alligator pond in 3 locations (Figure 26): in the arbor facing the wooden walkway (green), on the north end of the pond facing the water (red), and on the south end of the pond facing the water (yellow). These cameras were tripped by motion sensors and set to capture a series of 3 images with 1 second in between each image. This allowed for multiple photos of wildlife or visitors to be taken at any given time for quantification back at EIH. Cameras were also set up to capture photos on the hour, every hour during days they were deployed.

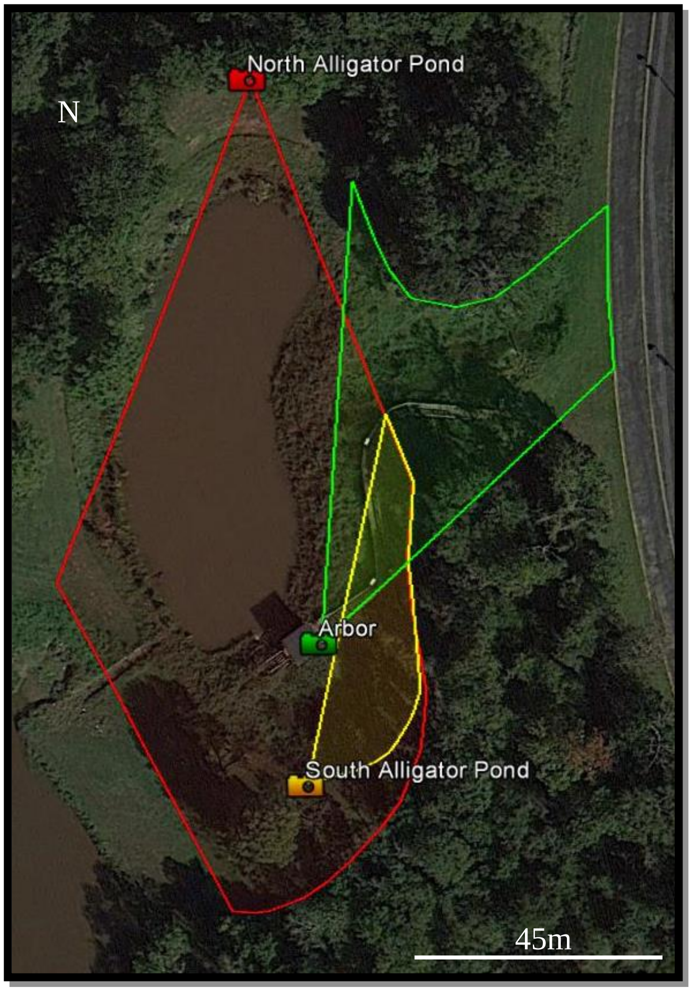

Figure 26. Locations and areas of visibility for game cameras set up at north alligator pond (red), south alligator pond (yellow), and the arbor (green).

In addition to wildlife images captured by these game cameras, images were also captured of the public visiting the constructed wetland. This allowed for quantification and qualification of human usage for the area. Human usage was broken down into 2 categories, number of adults present and number of children present. Additionally, it was documented on whether humans utilizing the constructed wetland area were biking or had dogs present at the time of their visit.

RESULTS

Construction of the wetland complex was completed on July 19, 2011. During the subsequent month the downstream pond was slowly filled with water from precipitation and in some cases irrigation water.

Precipitation

Precipitation data obtained from the Harris County Flood Control District rain gage located at Horsepen Bayou and Bay Area Blvd. during the period of October 1, 2010 through October 31, 2013 is presented in Figure 27. Although the median and minimum daily rainfall amounts were similar between pre and post wetland construction time periods, the maximum daily rainfall (5.8 inches) occurred during the pre-construction period (Figure 28). The occurrence of dry and wet weather sampling events is depicted in the graph and described below (Figure 27).

Water Quality Sampling

Dry and Wet Weather Water Quality Sampling

A total of 29 water quality sampling events occurred between October 2010 and July 2013. Twenty sampling events occurred during the pre-construction phase of the project and 9 events during the post-construction phase (Table 5 and Table 6, respectively). During both construction phases of the project, dry and wet weather samples were collected at specified sites. Prior to completion of construction, sites 2 and 12 were sampled during every event and, starting in 2011, site 13 was sampled at every event. Between 2010 and July 2012 (including both pre- and post-construction phases), all samples collected at sites 2 and 12 were taken from the middle of the ponds. On 22 June 2013, sites 1, 4, and 8 were also sampled to establish wet weather conditions within the complex prior to completion of construction.

Construction of the wetland complex was completed in July 2011. Two water quality sample events occurred that month. One sampling event occurred prior to official completion of construction on July 6, 2011 and one event just after completion of construction on July 19, 2011. This second event was conducted to establish baseline levels within the wetland complex before any new, natural recruitment by vegetation occurred within the complex. For the purposes of water quality sampling the period starting on July 20, 2011 is considered the post-construction period. However, for the purposes of automated water quality monitoring, which is described later, the period through August 8, 2011 is considered part of the pre-construction phase. In most cases automated monitoring in the post construction phase did not start till after October 2011.

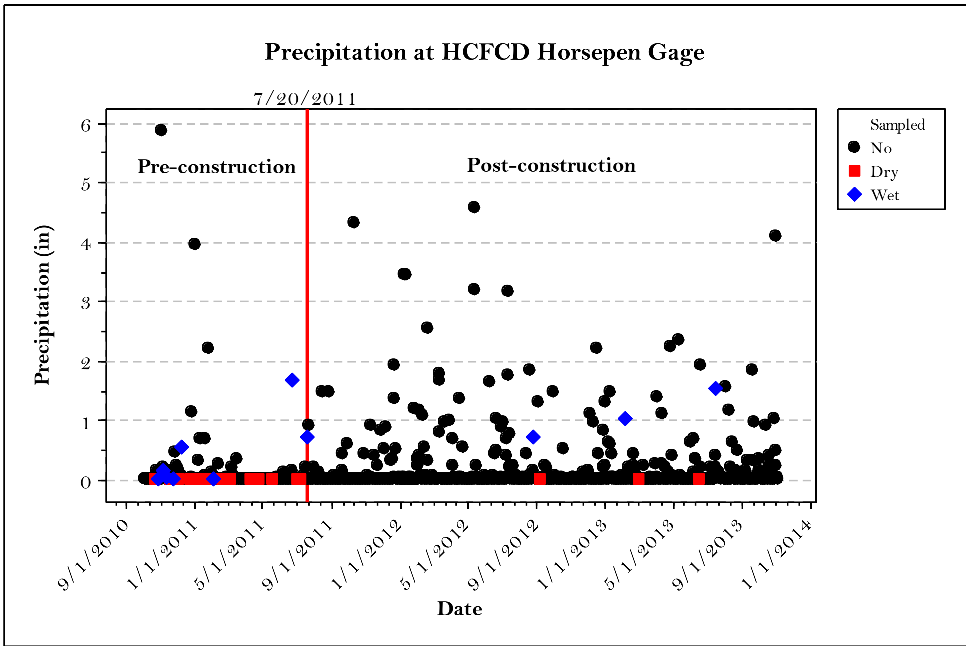

Figure 27. Daily precipitation recorded at the HCFCD rain gage in adjacent Horsepen Bayou at Bay Area Blvd. Dry and wet weather sampling events are denoted. Post construction period started July 20, 2011.

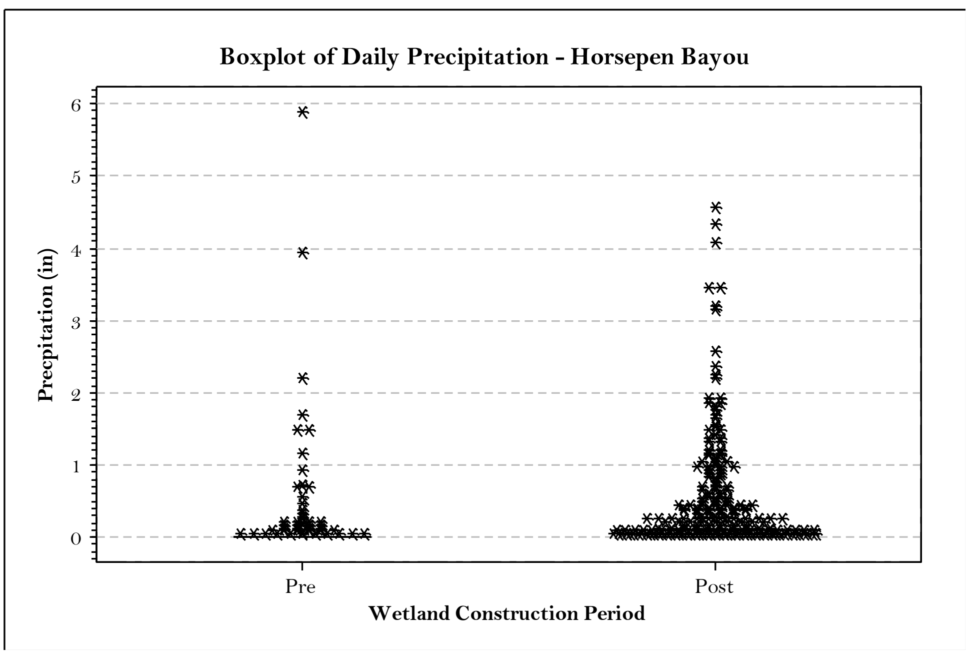

Figure 28. Boxplot of daily precipitation recorded at the HCFCD rain gage in adjacent Horsepen Bayou at Bay Area Blvd during the pre and post wetland construction period.

Continuous Water Quality Monitoring

Continuous water monitoring was conducted using YSI 6920 datasondes at three sites throughout the UHCL created wetland complex. This included the created wetland upstream of Alligator Pond at the Weir, in Alligator Pond near the outlet to Horsepen Bayou, and the Duck Pond near the outlet to Horsepen Bayou. Each of these data sets will be discussed separately and then discussed comprehensively in comparison to each other.

Alligator Pond

The results of Alligator Pond pre-project monitoring is presented in (Figure 29- 40). A total of 54,458 measurements were made at the Alligator Pond. Prior to construction of the wetland complex a total of 12,057 measurements were obtained. The depth of the YSI datasonde ranged between 0.01 to 2.29 meters with a median value of 0.64 meters. Water temperature varied between 7.5 and 32.6 ºC and followed expected seasonal trends (Figure 29). The median surface water temperature after construction of the wetland was significantly warmer than pre-wetland conditions (Figure 30). However, this may be due to the unequal number of measurements made before and after the wetland construction.

The specific conductance ranged between 0.003 mS/cm and 0.818 mS/cm (Figure 31). The majority of measurements were below 0.400 mS/cm which indicated that the source water was fresh with no brackish water infiltration from either Horsepen Bayou or other sources occurring. Median post wetland specific conductance levels (0.279 mS/cm) were significantly lower than the pre-wetland levels (0.337 mS/cm) (Figure 32). Peak levels occurred during December 2011 and June 2013. Surface water turbidity at the Alligator Pond ranged between 0 and 1453.1 NTUs but usually remained below 200 NTU with notable exceptions during mid-December 2010, early March 2011, August 2011, February 2012, June 2012, July 2012, and January 2013 (Figure 33). Highest median turbidity occurred after wetland construction (21.50 NTU) in comparison to pre wetland levels (3.90 NTU). However, it appeared that the variability including the frequency and intensity of high turbidity events as measured by the standard deviation declined after the wetland construction suggesting some degree of buffering of high suspended sediment events (SD = 237.2 versus 22.25 SD). The high turbidity periods in December 2010 and March 2011 were associated with high rainfall amounts recorded at the nearby HCFCD rain gage (Figure 27).

The surface water pH ranged between 5.9 and 10.5 (Figure 36). The majority of values ranged between 6.5 and 9.5 pH units. However, there was a significant change in the pH regime following the construction of the wetlands. The median pH value was higher and the variability in readings was greater (Figure 37). Most variation in pH was associated with daily fluctuations associated with algal photosynthesis and respiration. The pH of water is heavily influenced by the daily respiration and photosynthesis of algae and phytoplankton. During the day pH values tend to increase in response to declining levels of CO_2 (Boyd 1984). When the phytoplankton levels are high the fluctuation in daily pH will increase resulting in very low and high values in pH and dissolved oxygen.

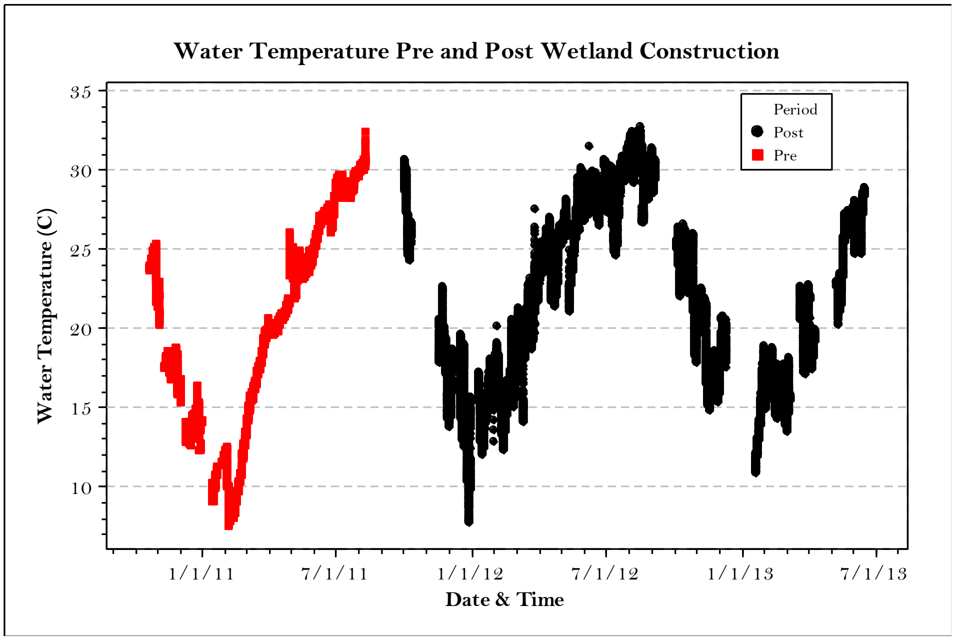

Figure 29. Results of automated continuous monitoring of surface water temperature at the Alligator Pond prior to and after wetland construction.

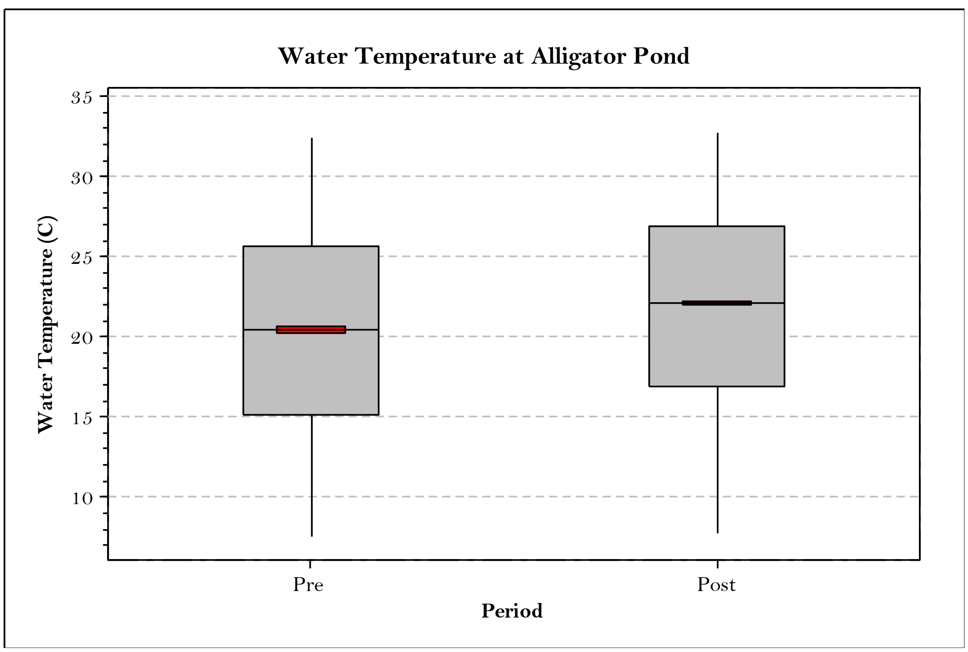

Figure 30. Boxplot and 95% confidence interval of median (red box) water temperature at the Alligator Pond prior to and after construction of the wetland.

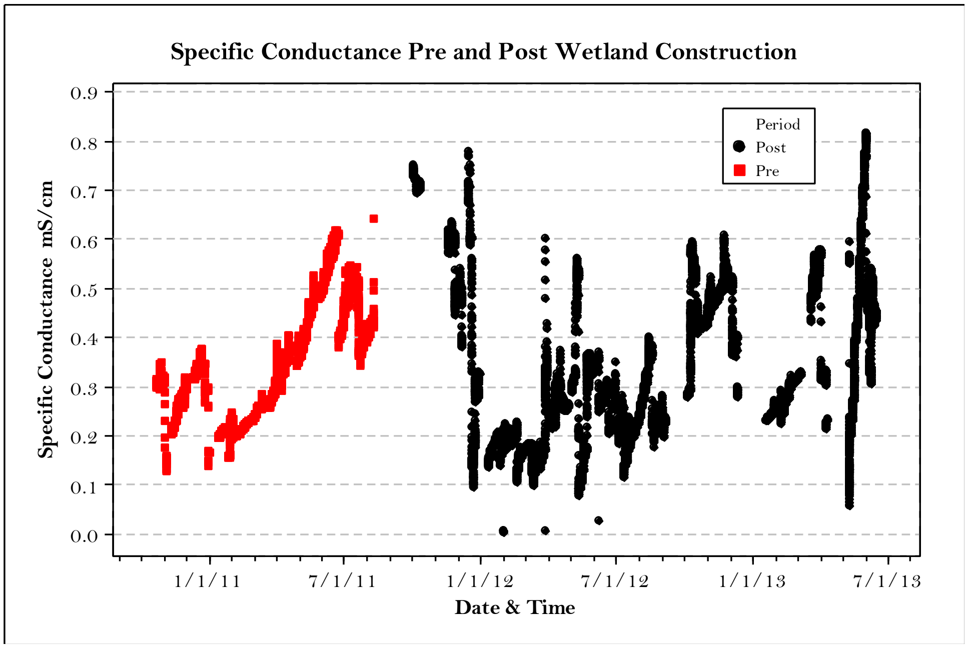

Figure 31. Results of automated continuous monitoring of surface specific conductance at the Alligator Pond prior to and after wetland construction.

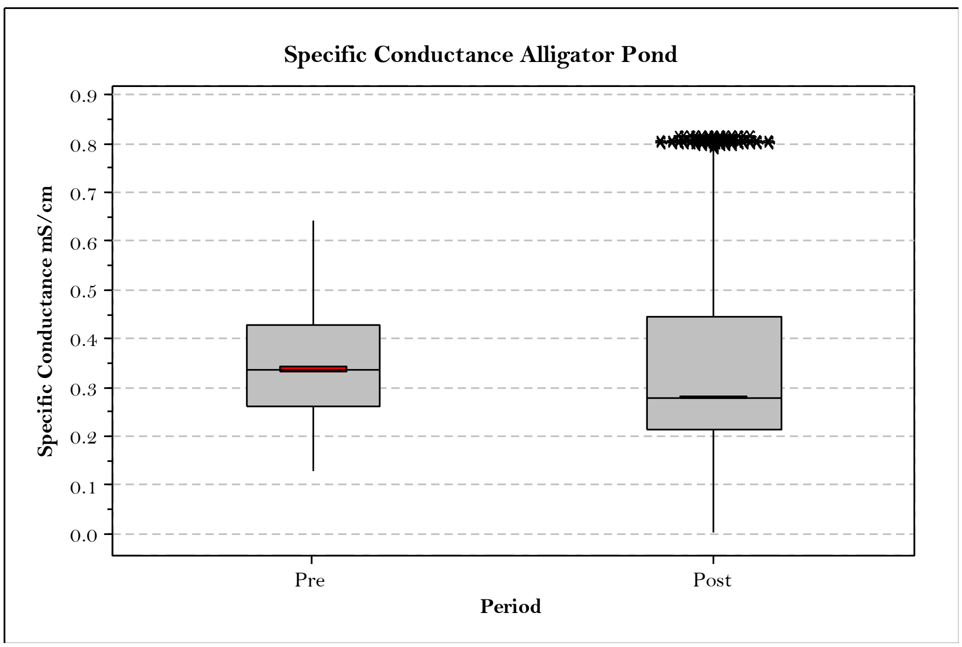

Figure 32. Boxplot and 95% confidence interval of median (red box) specific conductance at the Alligator Pond prior to and after construction of the wetland.

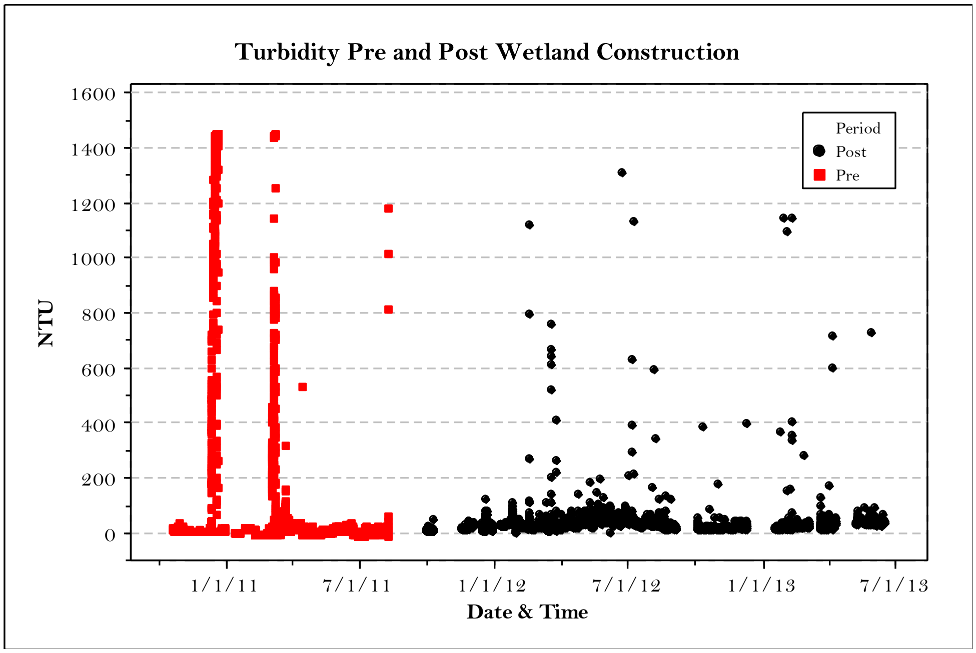

Figure 33. Results of automated continuous monitoring of surface turbidity at the Alligator Pond prior to and after wetland construction.

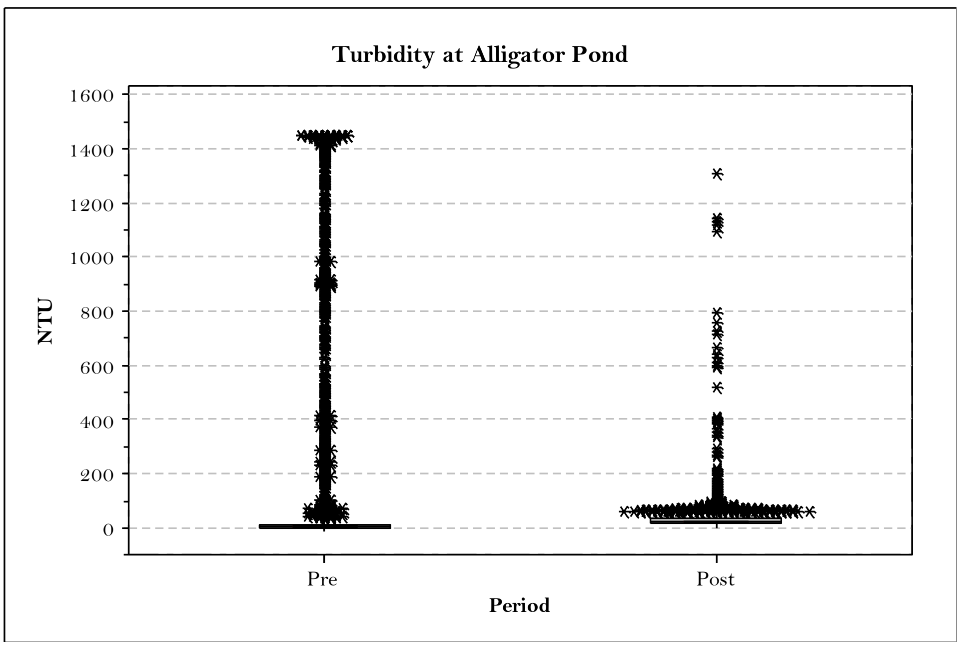

Figure 34. Boxplot and 95% confidence interval of median (red box) turbidity at the Alligator Pond prior to and after construction of the wetland.

Figure 35. Twenty-four hour rainfall amounts recorded at the nearby Horsepen Bayou at Bay Area Blvd. rain gage during December 2010. Data maintained by the HCFCD.

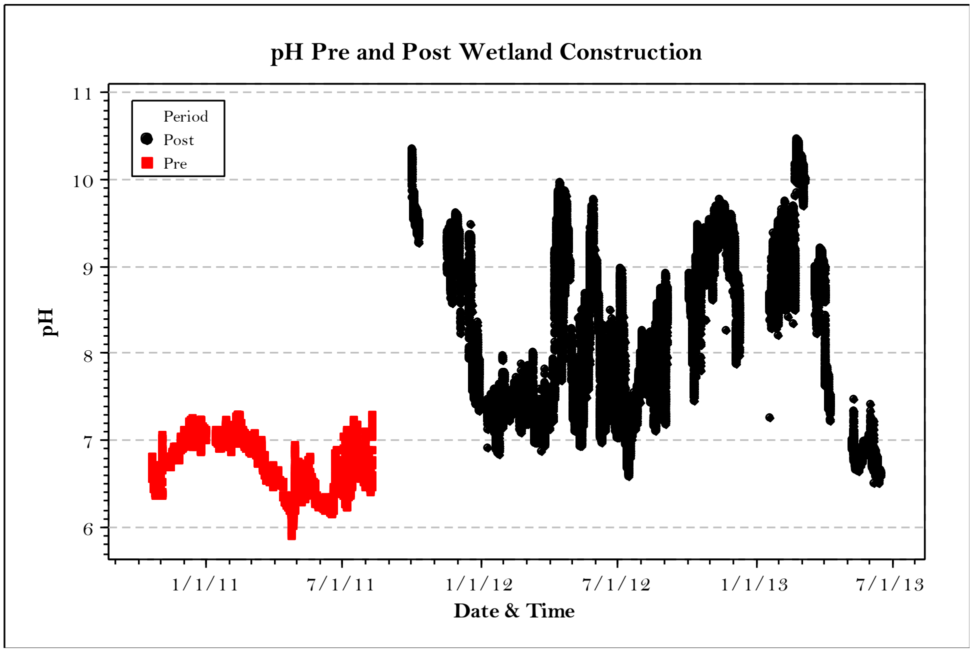

Figure 36. Results of automated continuous monitoring of surface pH at the Alligator Pond prior to and after wetland construction.

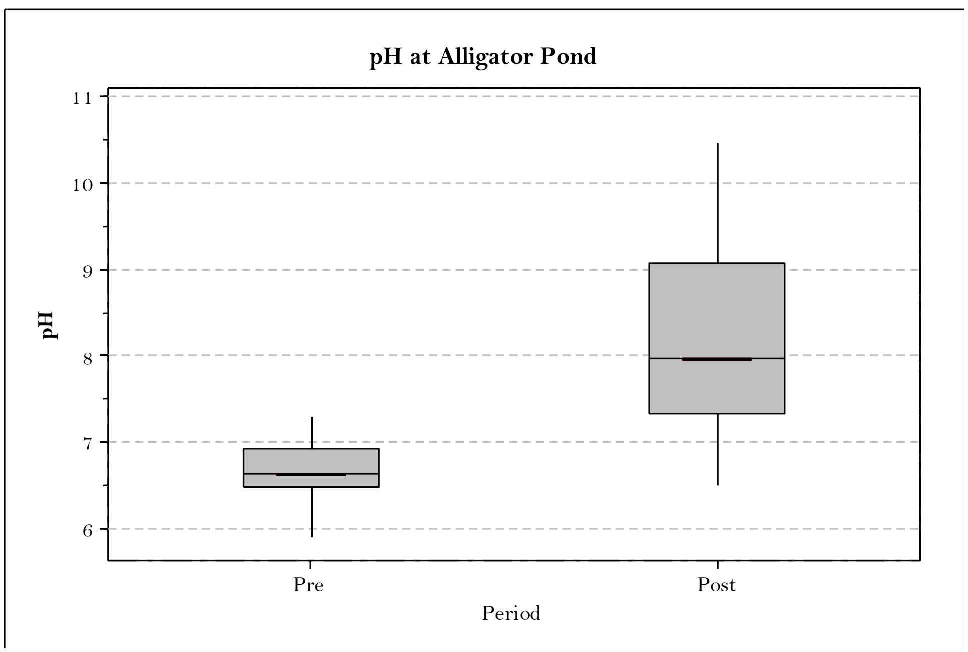

Figure 37. Boxplot and 95% confidence interval of median (red box) pH at the Alligator Pond prior to and after construction of the wetland.

Relative fluorescence is positively correlated with chlorophyll-*a* content and phytoplankton and/or algae biomass and is reported in units of µg/L RFU. This value is believed to be approximately equal to the chlorophyll-*content* in µg/L. Relative fluorescence varied between 0 and 500 µg/L RFU. High relative fluorescence values occurred during March through May 2011 and February 2012 (Figure 38). The median RFU levels were identical before and after the construction of the wetlands (Figure 39). In contrast, the variability as measured by the standard deviation was much higher during the pre-wetland period in contrast to the post wetland period (SD = 100.09 versus 13.68 µg/L). This pattern in variability suggests less blooms and massive declines in phytoplankton occurred after construction of the wetlands had occurred.

Dissolved oxygen levels were highly variable during the pre-construction period ranging from 0 to 39.5 mg/L, which is supersaturated (Figure 40). Overall the median dissolved oxygen level in Alligator Lake was lower prior to construction of the wetland in contrast to the post-wetland period (1.4 versus 5.7 mg/L) (Figure 41). However, the variability and maximum levels of dissolved oxygen were much higher before wetland construction versus afterwards (max values pre = 500, post = 480.3 µg/L; 75th percentile pre = 47.9, post = 16.2 µg/L; stdev pre = 4.75 µg/L, post = 3.98 µg/L). These patterns in dissolved oxygen indicate that the pond was more eutrophic prior to construction of the wetland than afterwards.

There did not appear to be a strong coupling of dissolved oxygen and RFU levels ($r = -0.201$, $p = \leq 0.01$). The amount of RFU in turn exhibited a weak negative correlation with turbidity ($r = -0.016$, $p \leq 0.01$). Although all of the remaining variables exhibited significant ($p \leq 0.01$) correlation coefficients, all but one pair (dissolved oxygen and pH; $r = .663$) were very weak ($r \leq 0.5$ absolute value). These data suggest that after construction of the wetlands the intensity of algal blooms declined and the overall level of dissolved oxygen increased. The temporal patterns displayed by the RFU and dissolved oxygen, when combined with the pH and turbidity data supports the hypothesis that less algal blooms including widely varying oxygen levels ranging from supersaturated to hypoxia occurred after construction of the wetland and that the intensity and frequency of high turbidity events also declined.

Created Wetland

The results of constructed wetland automated water quality monitoring are presented in (Figure 42- 47). A total of 44,319 measurements were logged at the constructed wetlands. The depth of the YSI datasonde ranged between 0.01 to 2.15 meters with a median value of 0.24 meters. Water temperature varied between 6.4 and 34.6 ºC with a median value of 21.0 ºC and followed expected seasonal trends (Figure 42).

Specific conductance varied between 0 and 0.789 mS/cm with a median of 0.338 mS/cm (Figure 43). Highest (≥ 0.700 mS/cm) specific conductance levels were logged during the months of December 2011, March 2012, May 2012, October and November 2012, and March and April 2013. The lowest (≤ 0.050) readings were recorded during February 2012, March 2012, and May - June 2012. All of these specific conductance levels indicate the wetland received only freshwater input from runoff in watershed and precipitation. High conductance levels reflect periods of low runoff and high evaporation. Low conductance levels reflect periods of high rainfall and dilution of dissolved solids.

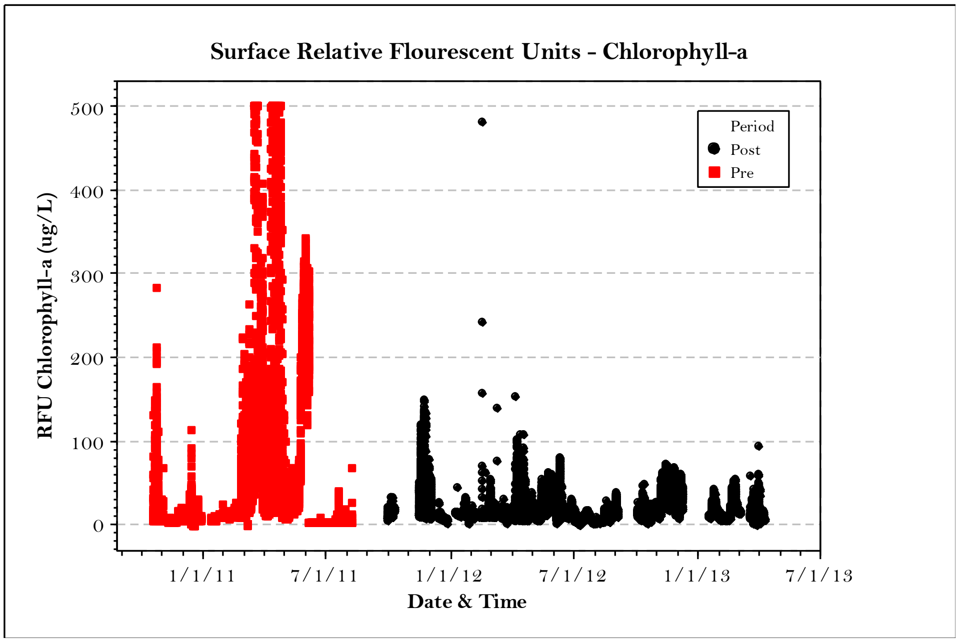

Figure 38. Results of automated continuous monitoring of surface relative fluorescence (RFU) in equivalent chlorophyll-*a* (µg/L) at the Alligator Pond prior to and after wetland construction.

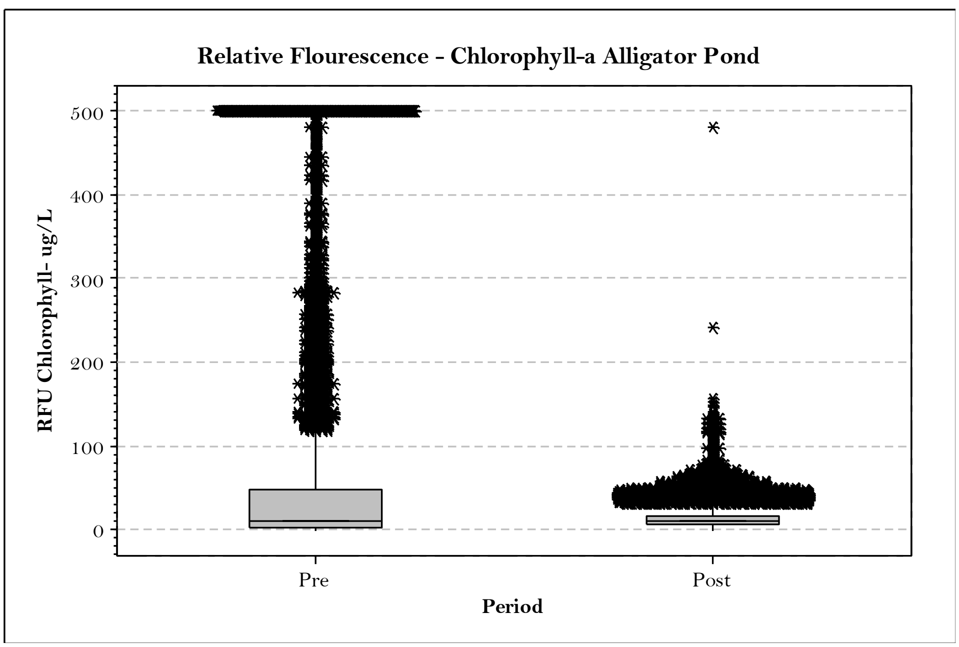

Figure 39. Boxplot and 95% confidence interval of median (red box) relative fluorescence (RFU) in µg/L chlorophyll-*a* at the Alligator Pond prior to and after construction of the wetland.

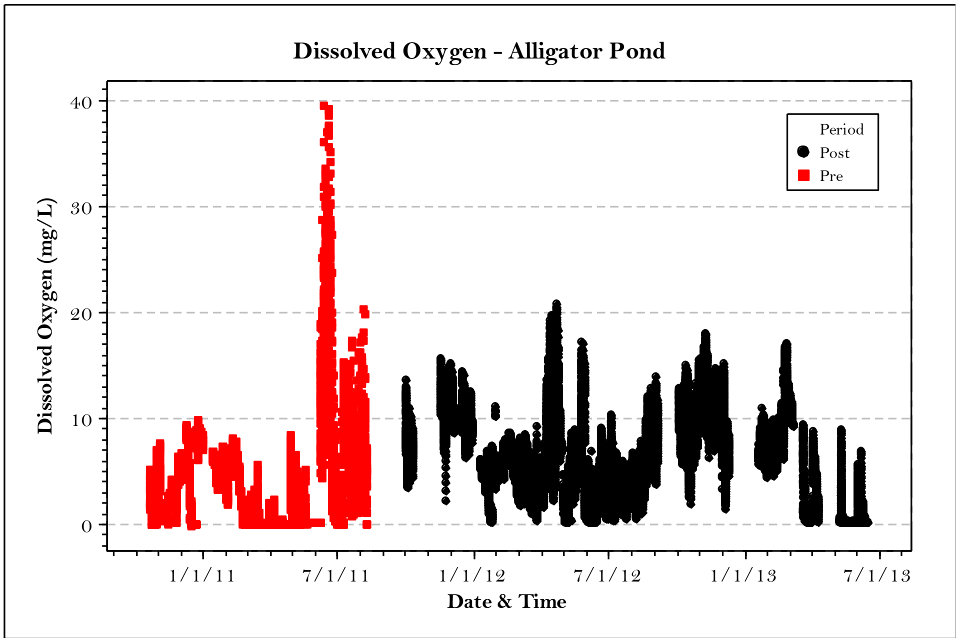

Figure 40. Results of automated continuous monitoring of surface dissolved oxygen at the Alligator Pond prior to and after wetland construction.

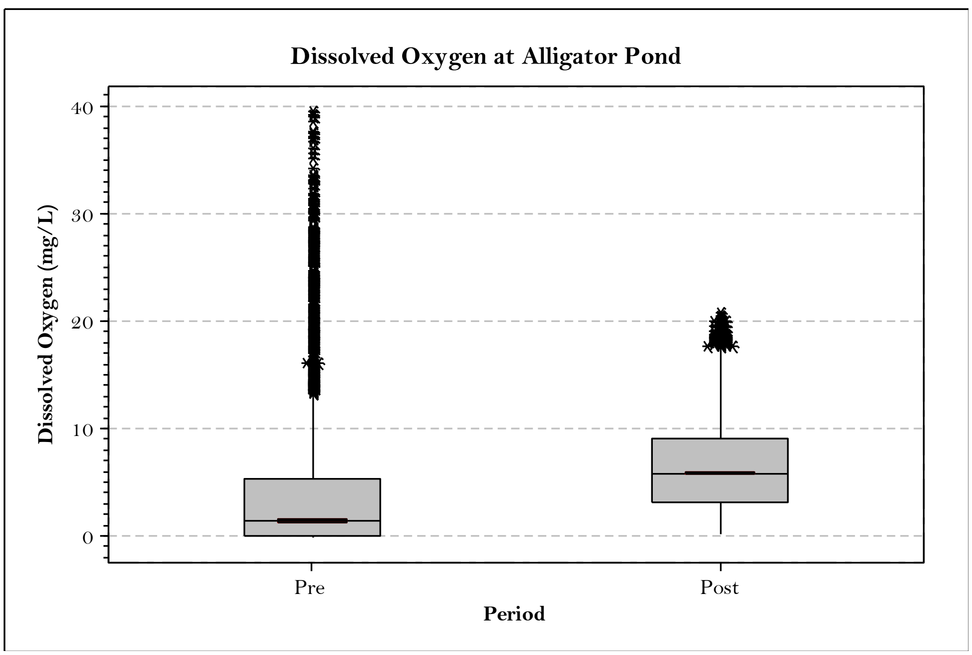

Figure 41. Boxplot and 95% confidence interval of median (red box) dissolved oxygen at the Alligator Pond prior to and after construction of the wetland.

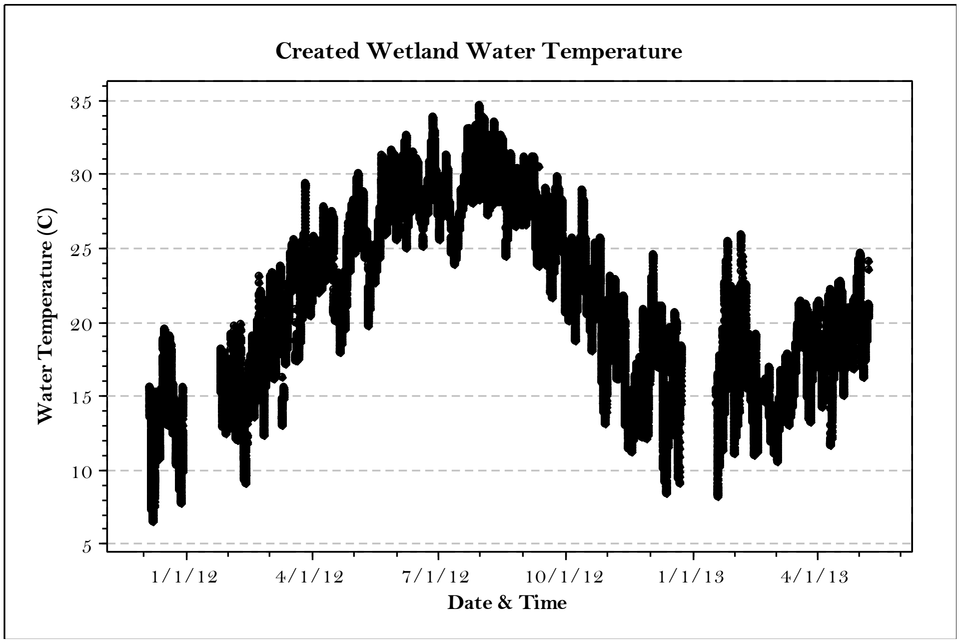

Figure 42. Results of automated continuous monitoring of surface water temperature at the constructed wetland upstream of Alligator Pond.

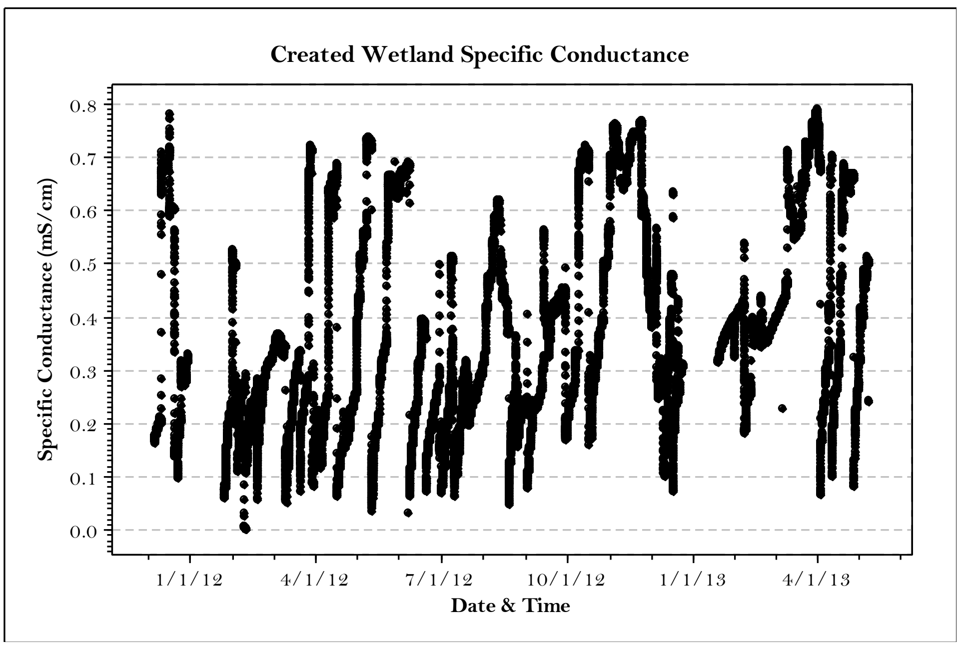

Figure 43. Results of automated continuous monitoring of specific conductance at the constructed wetland upstream of Alligator Pond.

Turbidity levels within the created wetland exhibited a median value of 13.90 NTU and varied between 0 and 1292.40 NTU (Figure 44). The majority (75th percentile) were less than or equal to 20.40 NTU. Highest (99.9th percentile) readings (≥ 352.0 NTU) were observed in May-August 2012, November-December 2012 and February 2013. Highest turbidity levels were normally associated with periods of freshwater inflow.

The pH levels within the created wetland exhibited a median value of 13.90 NTU and varied between 0 and 1292.40 NTU (Figure 45). The majority (75th percentile) were less than or equal to 7.2 units. The lowest quartile value was 6.96 units. Highest (99.9th percentile) readings (≥ 9.6 units) were observed in December 2011, February 2012, May-June 2012 and May 2013. Highest pH levels were normally associated with periods of high algal growth during warm weather months. All values were within levels that support aquatic life.

The relative fluorescence levels (RFU) in equivalent µg/L chlorophyll-*a* within the created wetland exhibited a median value of 13.50 µg/L and varied between 0 and 500 µg/L (Figure 46). The majority (75th percentile) were less than or equal to 17.8 µg/L. The lowest quartile value was 13.5 µg/L. Highest (99.9th percentile) readings (500.0 µg/L) were observed in February, May and July 2012. Highest RFU levels were normally associated with periods of high algal growth during warm weather months.

The dissolved oxygen levels within the created wetland exhibited a median value of 4.2 mg/L and varied between 0.0 and 18.6 mg/L (Figure 47). The majority (75th percentile) of readings were less than or equal to 6.8 mg/L. The lowest quartile value was 2.0 mg/L. Highest (99.9th percentile) readings (16.2 mg/L) were observed in February and May 2012. Highest dissolved oxygen levels were normally associated with periods of high algal growth and/or physical aeration during high flows.

Duck Pond – Control Area

The Duck Pond was located downstream and adjacent to the Alligator Pond which is associated with the constructed wetland. Water quality data was monitored at this waterbody to provide a regional control site. Similar to Alligator Pond and the constructed wetland water temperature followed normal seasonal trends (Figure 48). Water temperature fluctuated between 8.3 and 33.6 ºC with a median temperature of 21.9 ºC. We also divided the monitoring period to the period prior to and after construction of the wetland in order to directly compare the water quality at the control Duck pond to the appropriate time period of the Alligator Pond and the wetland. The median water temperature during the time period prior to construction of the wetland was significantly higher (23.8 versus 21.6 ºC) than the time period after construction of the wetland (Figure 49).

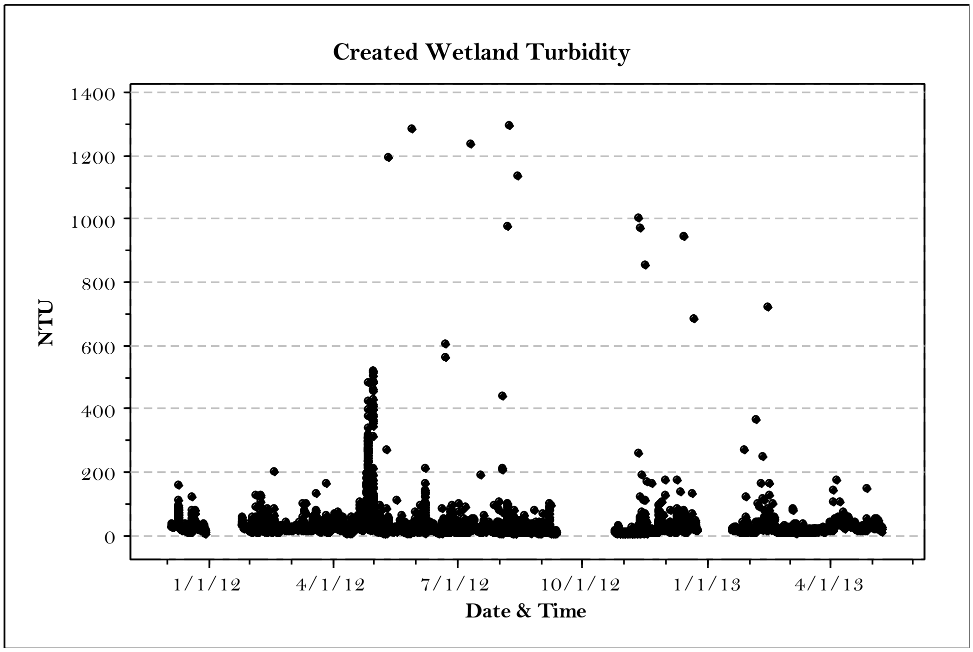

Figure 44. Results of automated continuous monitoring of turbidity at the constructed wetland upstream of Alligator Pond.

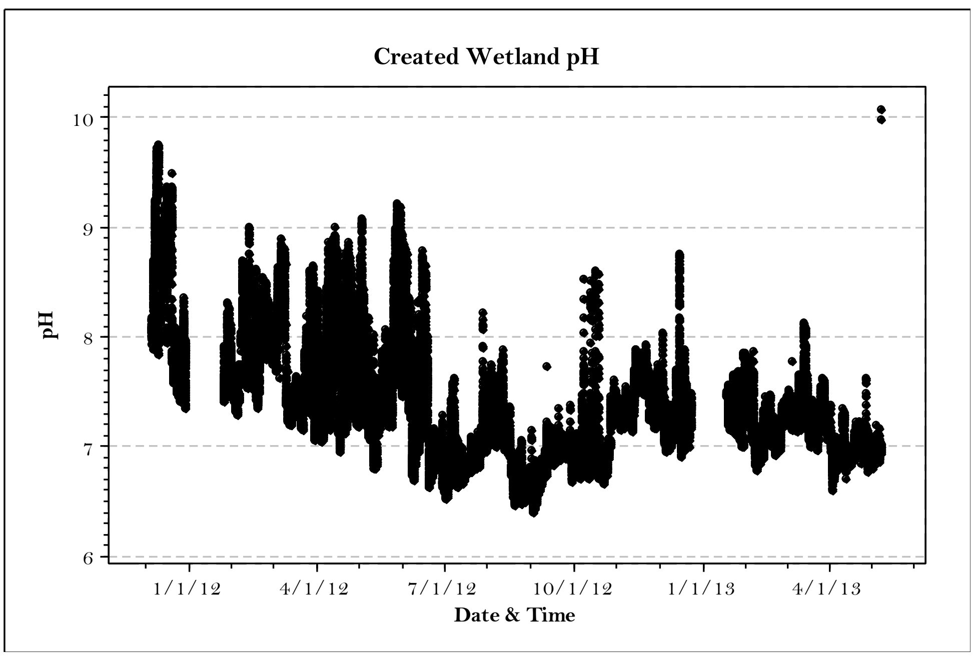

Figure 45. Results of automated continuous monitoring of pH at the constructed wetland upstream of Alligator Pond.

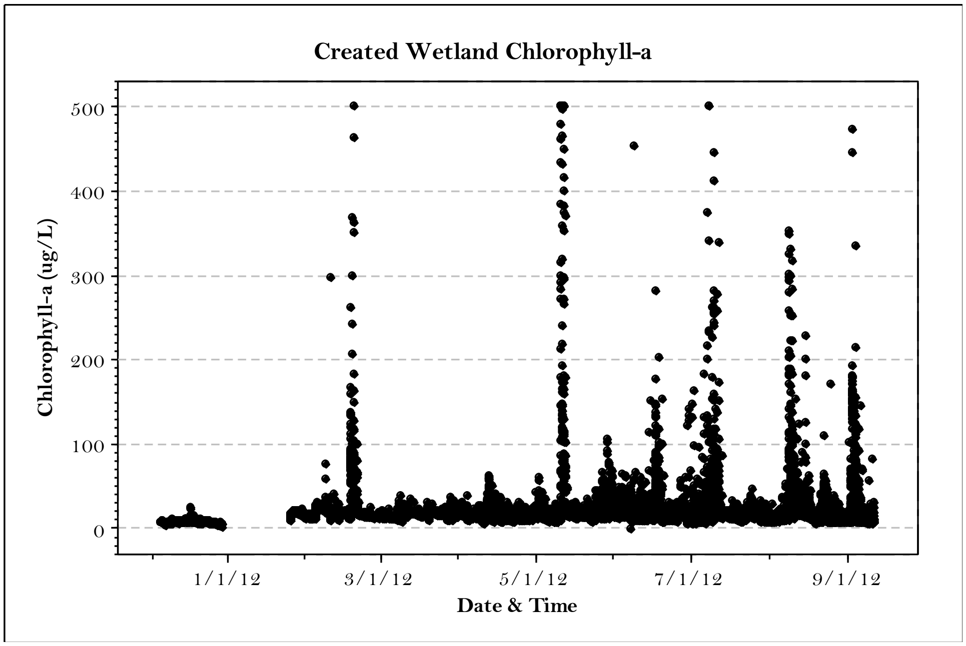

Figure 46. Results of automated continuous monitoring of chlorophyll-*a* at the constructed wetland upstream of Alligator Pond.

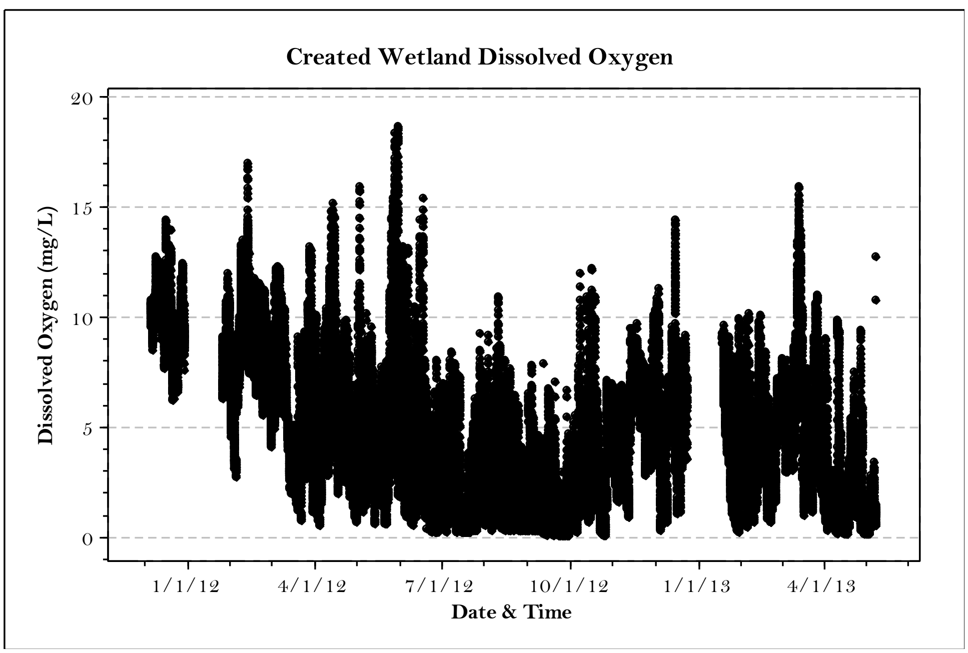

Figure 47. Results of automated continuous monitoring of dissolved oxygen at the constructed wetland upstream of Alligator Pond.

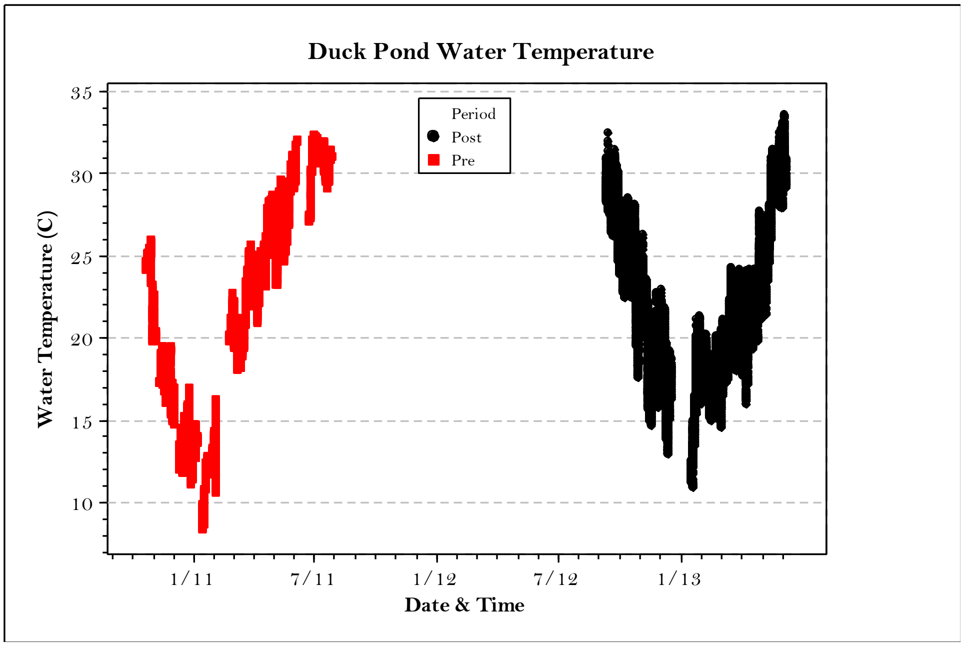

Figure 48. Results of automated continuous monitoring of water temperature at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond.

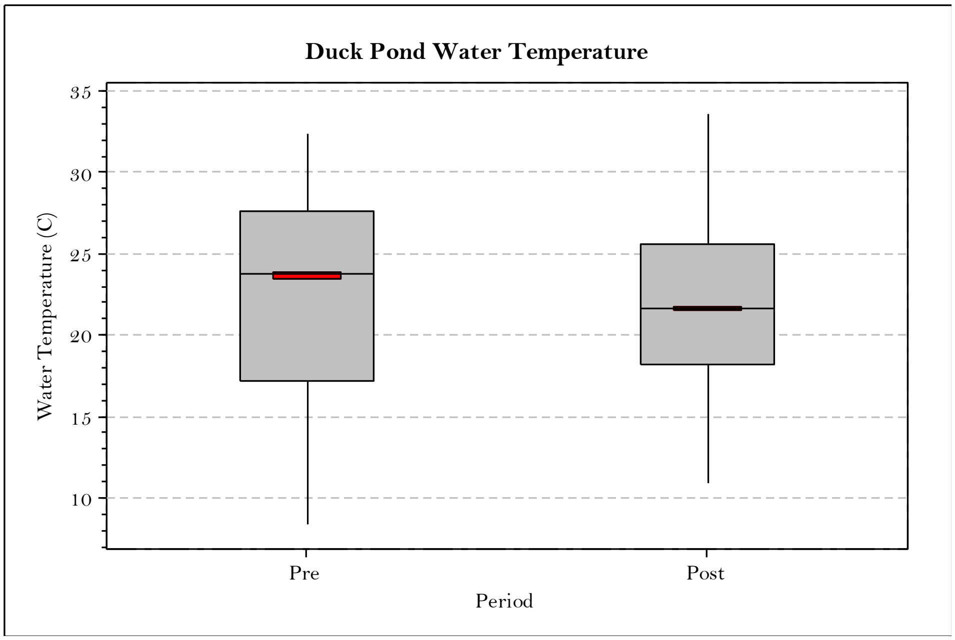

Figure 49. Boxplot of automated continuous monitoring of water temperature at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval for the median.

The specific conductance at the Duck Pond ranged between 0.098 and 0.536 mS/cm with a median level of 0.215 mS/cm (Figure 50). The majority (75th percentile) of values were 0.290 mS/cm or less. Median specific conductance levels were higher during the preconstruction period of the wetland (Figure 51). The highest (≥ 99.9th percentile) values (≥ 0.534 mS/cm) were encountered during May and June 2011 during the preconstruction phase of the wetland.

During the study period the turbidity at the Duck Pond ranged between 0.00 and 1540.00 NTUs with a median value of 11.20 NTU (Figure 52). The majority (75th percentile) were less than or equal to 16.70 NTU. The largest (> 99.9th percentile) turbidity values (1448.34 NTU) were observed during July 2011. Additional months that exhibited high (≥ 1200 NTU) turbidity values included October 2010, April 2011, June 2011, and April and May 2012. The median turbidity was lower during the pre-wetland period versus the post-wetland construction

The pH at the Duck Pond ranged between 4.1 and 9.6 unit with a median level of 7.3 units (Figure 54). The majority (75th percentile) of values were 7.8 pH units or less. Median pH levels were higher (7.5 versus 7.6) during the preconstruction period of the wetland (Figure 55). The highest (≥ 99.9th percentile) values (≥ 9.3 units) were encountered during December 2010, July 2011 and March 2013. Very low (< 5.0 pH units) were encountered during November 2010. The reason for these extremely low pH values is unknown. After November 2010 the pH steadily increased through March 2011. After that month pH values never fell below 6.5 standard units. From August 2011 through June 2012 automated monitoring of Duck Pond was not conducted.

The RFU levels in equivalent µg/L chlorophyll-*a* units ranged between 4.9 and 500.0 with a median level of 21.4 µg/L at the Duck Pond (Figure 56). The majority (75th percentile) of values were 33.5 µg/L or less. Relative fluorescence was not measured during the pre-wetland period due to the lack of available fluorometry probes (Figure 57). The highest (≥ 99.9th percentile) values (≥ 441.49 µg/L) were encountered during February through March 2013. RFU level was less than 100 µg/L during all monitored months in 2012. Automated monitoring of RFU was not conducted at the Duck Pond from December 18, 2012 through January 17 2013.

Dissolved oxygen levels at the Duck Pond ranged between 0.0 and 16.4 mg/L with a median level of 6.8 units (Figure 58). The majority (75th percentile) of values were 8.5 mg/L or less. Median dissolved oxygen levels were significantly lower (5.8 versus 7.2 mg/L) during the preconstruction period of the wetland (Figure 59). The highest (≥ 99.9th percentile) values (≥ 14.3 mg/L) were encountered during May 2011 and March 2013. Hypoxic conditions (< 2.0 mg/L dissolved oxygen) were encountered during October to November 2010, January to July 2011, September 2012, and March-May 2013. The reason for these extremely low dissolved oxygen levels is unknown but believed to be associated with warm weather conditions and periods following intense algal blooms. From August 2011 through August 2012 automated monitoring of dissolved oxygen in Duck Pond was not conducted due to probe malfunction and/or unavailability.

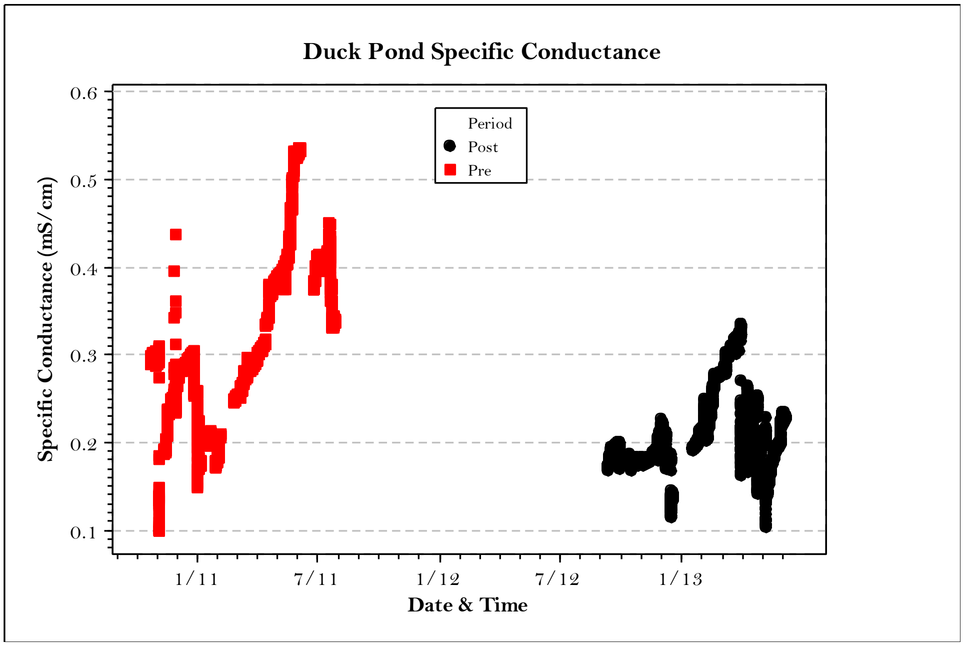

Figure 50. Results of automated continuous monitoring of specific conductance at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond.

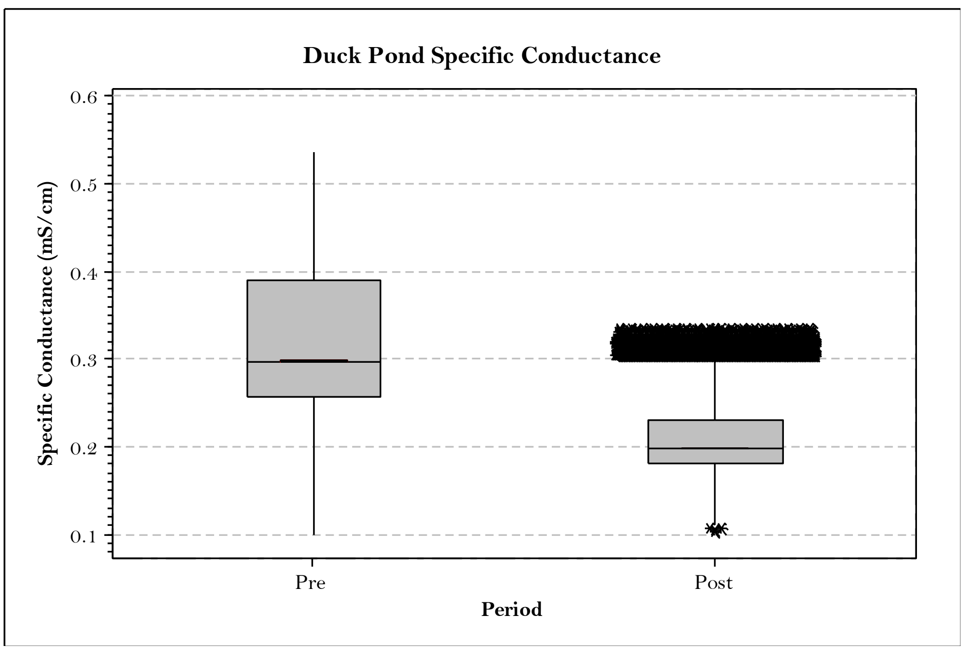

Figure 51. Boxplot of automated continuous monitoring of specific conductance at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval for the median.

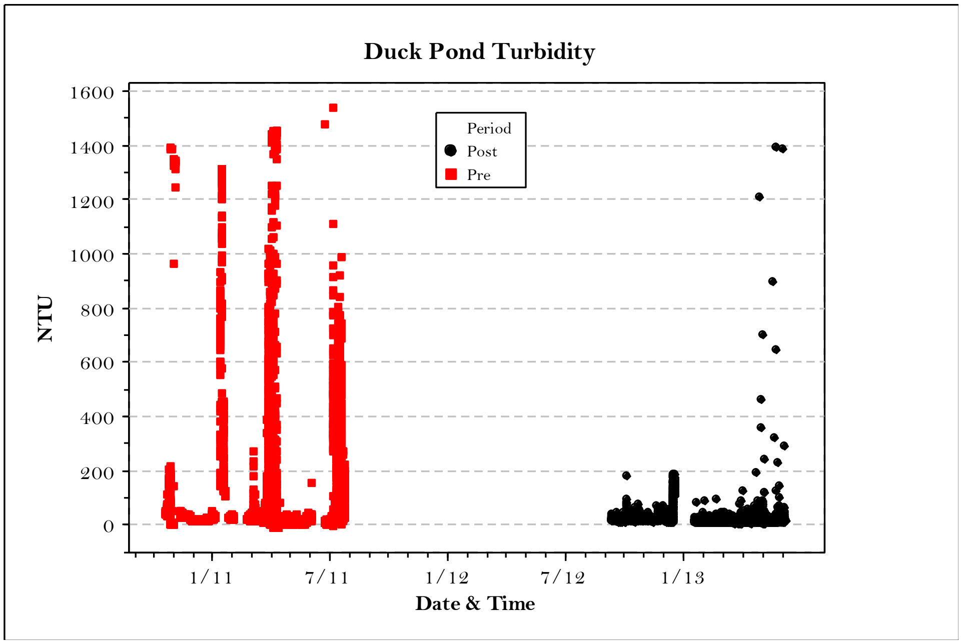

Figure 52. Results of automated continuous monitoring of turbidity at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond.

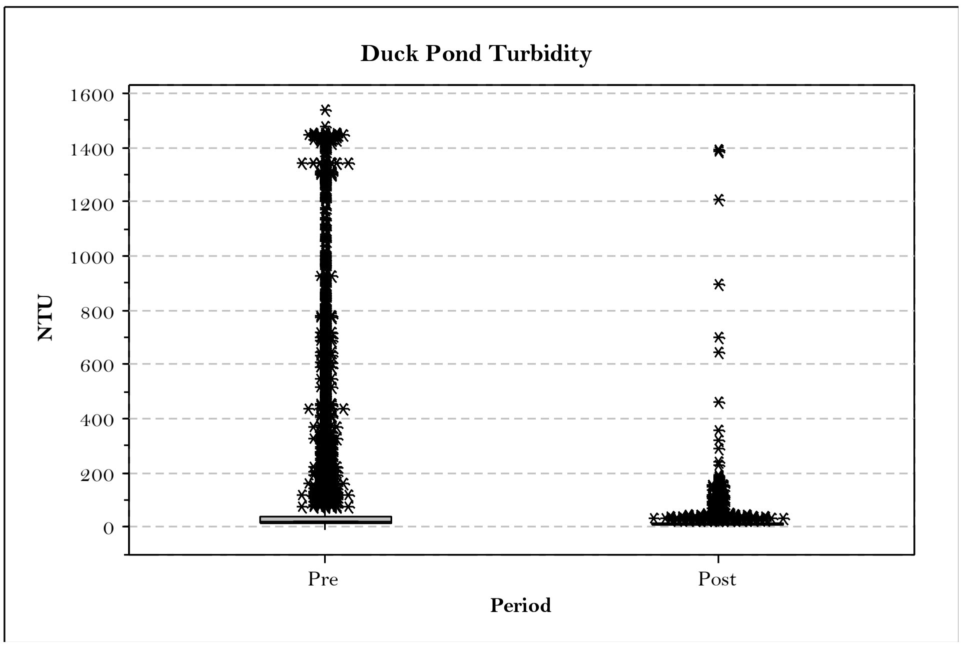

Figure 53. Boxplot of automated continuous monitoring of turbidity at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval.

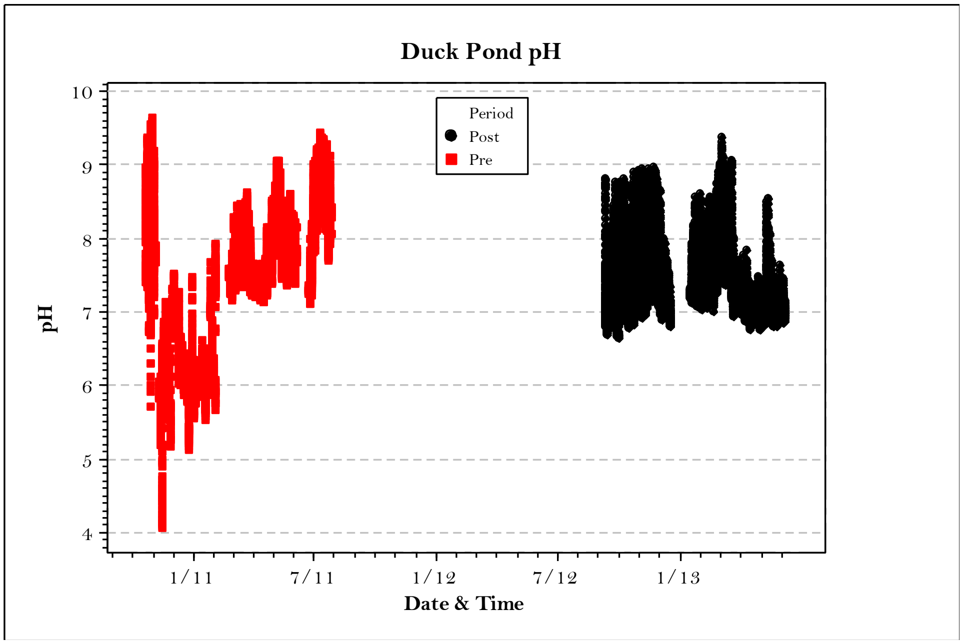

Figure 54. Results of automated continuous monitoring of pH at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond.

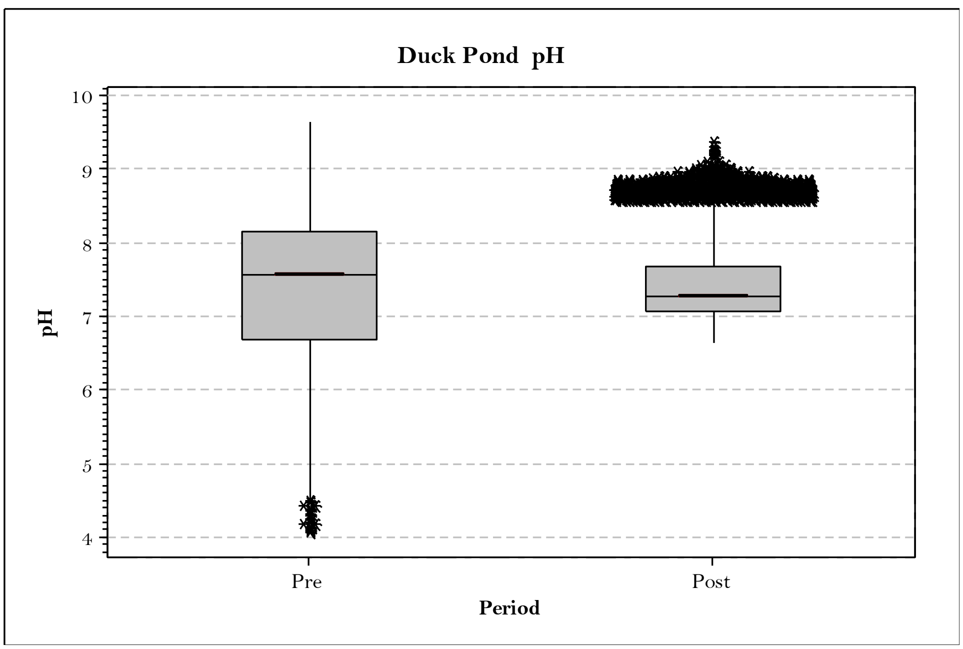

Figure 55. Boxplot of automated continuous monitoring of pH at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval of the median.

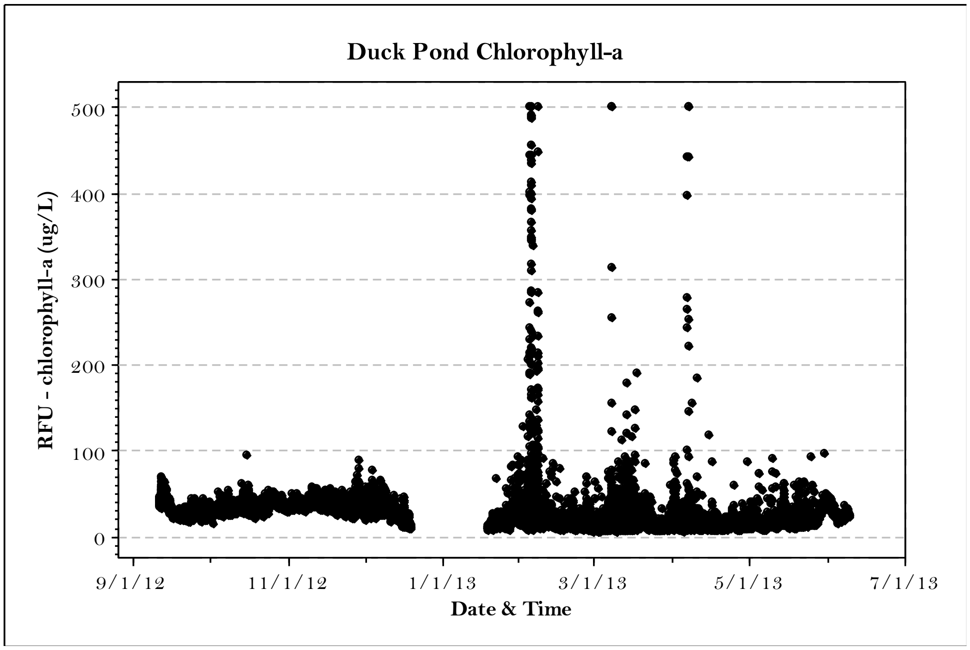

Figure 56. Results of automated continuous monitoring of relative fluorescent units (RFU) in µg/L equivalent chlorophyll-*a* at the Duck Pond after completion of the constructed wetland at Alligator Pond.

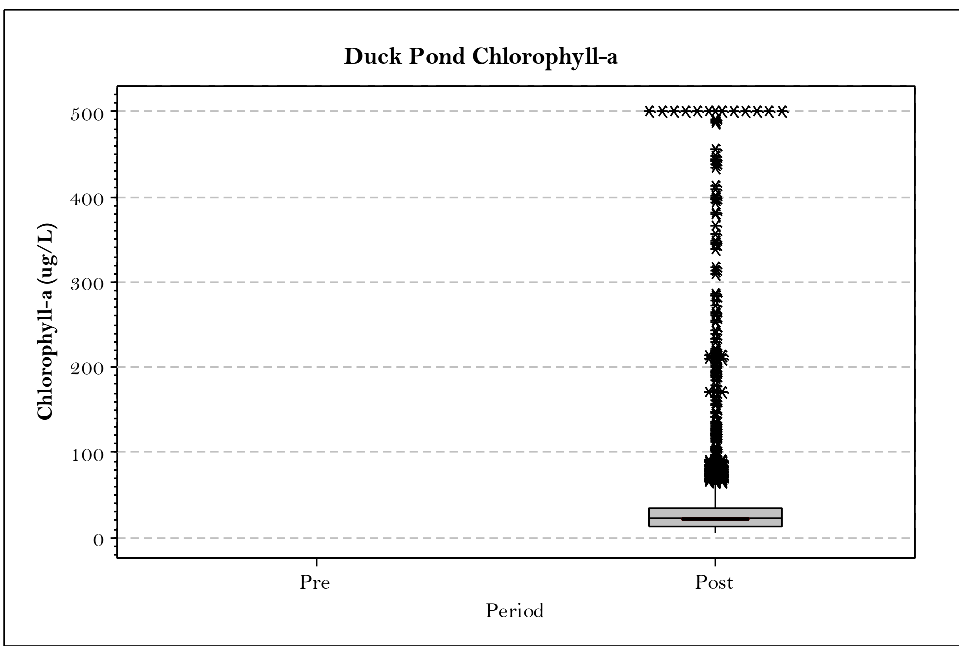

Figure 57. Boxplot of automated continuous monitoring of relative fluorescent units (RFU) in µg/L equivalent chlorophyll-*a* at the Duck Pond after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval of the median.

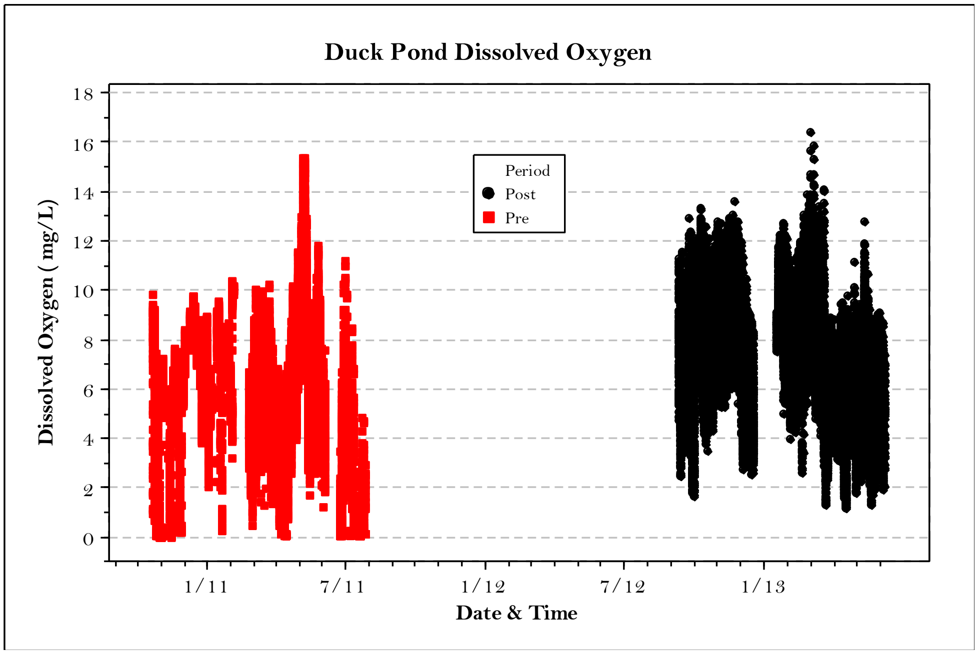

Figure 58. Results of automated continuous monitoring of dissolved oxygen at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond.

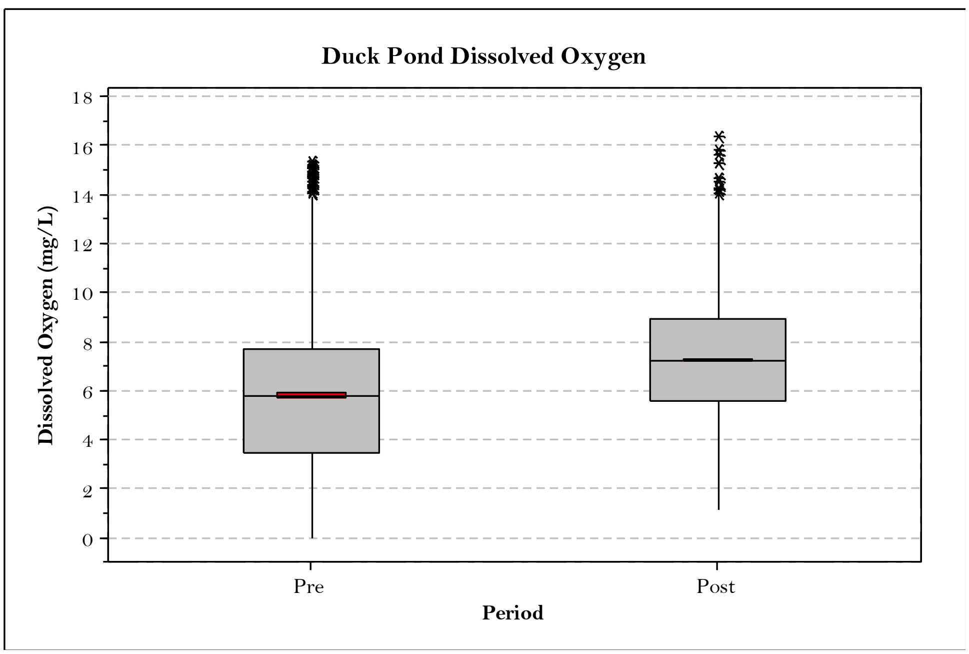

Figure 59. Boxplot of automated continuous monitoring of dissolved oxygen at the Duck Pond prior to and after completion of the constructed wetland at Alligator Pond. Red box denotes 95% confidence interval of the median.

Dry and Wet Weather Water Quality Sampling

A total of 29 water quality sampling events occurred between October 2010 and July 2013. Twenty sampling events occurred during the pre-construction phase of the project and 9 events during the post-construction phase (Table 5 and Table 6, respectively). During both construction phases of the project, dry and wet weather samples were collected at specified sites. Prior to completion of construction, sites 2 and 12 were sampled during every event and, starting in 2011, site 13 was sampled at every event. Between 2010 and July 2012 (including both pre- and post-construction phases), all samples collected at sites 2 and 12 were taken from the middle of the ponds. On 22 June 2013, sites 1, 4, and 8 were also sampled to establish wet weather conditions within the complex prior to completion of construction. Only summary data is presented to evaluate the overall effectiveness of the wetland system at the downstream discharge point of the wetland. The remaining data is electronically available for further analysis.

Construction of the wetland complex was completed in July 2011. Two water quality sample events occurred that month. One sampling event occurred prior to official completion of construction on July 6, 2011 and one event just after completion of construction on July 19, 2011. This second event was conducted to establish baseline levels within the wetland complex before any new, natural recruitment by vegetation occurred within the complex. For the purposes of water quality sampling the period starting on July 20, 2011 is considered the post-construction period. However, for the purposes of automated water quality monitoring, which was described earlier, the period through August 8, 2011 is considered part of the pre-construction phase. In most cases automated monitoring in the post construction phase did not start till after October 2011.

A summary of water quality data collected at the end of the wetland system during the study period before and after construction of the wetland and during wet and dry weather conditions is presented in (Figure 61- 108). The number of samples collected was fairly evenly distribution before and after construction of the wetland system (Figure 60). However, due to the staggered nature of sample collection the number of samples collected between sites was not equivalent (Figure 61). A higher number of samples were collected at Horsepen Bayou to provide a comparison with the two pond systems. With the exception of mainstem Horsepen Bayou, more samples were generally collected after the construction of the wetland upstream of Alligator Pond (Figure 62). With the exception of Horsepen Bayou, generally there were more samples collected during wet weather conditions (Figure 63). Due to irregular and sometimes turbulent flow it was difficult to estimate the flow rate during some sampling events. This resulted in a wide range of estimated flow regimes through the wetland and/or ponds (Figure 64). Fortunately we used daily precipitation as a metric of freshwater input to the wetland and pond systems (Figure 65). The highest daily rainfall event that was sampled was 1.68 inches of precipitation during the pre-wetland period.

Table 5 Water Quality Sampling events pre-construction at the created wetland on the UHCL campus. Note: samples taken at site 2 and 12 from 2010 up to July 2012 were taken from the middle of the ponds.

	Date	Event	Site	Description
Pre Construction	10/20/2010	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	10/27/2010	Wet	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	11/3/2010	Wet	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	11/10/2010	Wet	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	11/17/2010	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	11/23/2010	Wet	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	12/1/2010	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	12/8/2010	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	12/21/2010	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	1/6/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	1/20/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	2/2/2011	Wet	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
	2/16/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou

Table 5 cont. Water Quality Sampling events pre-construction at the created wetland on the UHCL campus. Note: samples taken at site 2 and 12 from 2010 up to July 2012 were taken from the middle of the ponds.

	Date	Event	Site	Description
Pre Construction	3/2/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	4/8/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	4/22/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	5/18/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	6/22/2011	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	6/29/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	7/6/2011	Dry	2	Outlet Control (Duck) Pond
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	7/19/2011	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409

Table 6. Water Quality sampling events post-construction at the created wetland on the UHCL campus. Note: samples taken at site 2 and 12 from 2010 up to July 2012 were taken from the middle of the ponds.

	Date	Event	Site	Description
Post Construction	8/24/2012	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			5	Primary Treatment wetland Inlet - primary wetland complex *first flush sampler*
			6	Treatment wetland road ditch inlet - Inlet to secondary wetland
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			9	Secondary Treatment Wetland inlet *first flush sampler*
			10	Secondary Treatment wetland outlet- at weir overfall
			11	Secondary Treatement wetland outlet *first flush sampler*
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
			14	Precipitation and Dry Deposition Collector at EIH building
	9/6/2012	Dry	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			7	Solar powered Inlet from Horsepen Bayou - *dry weather only*
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			10	Secondary Treatment wetland outlet- at weir overfall
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	9/24/2012		14	Precipitation and Dry Deposition Collector at EIH building
	2/6/2013	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			5	Primary Treatment wetland Inlet - primary wetland complex *first flush sampler*
			6	Treatment wetland road ditch inlet - Inlet to secondary wetland
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			9	Secondary Treatment Wetland inlet *first flush sampler*
			10	Secondary Treatment wetland outlet- at weir overfall
			11	Secondary Treatement wetland outlet *first flush sampler*
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
			14	Precipitation and Dry Deposition Collector at EIH building

Table 6 cont. Water quality sampling events post-construction at the created wetland on the UHCL campus. Note: samples taken at site 2 and 12 from 2010 up to July 2012 were taken from the middle of the ponds.

	Date	Event	Site	Description
Post Construction	3/1/2013	Dry	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			7	Solar powered Inlet from Horsepen Bayou - *dry weather only*
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			10	Secondary Treatment wetland outlet- at weir overfall
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
			14	Precipitation and Dry Deposition Collector at EIH building
	6/17/2013	Dry	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			7	Solar powered Inlet from Horsepen Bayou - *dry weather only*
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			10	Secondary Treatment wetland outlet- at weir overfall
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
	6/21/2013		14	Precipitation and Dry Deposition Collector at EIH building
	7/15/2013	Wet	1	Inlet Control (Duck) Pond
			2	Outlet Control (Duck) Pond
			4	Primary Treatment wetland Inlet - primary wetland complex
			5	Primary Treatment wetland Inlet - primary wetland complex *first flush sampler*
			6	Treatment wetland road ditch inlet - Inlet to secondary wetland
			8	Secondary Treatment Wetland inlet, immediately upstream of site 6 and site 7
			9	Secondary Treatment Wetland inlet *first flush sampler*
			10	Secondary Treatment wetland outlet- at weir overfall
			11	Secondary Treatement wetland outlet *first flush sampler*
			12	Downstream of treatment wetland at Alligator Pond standpipe into Horsepen Bayou
			13	Horsepen Bayou at Bay Area Blvd, TCEQ Station ID:11409
			14	Precipitation and Dry Deposition Collector at EIH building

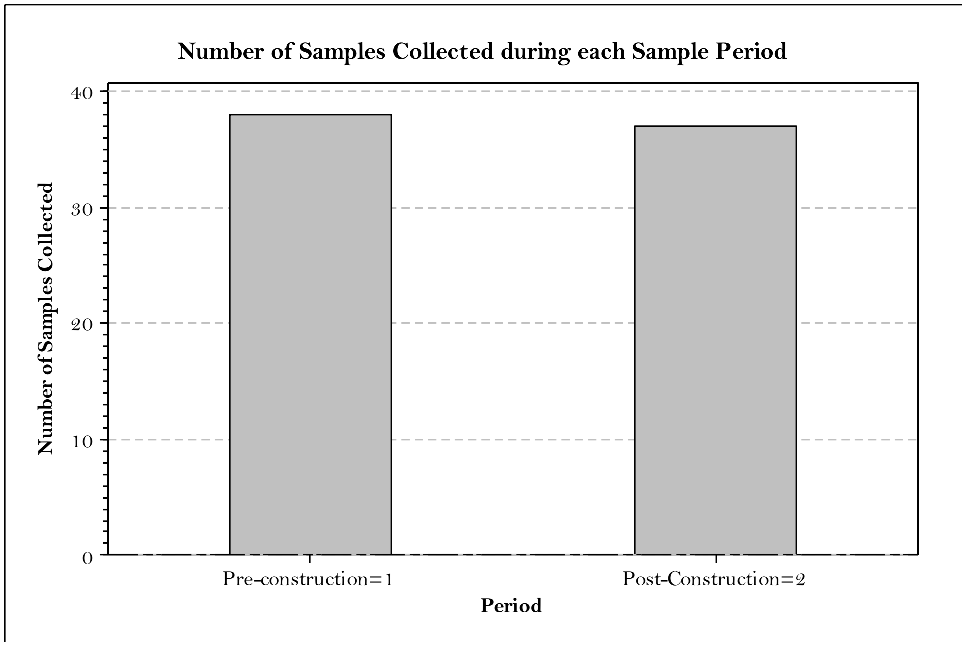

Figure 60. Number of discharge samples collected before and after construction of the wetland from all three sites combined including Alligator Pond located downstream of the constructed wetland, the control site Duck Pond and the upstream receiving water Horsepen Bayou at Bay Area Blvd.

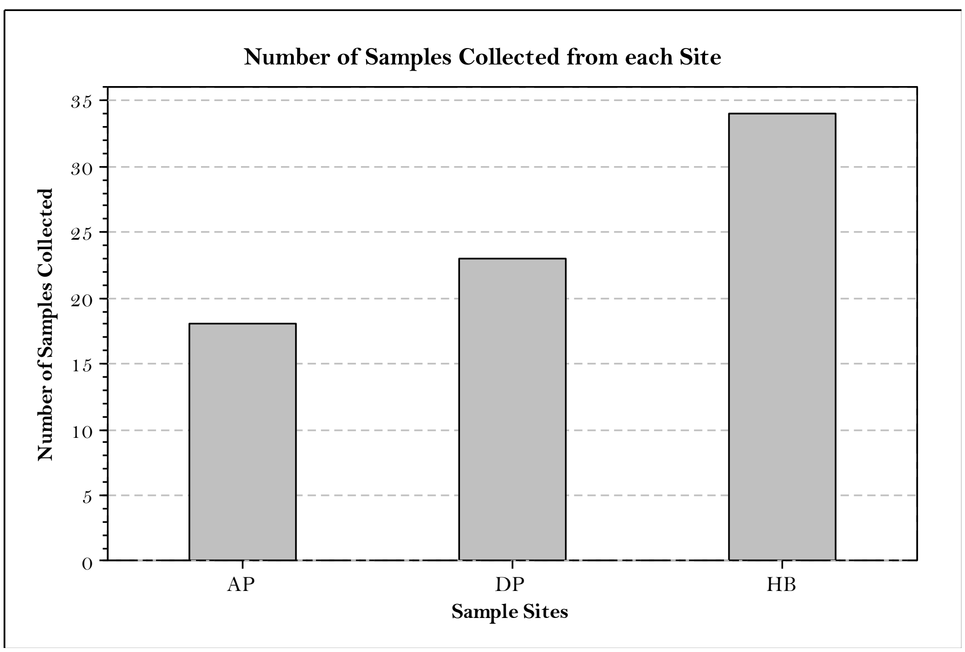

Figure 61. Number of discharge samples collected from Alligator Pond located downstream of the constructed wetland, the control site Duck Pond and the upstream receiving water Horsepen Bayou at Bay Area Blvd during pre-construction and post-construction wetland periods.

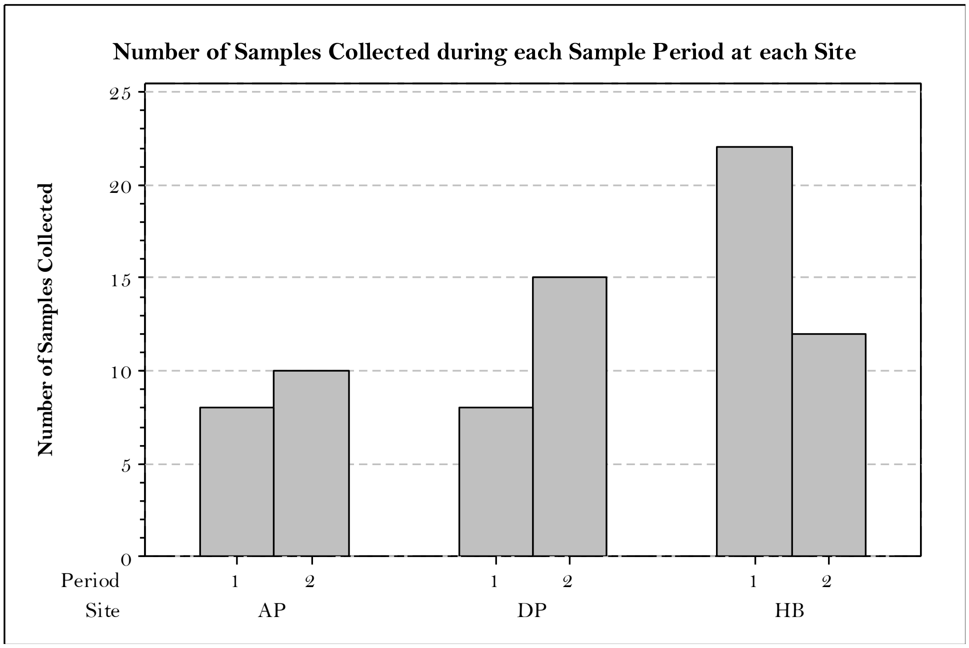

Figure 62. Number of discharge samples collected before and after construction of the wetland from Alligator Pond (AP) located downstream of the constructed wetland, the control site Duck Pond (DP) and the upstream receiving water Horsepen Bayou (HB) at Bay Area Blvd.

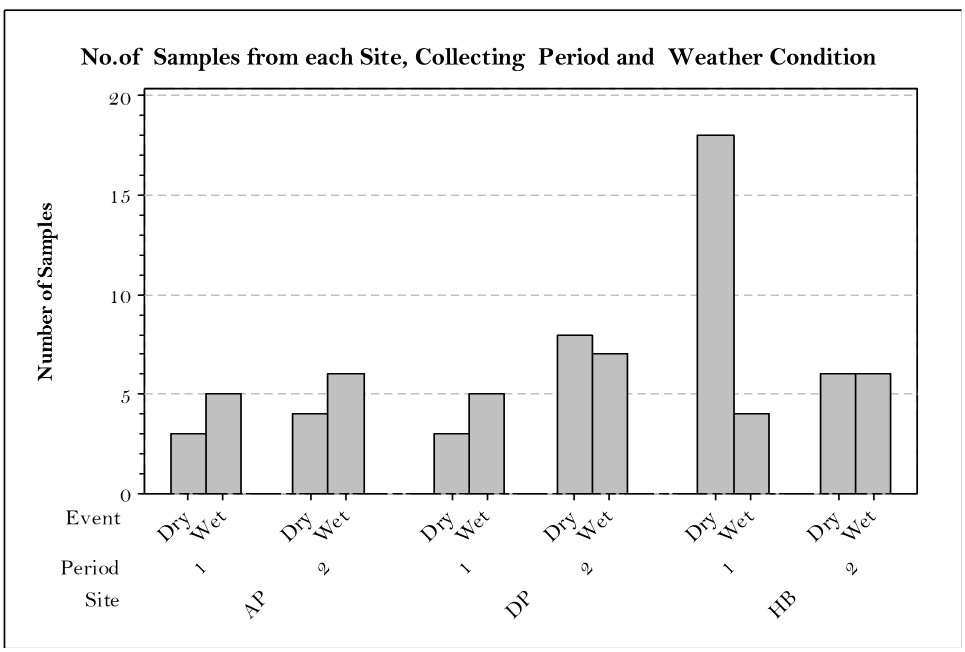

Figure 63. Number of discharge samples collected during wet and dry weather conditions, before and after construction of the wetland from AP located downstream of the constructed wetland, the control site DP and the upstream receiving water HB at Bay Area Blvd.

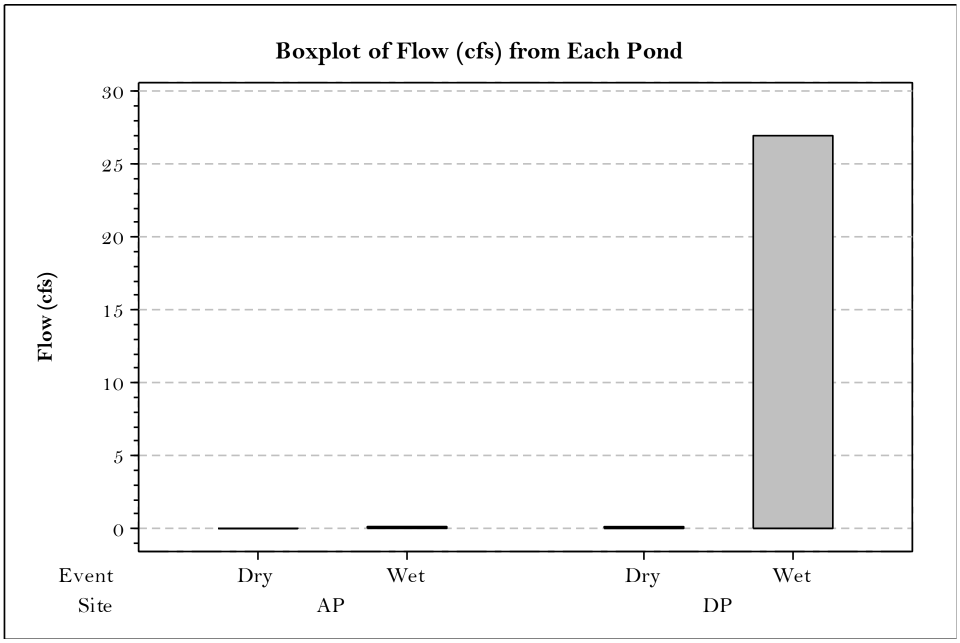

Figure 64. Boxplot showing the distribution of estimated flows from Alligator Pond (AP) located downstream of the constructed wetland and the control site Duck Pond (DP).

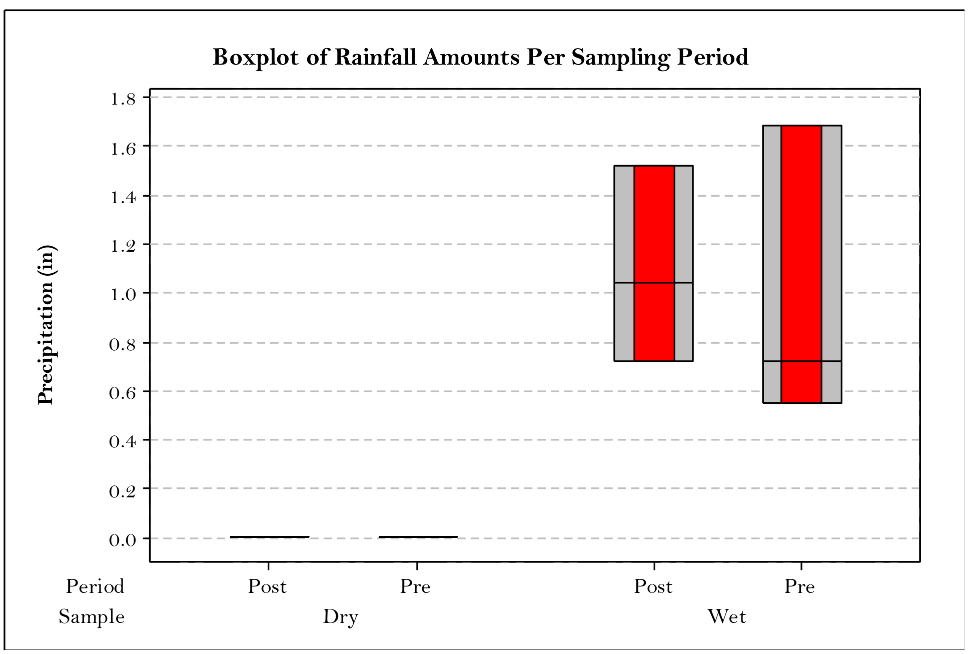

Figure 65. Daily precipitation levels which occurred during water quality sampling events at the two ponds and HB during dry and wet weather conditions before and after installation of the wetland.

The water temperature measured during sample collection reflected seasonal trends. Each site exhibited similar temperature regimes (Figure 67). The specific conductance and salinity regimes reflected the tidal nature and influence of drought conditions on Horsepen Bayou (Figure 68 - 71). The pH values measured were within levels that support aquatic life during both wet and dry weather conditions (Figure 72 - 73). However, the elevated pH levels observed at the Duck Pond suggest this waterbody is eutrophic. This pattern is consistent with the observed algal blooms consisting of blue green algal mats that occur there each year. The highest levels of pH usually occurred during dry weather sampling. This is likely due to reduced turbidity that allows light to penetrate the water column and stimulate algal growth.

Dissolved oxygen levels appeared to approach hypoxic conditions during the pre-construction phase at Alligator Pond in comparison to the post-construction period. (Figure 74 and 75). The Duck Pond never exhibited low oxygen levels. Carbonaceous oxygen demand remained low (< 6 mg/L) and never approached high levels (Figure 76 and 77). This suggests that organic loading is not a major issue in either ponds watershed. The total organic carbon content of the water column declined at the Alligator Pond after installation of the wetland during both wet and dry weather conditions (Figure 78 and 79). However, this decline was also observed at both the Duck Pond and to a lesser extent Horsepen Bayou. The cause of this general decline is unknown, but the greatest difference or reduction occurred at the Alligator Pond after construction of the wetland.

Although statistically insignificant, nitrate and nitrite nitrogen levels appeared to decline at the Alligator Pond after construction of the wetland complex (Figure 80 and 81). However, this decline was also observed at the Duck Pond and Horsepen Bayou. However, the levels of nitrates and nitrites was highly elevated (>2 mg/L) in Horsepen Bayou. Ammonia nitrogen levels actually increased at the Alligator Pond after wetland construction during dry weather conditions (Figure 82 and 83). In contrast all sites exhibited declining ammonia nitrogen levels during the period after wetland construction. These trends were however statistically insignificant (95% confidence interval of median values overlaps). The calculated total nitrogen levels (TKN + NO_{2+3}-N) exhibited statistically significant declines in median total nitrogen levels during dry weather conditions at the Alligator Pond and Duck Pond after installation of the wetland (Figure 84 and 85). This decline was less obvious during wet weather sampling and was not statistically significant at the Alligator Pond and Horsepen Bayou sites. The highest total nitrogen levels were generally observed at the Duck Pond.

The greatest decline in any nutrient occurred in the reduction of orthophosphates and total phosphorus at the Alligator Pond after construction of the wetland (Figure 86 - 89). Less dramatic declines which were statistically insignificant occurred at the Duck Pond. However, significant declines in phosphorus occurred within Horsepen Bayou. It should be noted, that due to the intrusion of the salt-wedge into the bayou, the dynamics of free phosphorus ions can be influenced by the hypoxia often associated with this halocline. Under hypoxic conditions, phosphorus can be remobilized from the sediment.

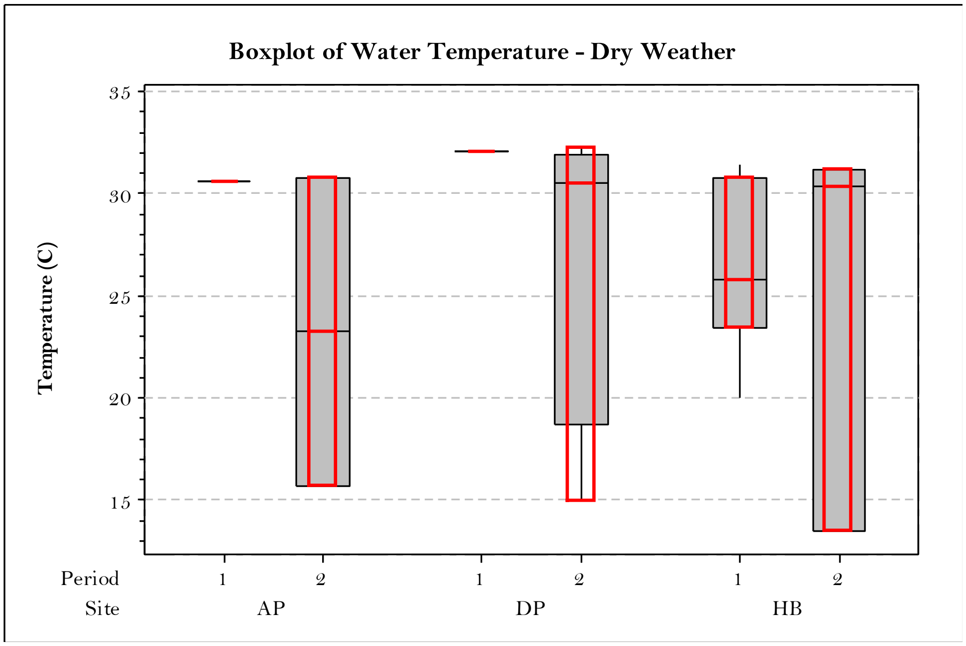

Figure 66. Boxplot of water temperature measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

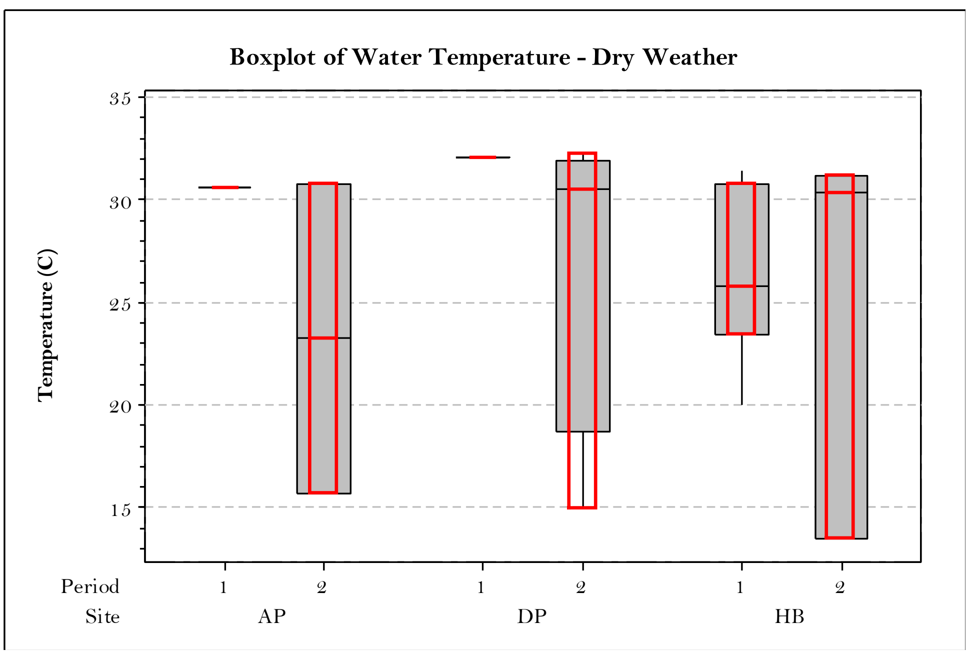

Figure 67. Boxplot of water temperature measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

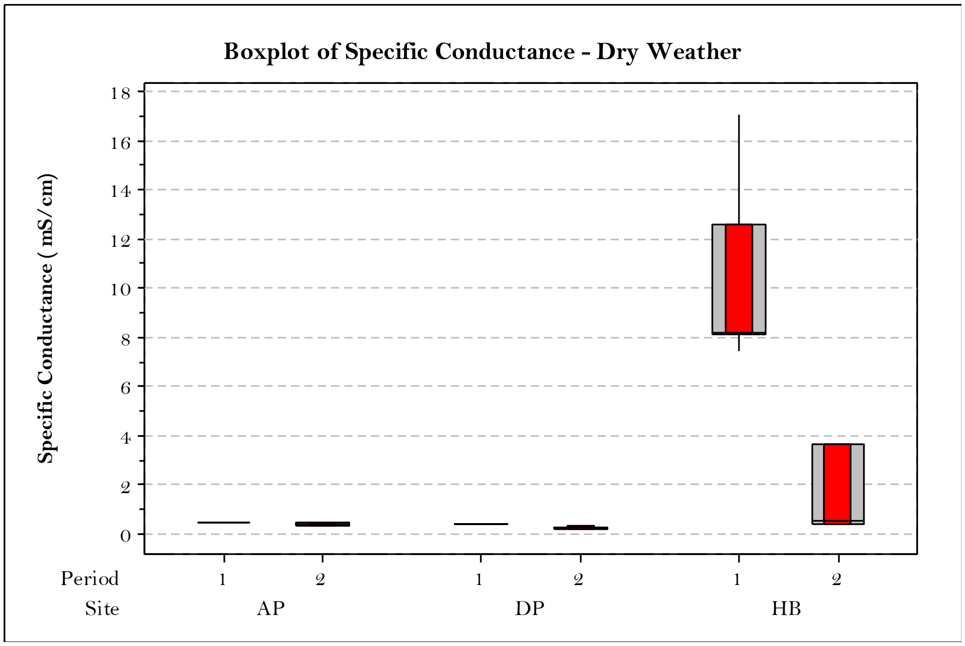

Figure 68. Boxplot of specific conductance measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

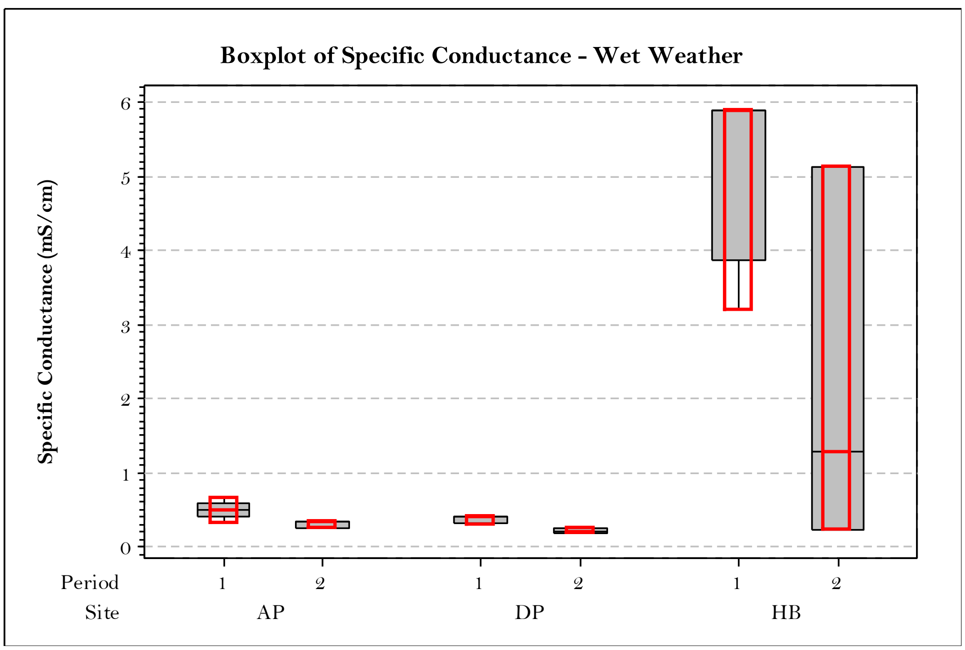

Figure 69. Boxplot of specific conductance measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

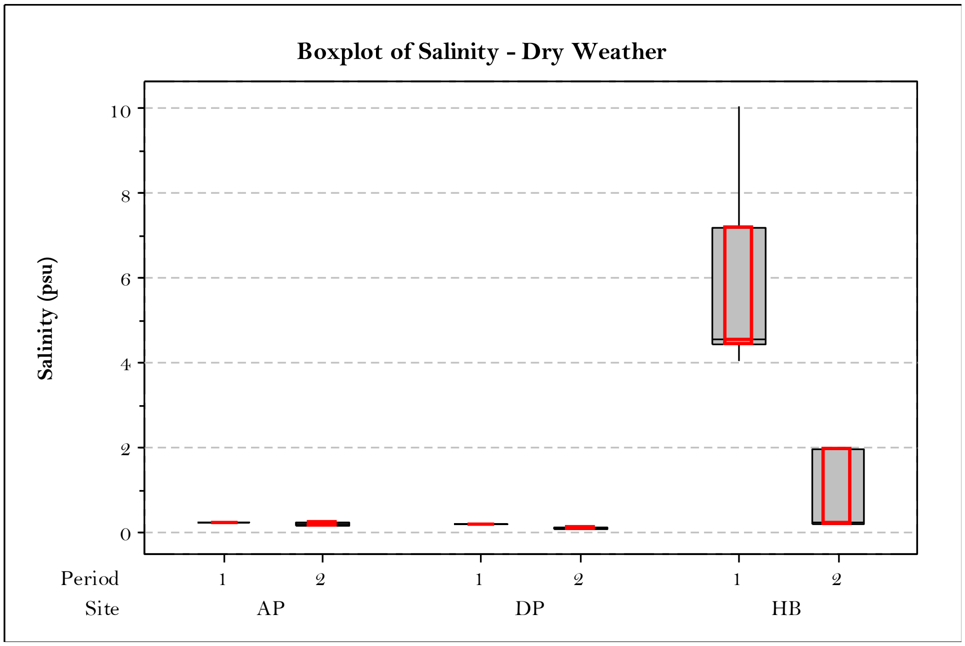

Figure 70. Boxplot of salinity measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

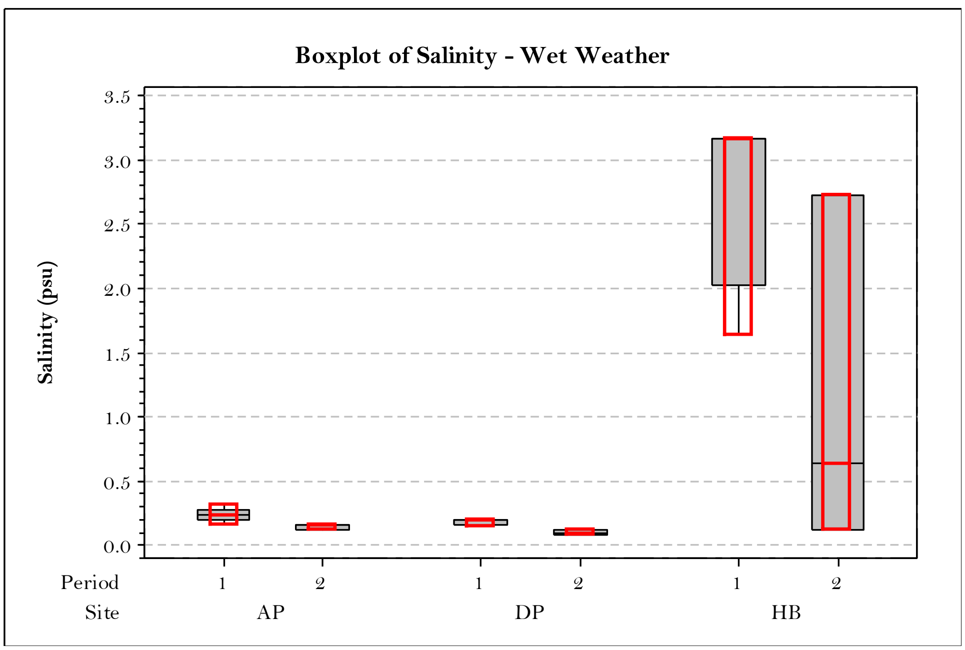

Figure 71. Boxplot of salinity measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

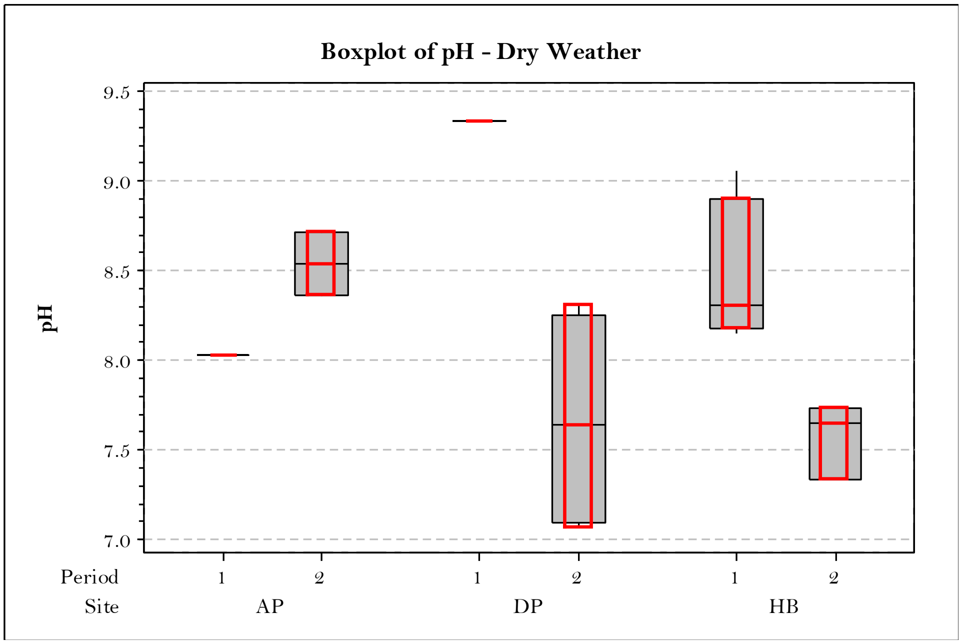

Figure 72. Boxplot of pH measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

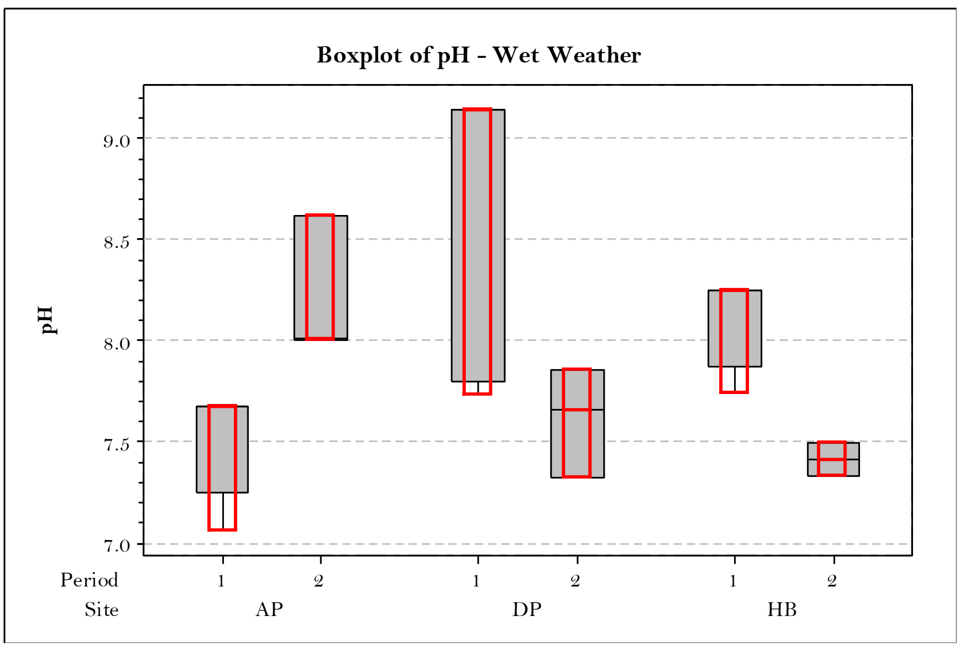

Figure 73. Boxplot of pH measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

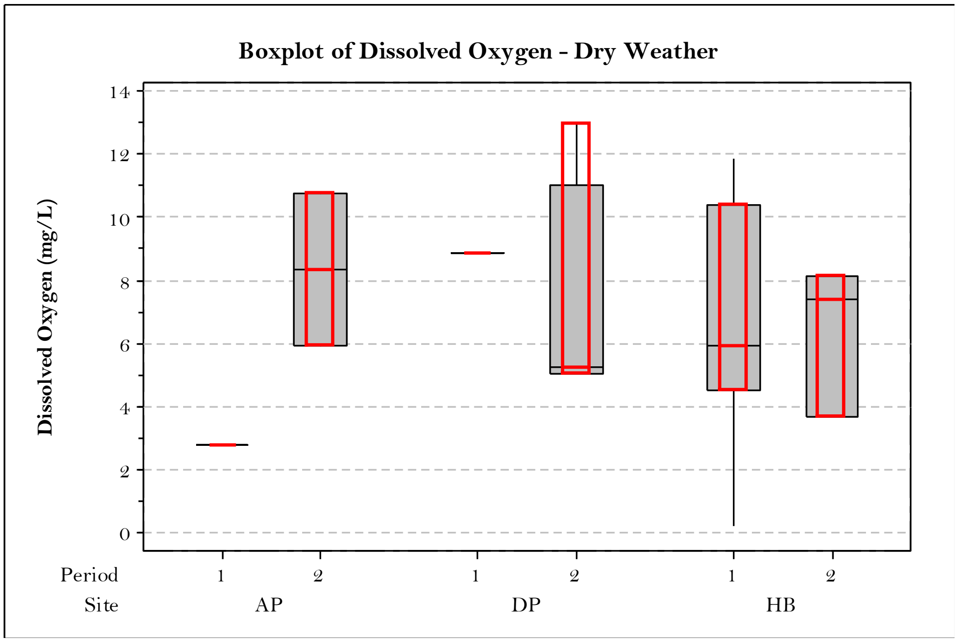

Figure 74. Boxplot of dissolved oxygen measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

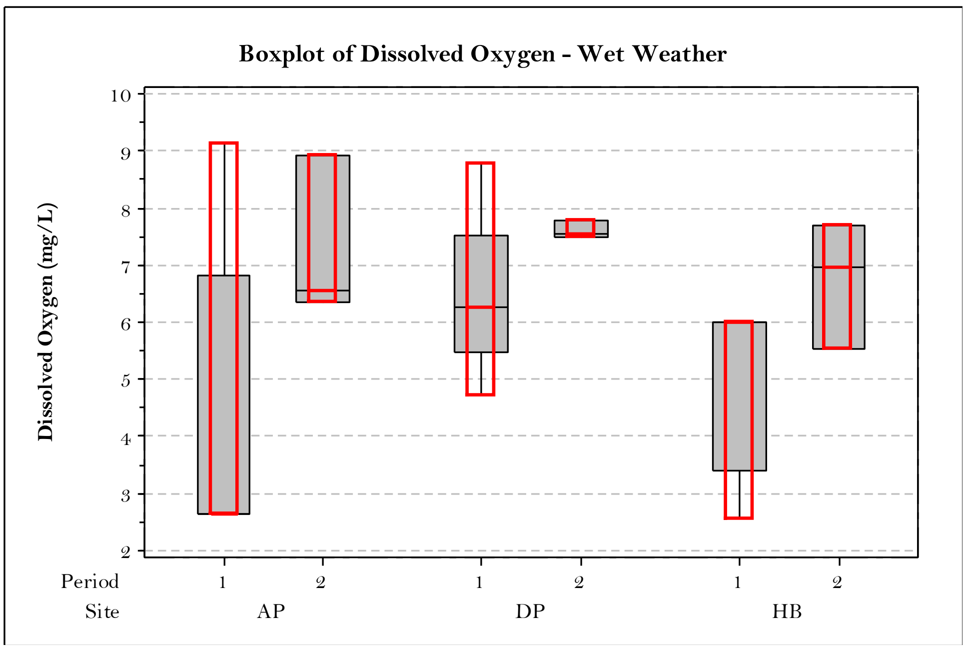

Figure 75. Boxplot of dissolved oxygen measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

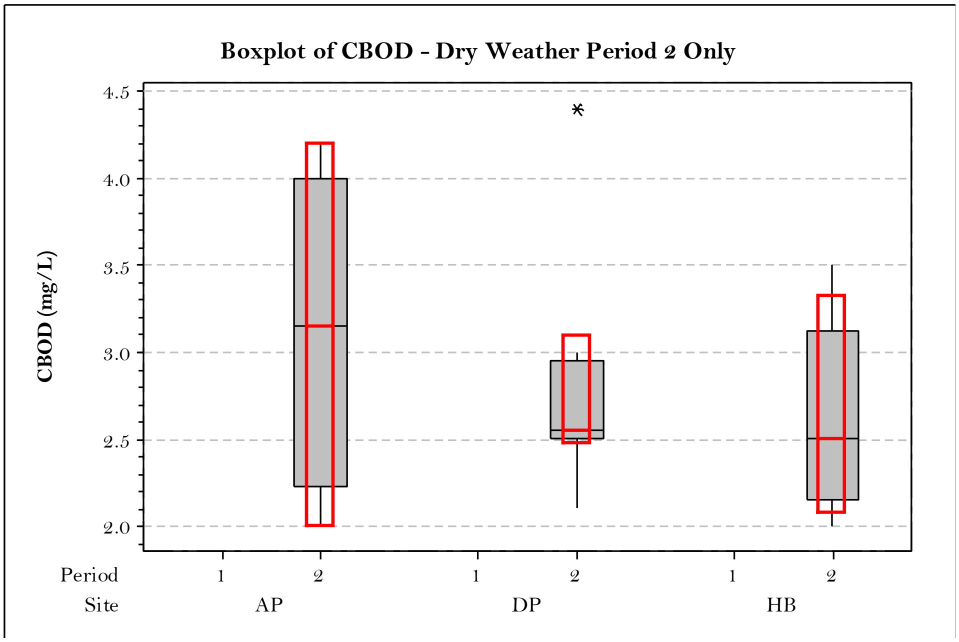

Figure 76. Boxplot of carbonaceous biochemical oxygen demand measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median. No measurements made during period 1.

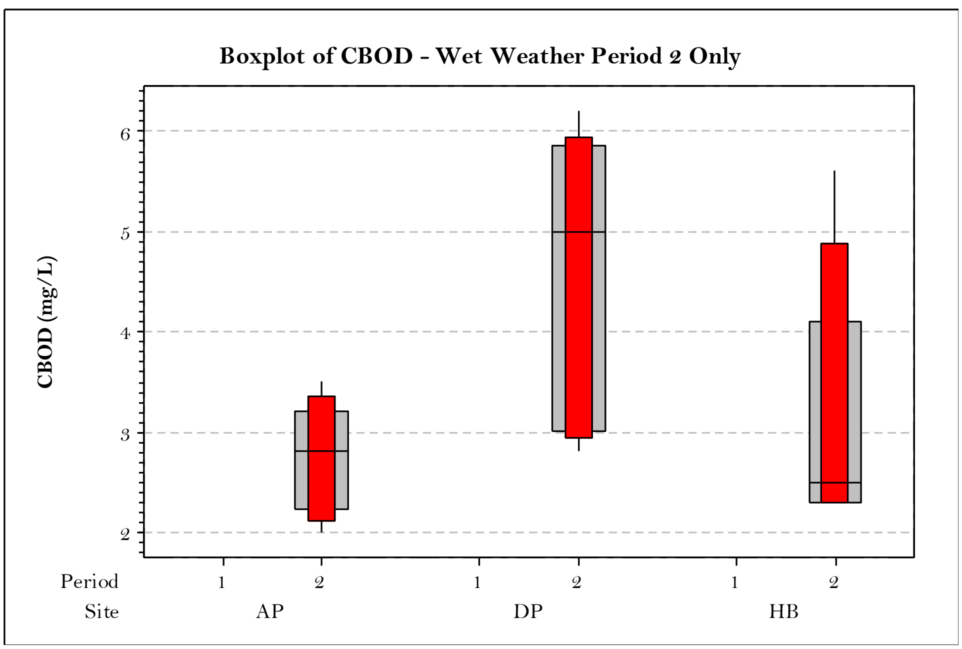

Figure 77. Boxplot of carbonaceous biochemical oxygen demand measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median. No measurements made during period 1.

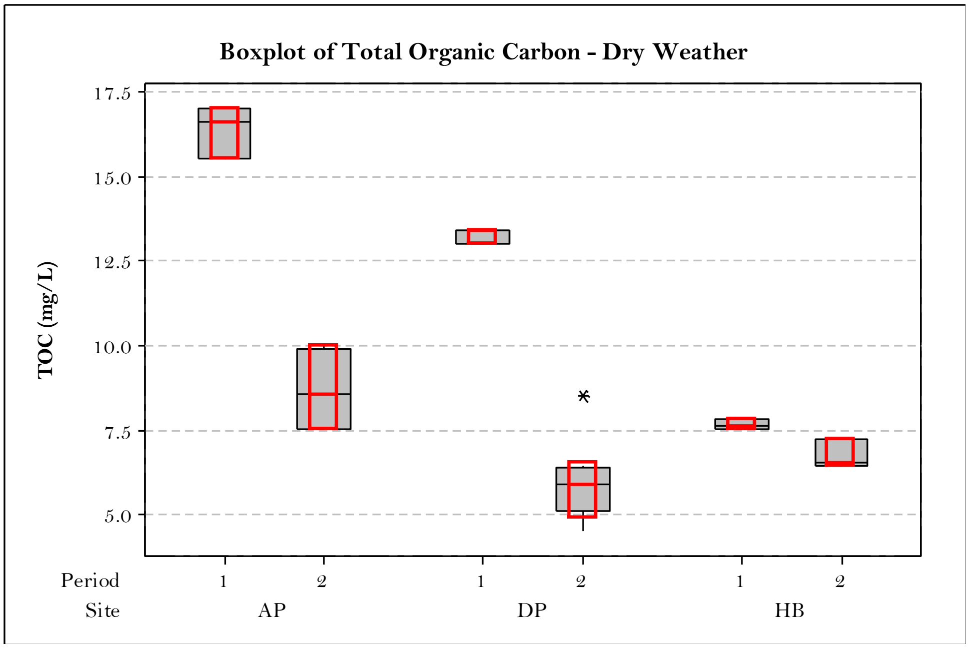

Figure 78. Boxplot of total organic carbon measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

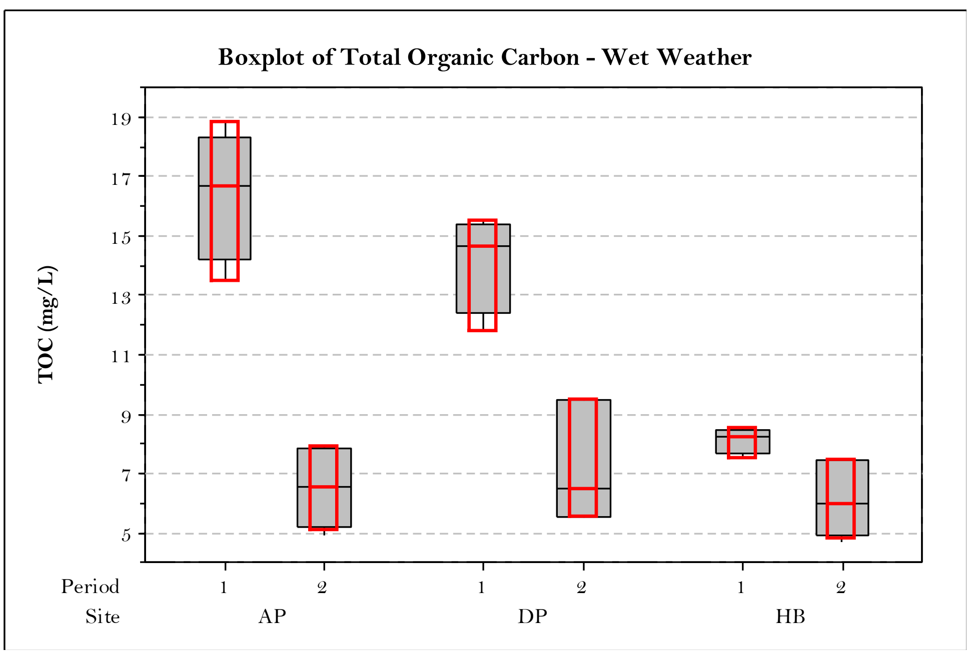

Figure 79. Boxplot of total organic carbon measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

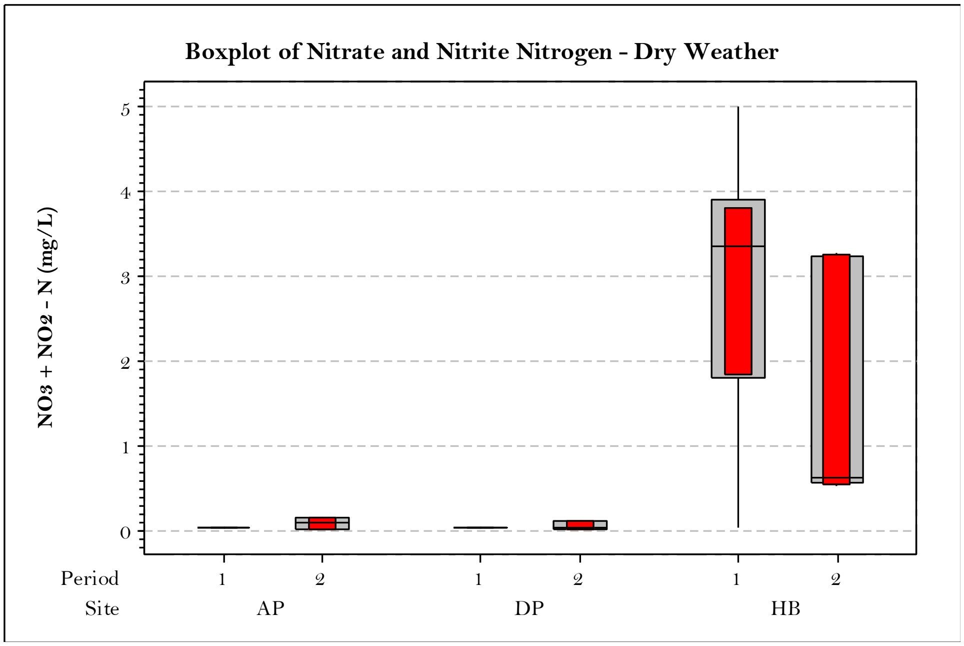

Figure 80. Boxplot of nitrate plus nitrite nitrogen measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

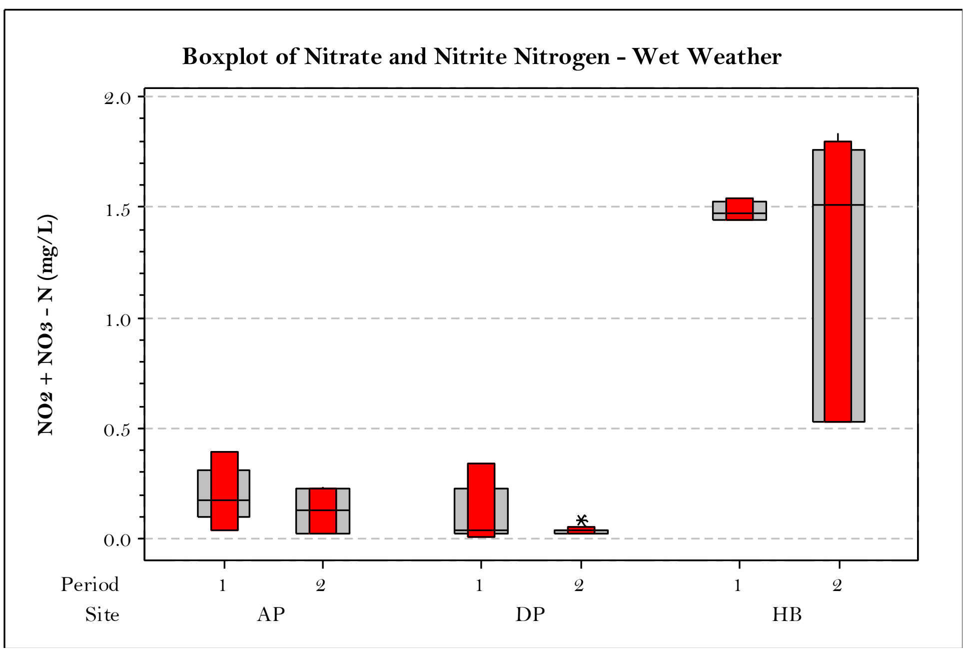

Figure 81. Boxplot of nitrate plus nitrite nitrogen measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

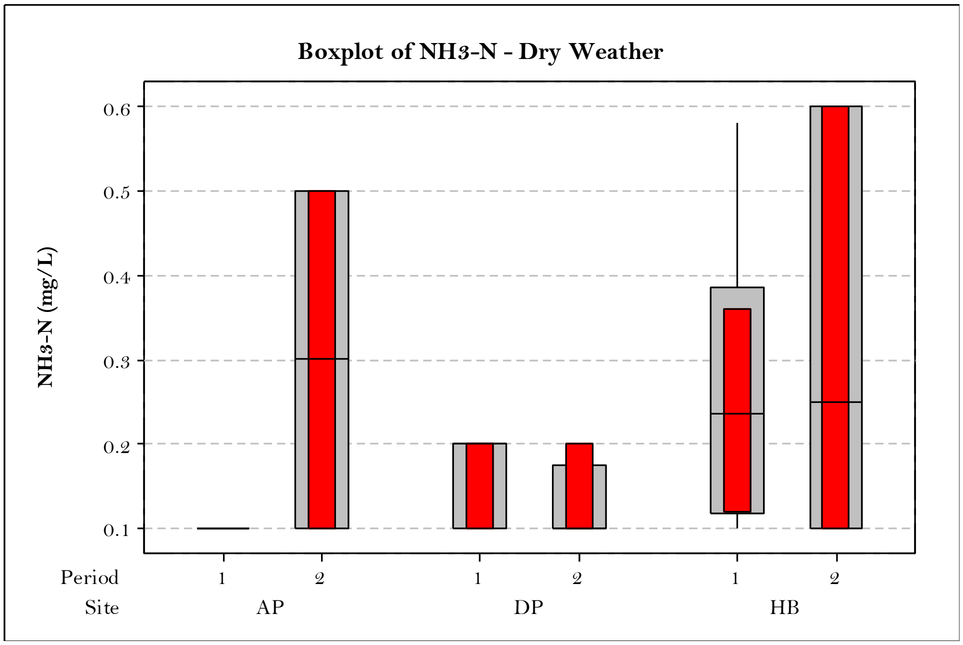

Figure 82. Boxplot of ammonia nitrogen measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

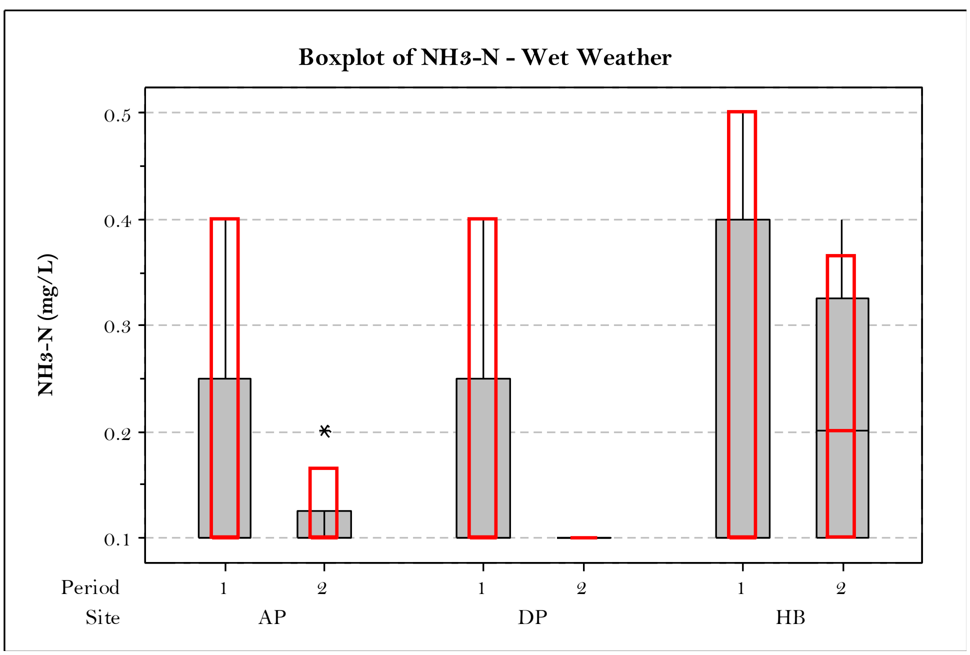

Figure 83. Boxplot of ammonia nitrogen measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

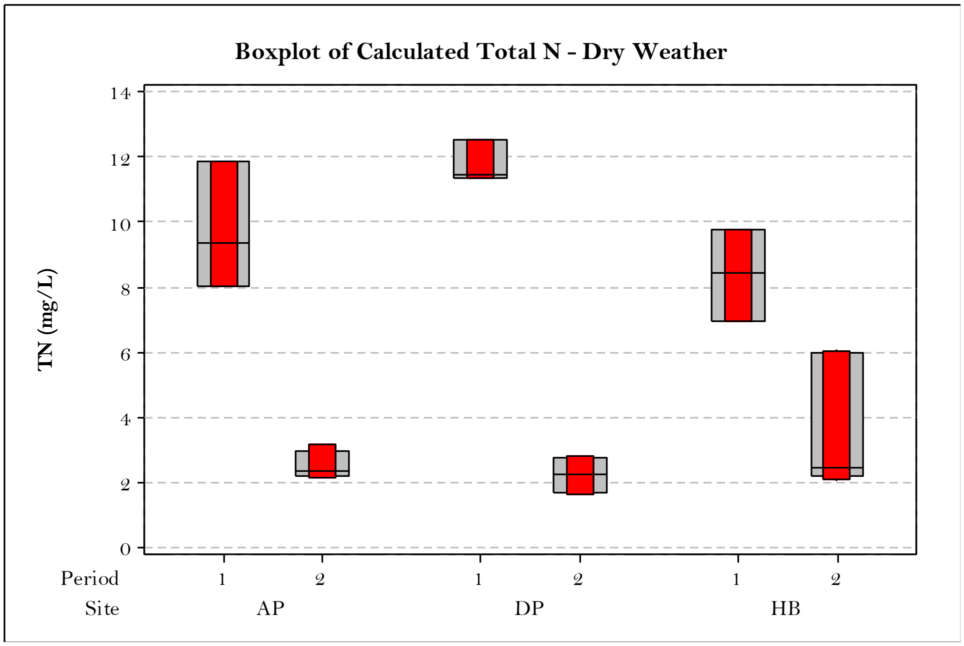

Figure 84. Boxplot of calculated total nitrogen measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

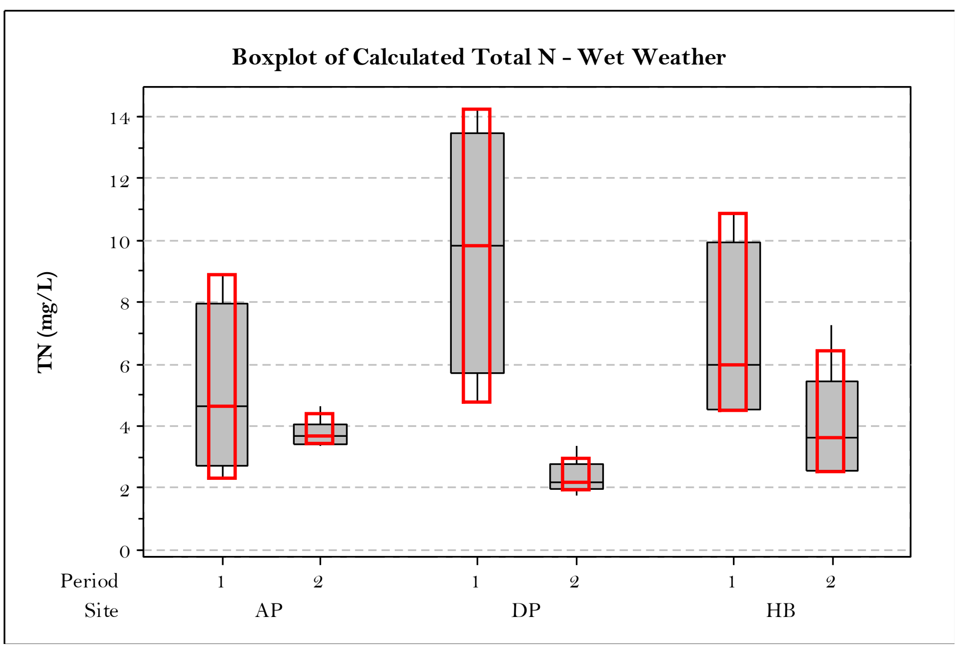

Figure 85. Boxplot of calculated total nitrogen measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

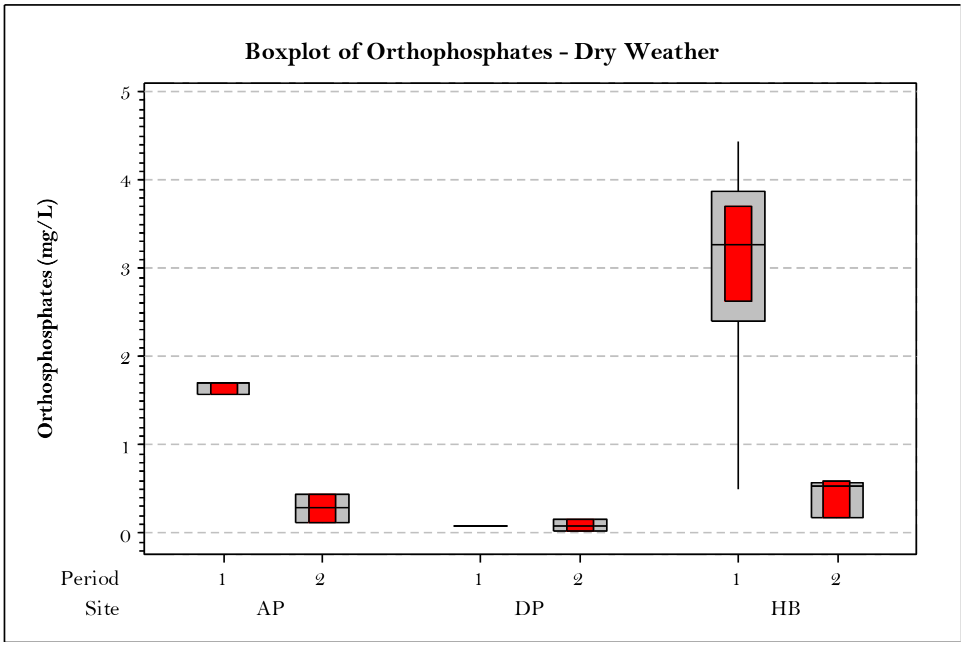

Figure 86. Boxplot of orthophosphate measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

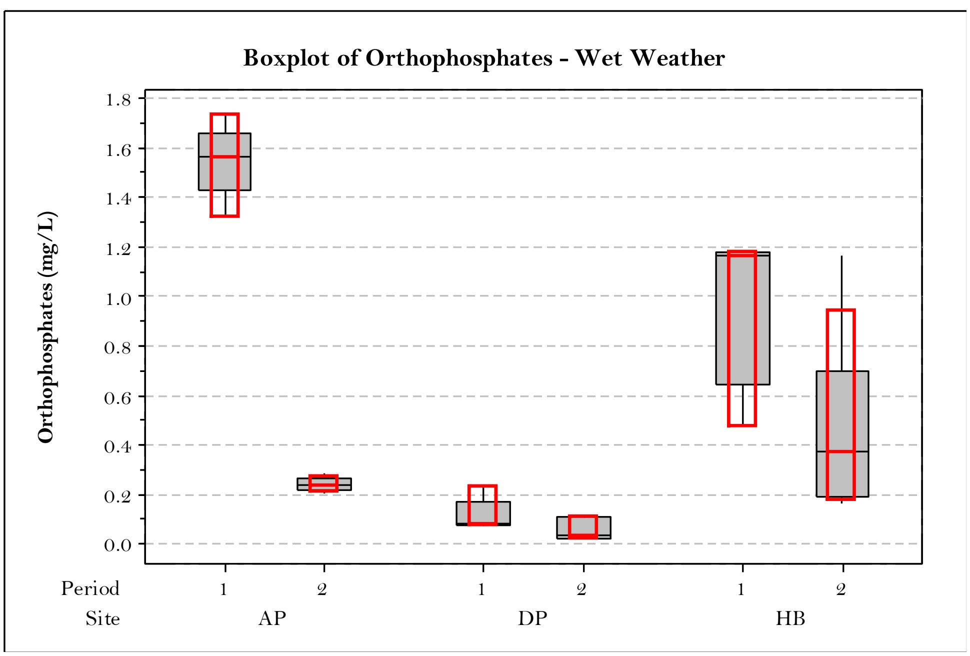

Figure 87. Boxplot of orthophosphate measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

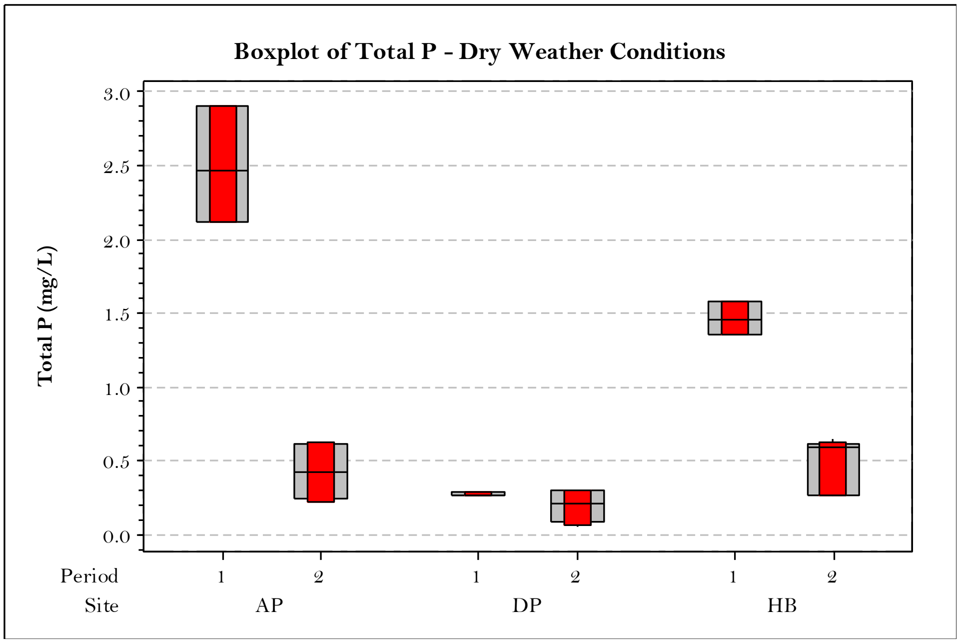

Figure 88. Boxplot of total phosphorus measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

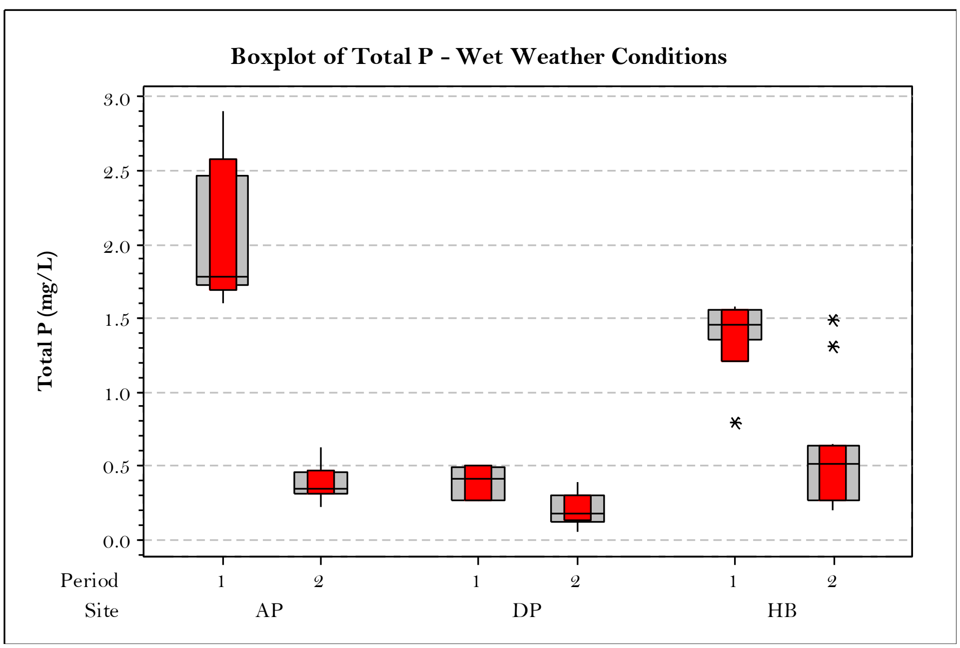

Figure 89. Boxplot of total phosphorus measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

Chlorophyll-*a* levels declined at all sites between the period before the wetland was constructed and the post-construction phase (Figure 90 and 91). Therefore it is difficult to suggest that the wetland alone was responsible for reducing the likelihood of high algal levels. This difference was statistically significant under dry weather conditions. The relationship of primary production and nutrient dynamics in the ponds needs to be further investigated.

The amount of TSS appeared to increase at the Alligator Pond but was statistically insignificant Figure 92 and 93. It is difficult to determine the cause for this difference. However, the wetland did experience some erosion problems initially until the levee was prepared. This may have contributed to elevated suspended solids. This is supported by statistically significant increases in turbidity at the Alligator Pond after construction of the wetland (Figure 94 and 95).

Enterococci and *E. coli* bacteria showed significant declines in density during dry weather sampling at the Alligator pond following construction of the wetland (Figure 96 -99). This patter did not occur during all wet weather events. The Duck Pond and Horsepen Bayou did not exhibit this pattern in reductions. This provides strong evidence that the wetland was effective in reducing levels from 100-880 MPN/100 ml down to less than 50 MPN/100 of *E. col*i and/or Enterococci indicator bacteria. We observed during the post construction period that the dry weather levels of *E. coli* bacteria increased in Horsepen Bayou in contrast to our wetland site. During 2011 and 2012 we had very low base flows in the bayou due to the extended drought. Elevated *E. coli* levels could be due to the majority of stream flow being dominated by wastewater flows downstream of the Clear Lake City wastewater facility (WWTP) and facilities located near Ellington field.

We examined the relationship of various nutrients and pollutants and rainfall amounts. We found that this relationship was not consistent (Figure 100-106). It appeared that Horsepen Bayou was the least sensitive to increased flows and resulting increases in selected pollutants such as TSS, nitrogen and phosphorus. However, Alligator Pond tended to exhibit a more sensitive response, although in general the level of these pollutants was lower than the other sites at comparable flows, especially after construction of the wetland. Interestingly, high TSS values occurred at Alligator Pond in response to increased rainfall after construction of the wetland. This again suggests that during the first two years erosion of the levee and other unstable soils may have been occurring.

We attempted to determine if, as observed in the literature and other recent studies, that indicator bacteria are more likely to be elevated in waterbodies containing high suspended solids. We were unable to detect any consistent trend, partly due to the confounding of the dynamics of each waterbody (Figure 107 and 108). By careful examination of the two figures one could see that it appears that the relationship (e.g. slope) between TSS and selected pollutants may be different for Horsepen Bayou versus the ponds. However, due to the low sample size it is not possible to separate these data sets and attempt to re-analyze the data for any possible relationships at this time.

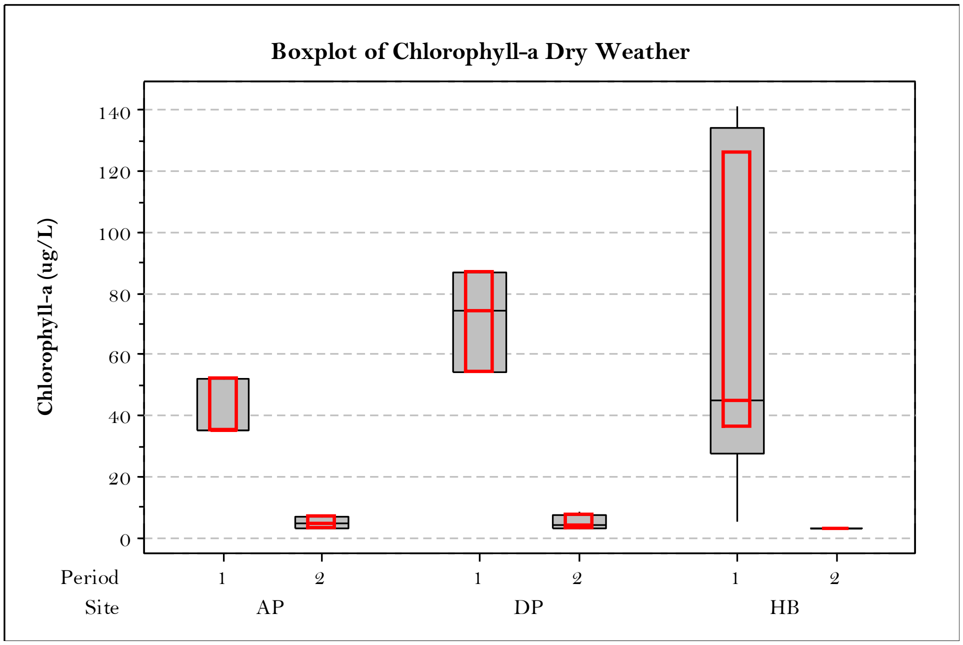

Figure 90. Boxplot of chlorophyll-*a* measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

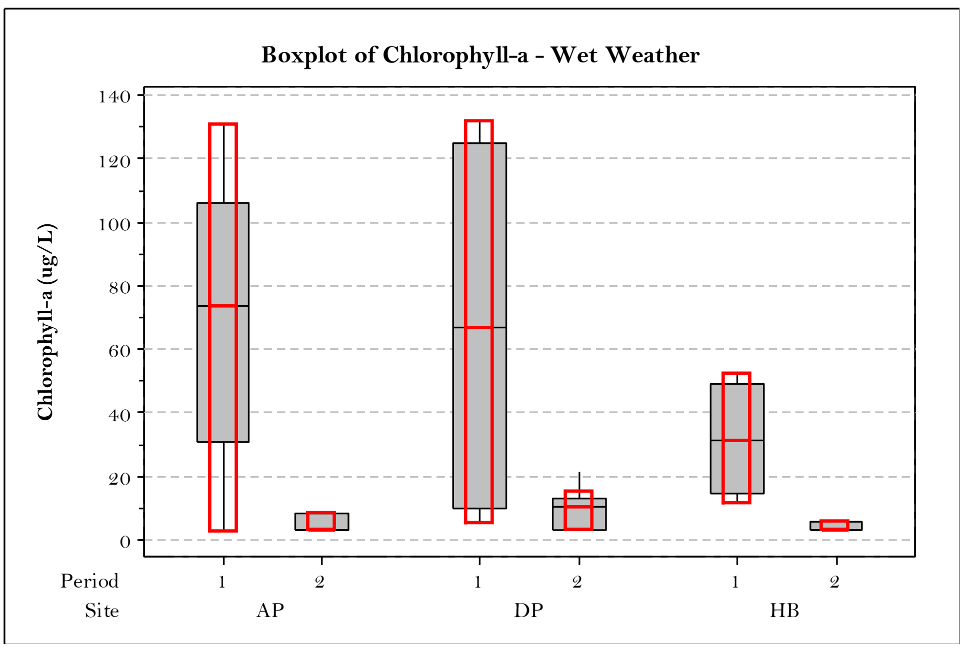

Figure 91. Boxplot of chlorophyll-*a* measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

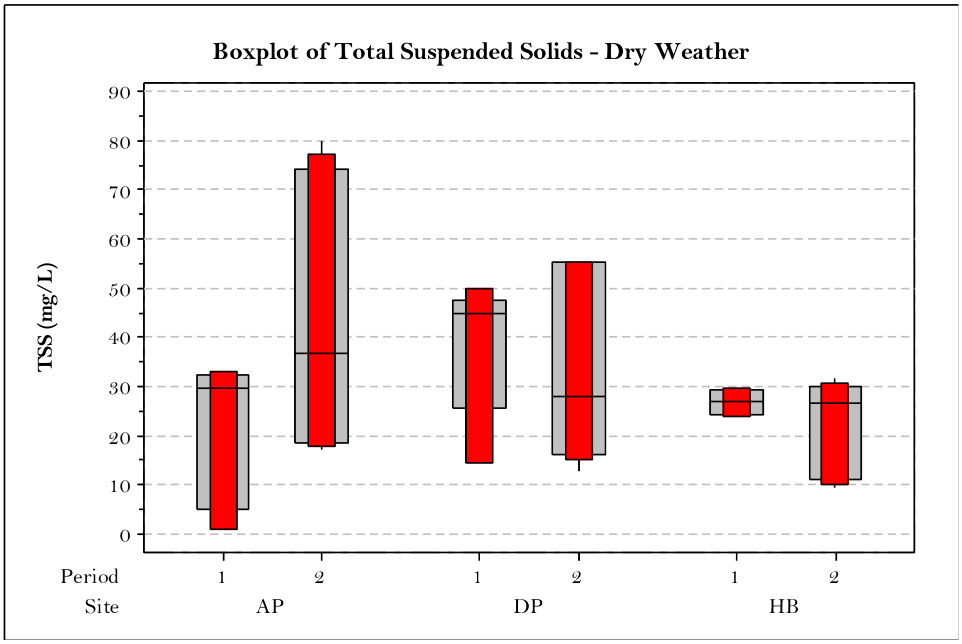

Figure 92. Boxplot of total suspended solids measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

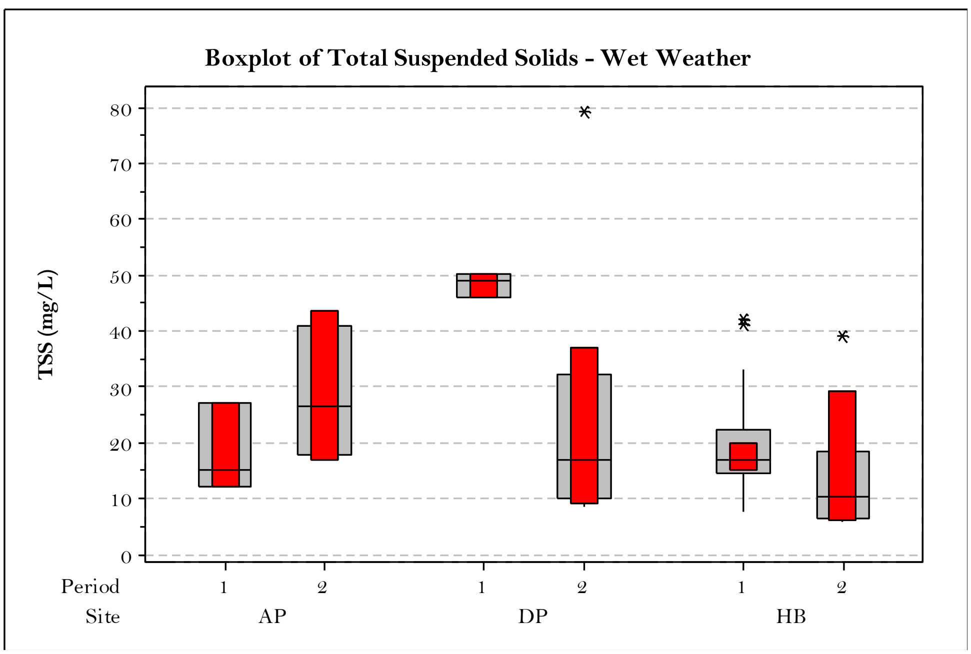

Figure 93. Boxplot of total suspended solids measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

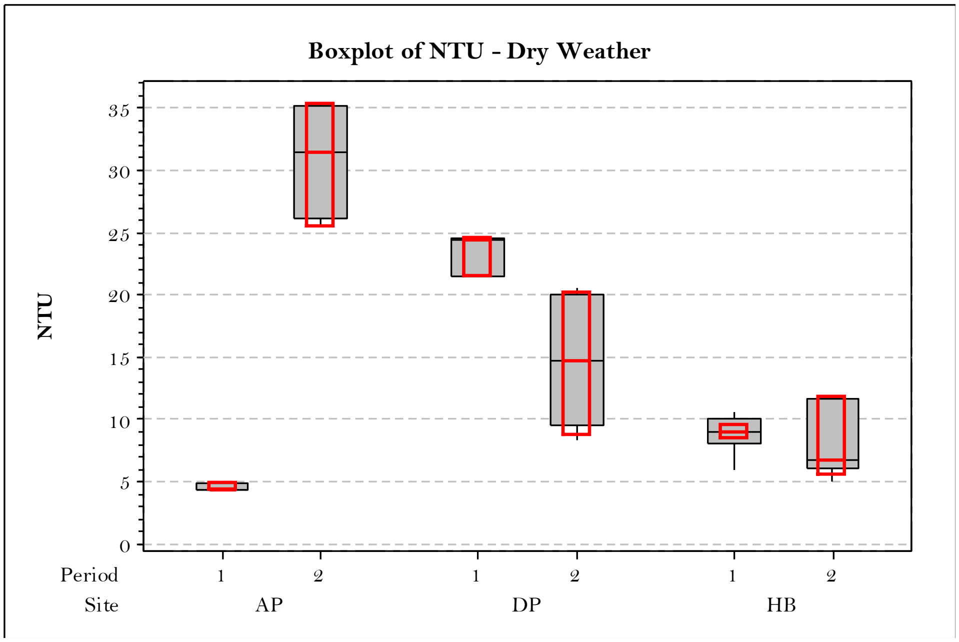

Figure 94. Boxplot of nephelometric turbidity units measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

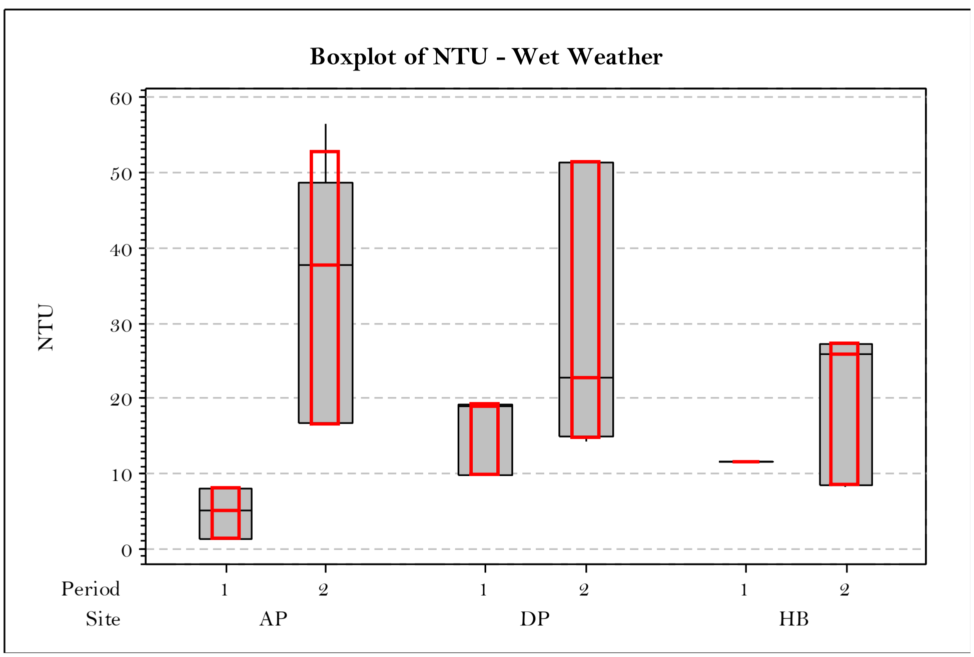

Figure 95. Boxplot of nephelometric turbidity units measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

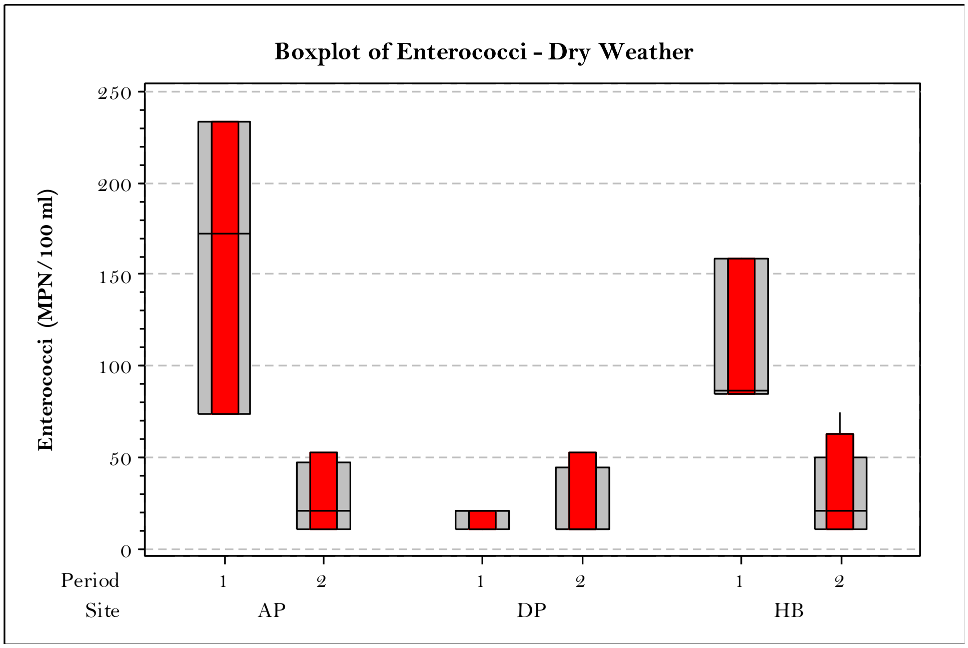

Figure 96. Boxplot of most probable number of Enterococci bacteria measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

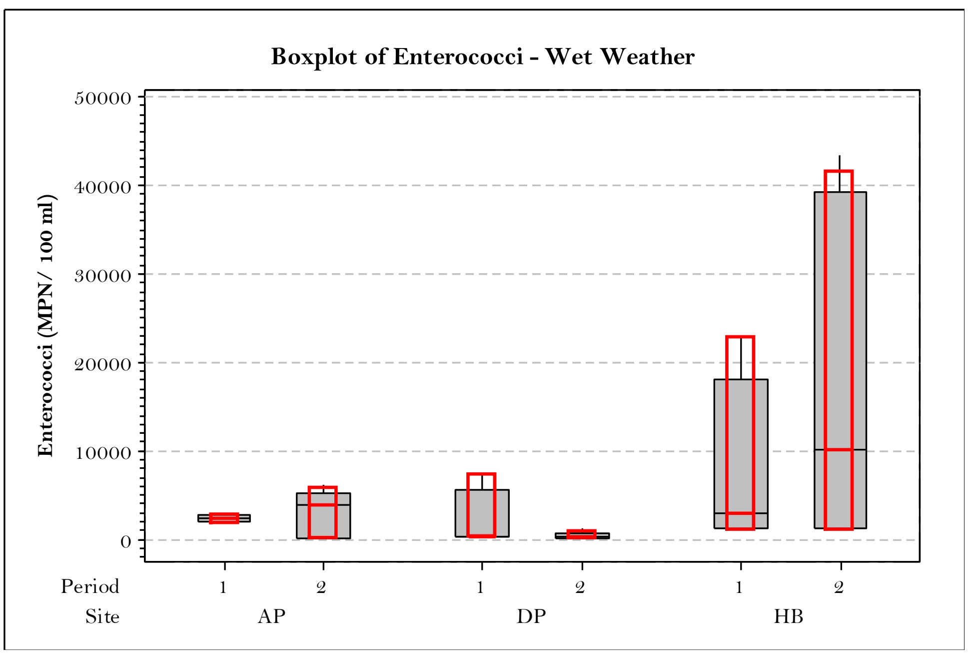

Figure 97. Boxplot of most probable number of Enterococci bacteria measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

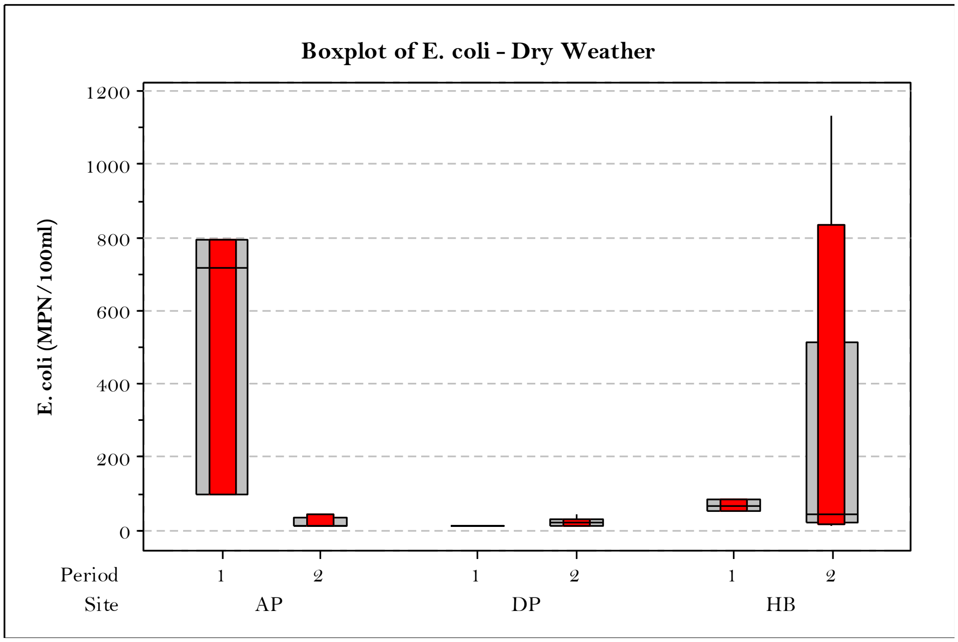

Figure 98. Boxplot of most probable number of *E. coli* bacteria measured during dry weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

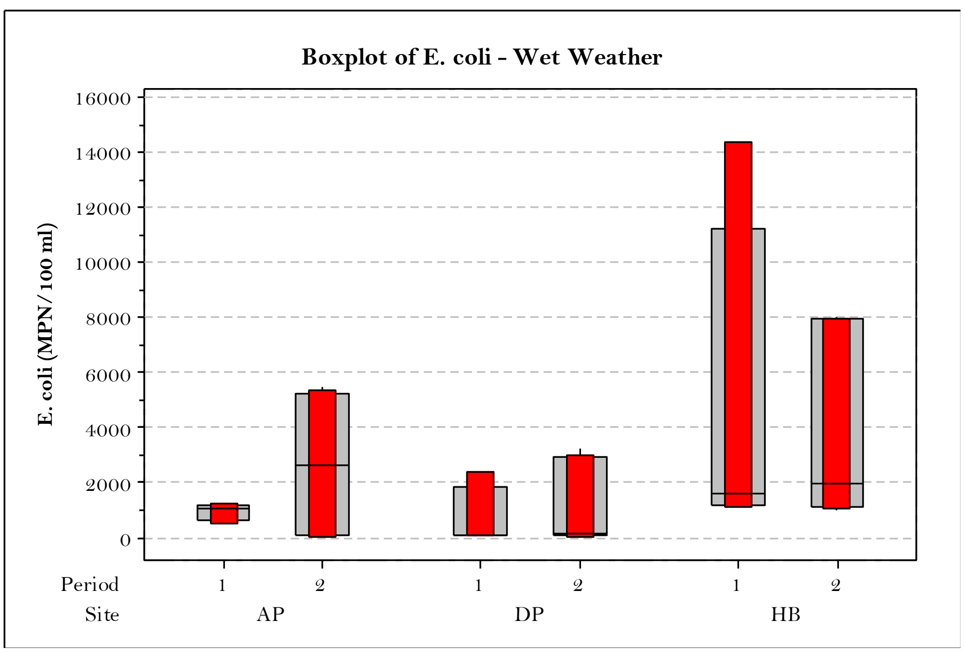

Figure 99. Boxplot of most probable number of *E. coli* bacteria measured during wet weather conditions at outfall from each pond system (AP – alligator pond downstream from wetland; DP – Duck Pond; HB – Horsepen Bayou at Bay Area Blvd; 1 = pre-construction and 2 = post construction wetland). Red bar denotes 95% confidence interval of median.

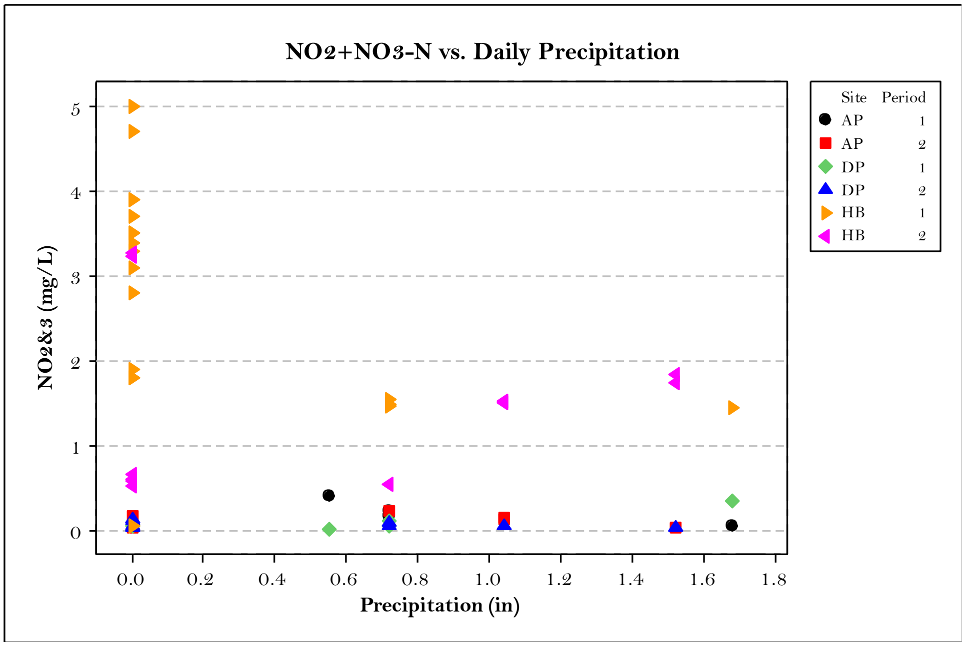

Figure 100. Relationship between nitrite + nitrate nitrogen and daily precipitation at each site before and after construction of the wetland.

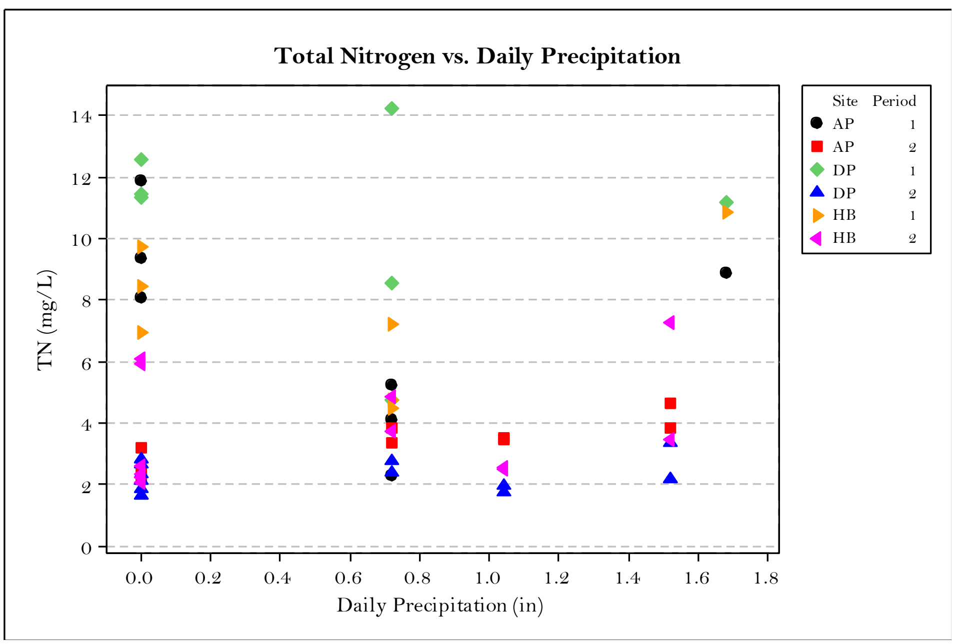

Figure 101. Relationship between total nitrogen and daily precipitation at each site before and after construction of the wetland.

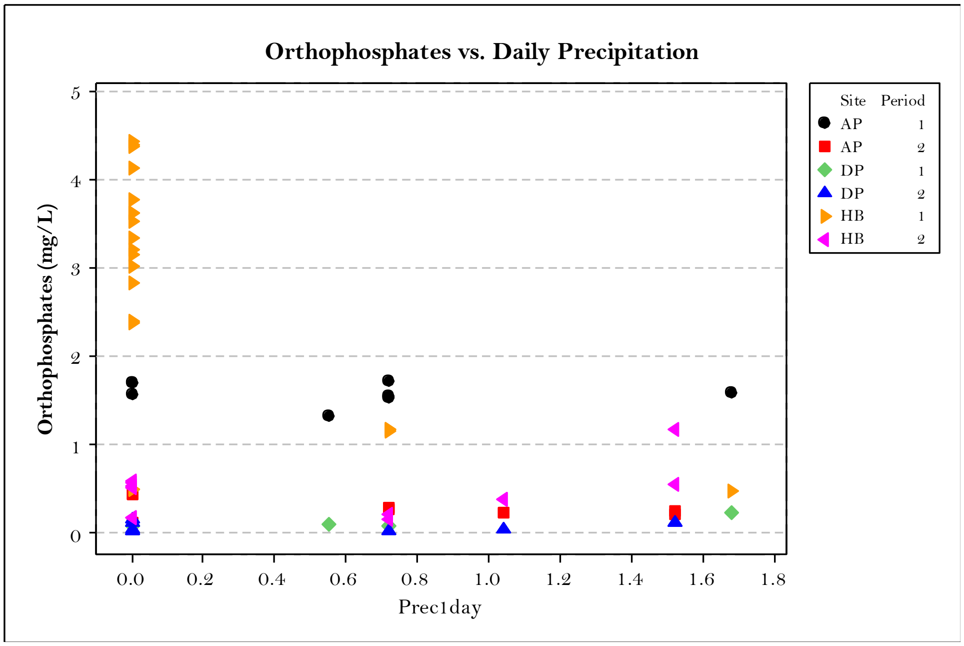

Figure 102. Relationship between orthophosphates and daily precipitation at each site before and after construction of the wetland.

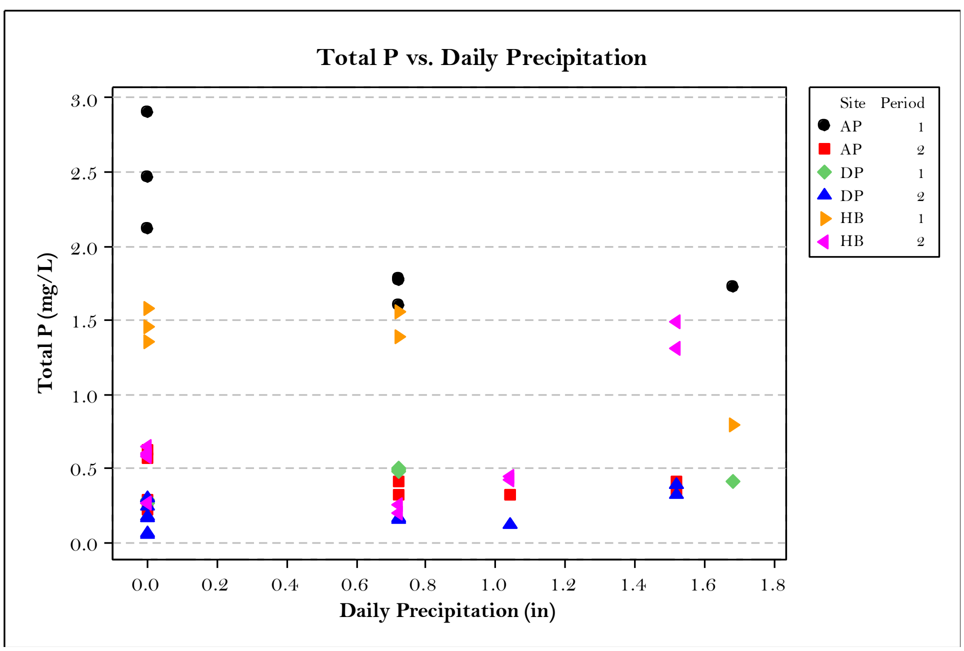

Figure 103. Relationship between total phosphorus and daily precipitation at each site before and after construction of the wetland.

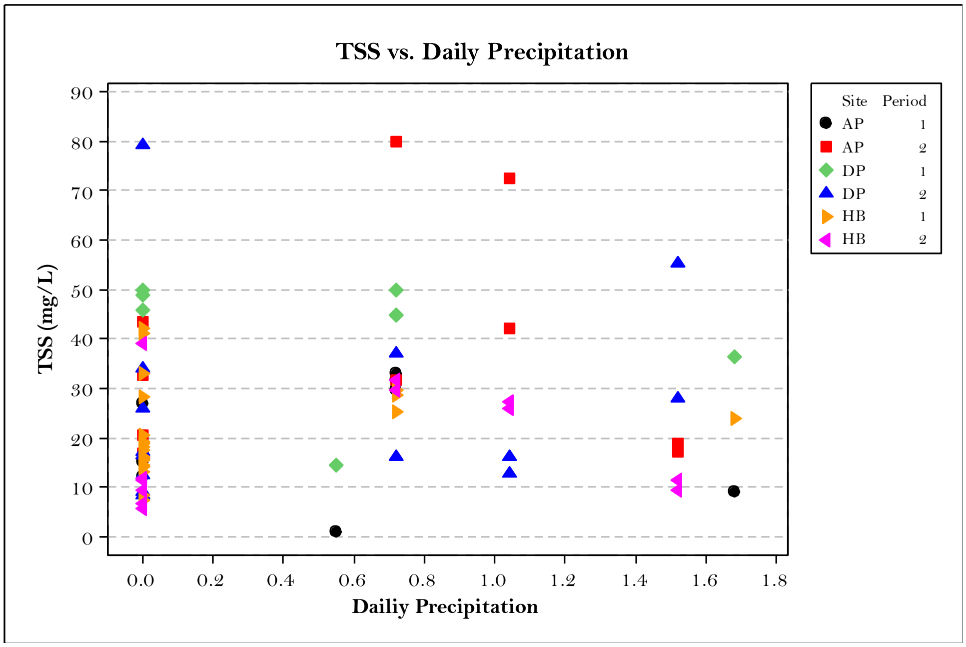

Figure 104. Relationship between total suspended solids and daily precipitation at each site before and after construction of the wetland.

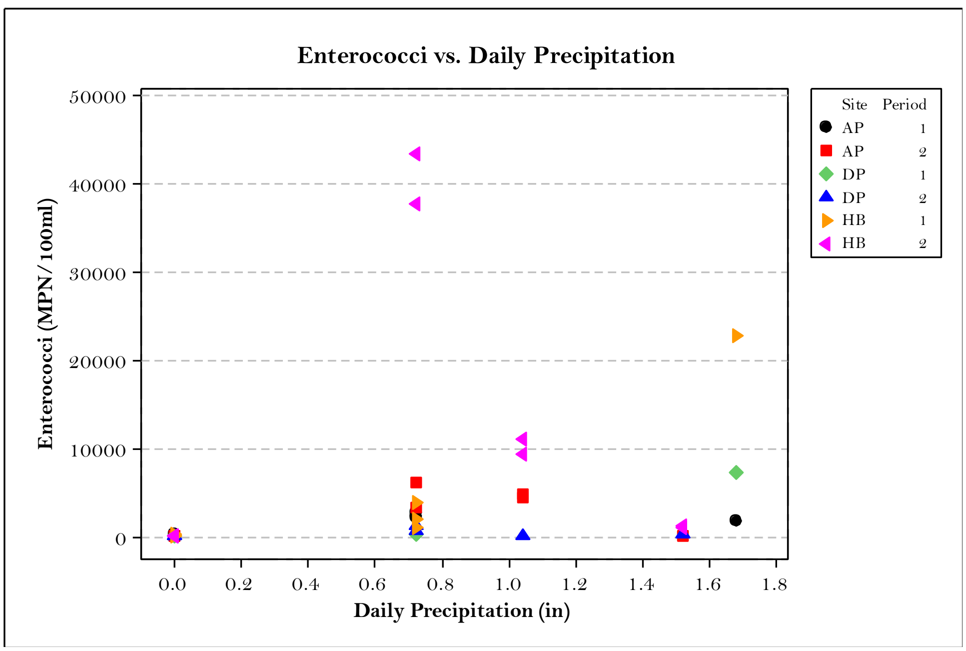

Figure 105. Relationship between Enterococci levels and daily precipitation at each site before and after construction of the wetland.

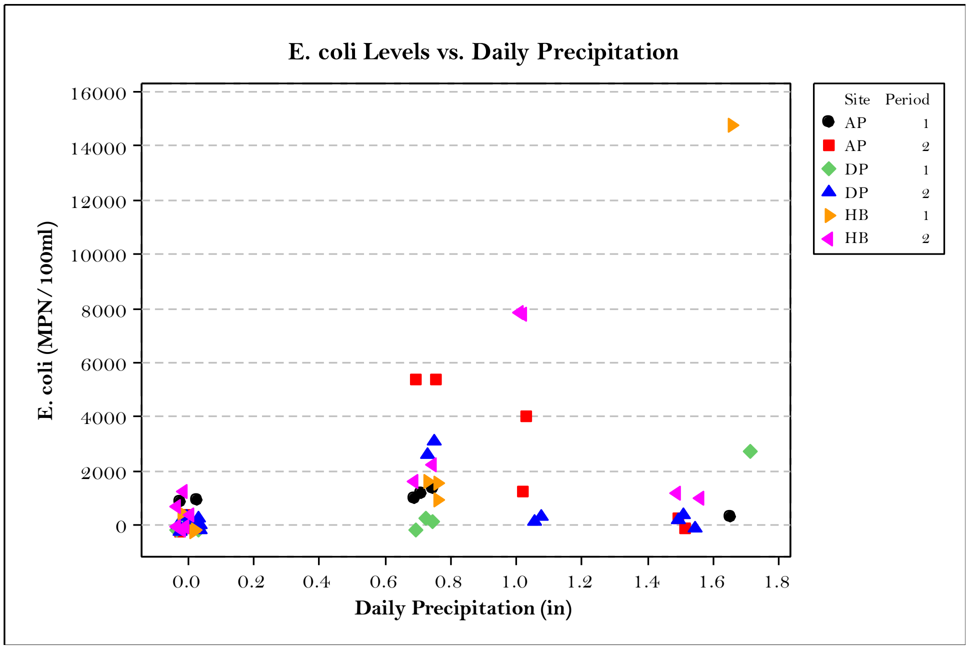

Figure 106. Relationship between *E. coli* levels and daily precipitation at each site before and after construction of the wetland.

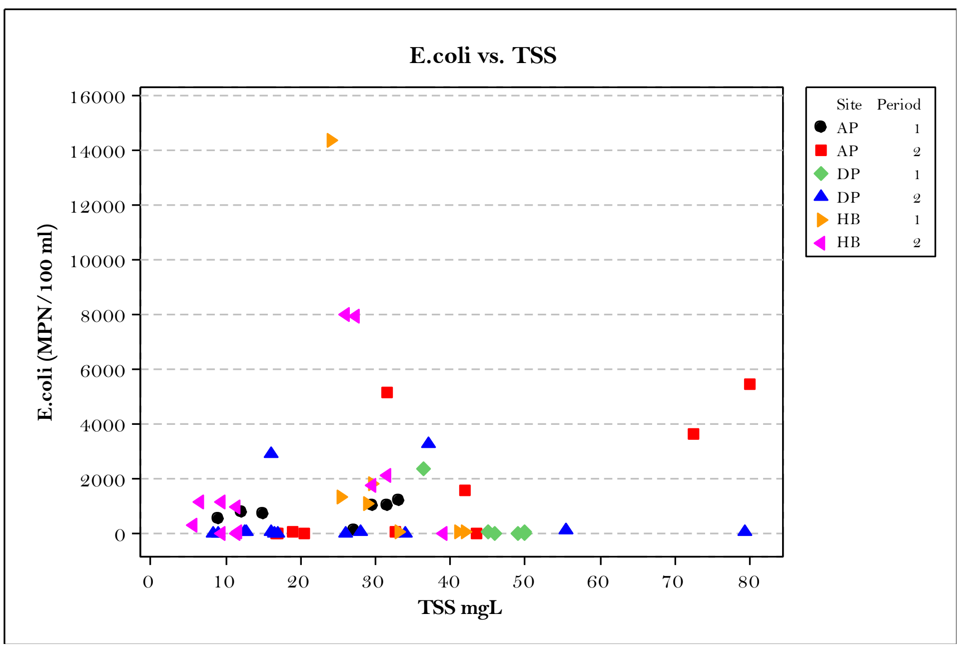

Figure 107. *E. coli* versus suspended solids concentrations at the ponds and Horsepen Bayou.

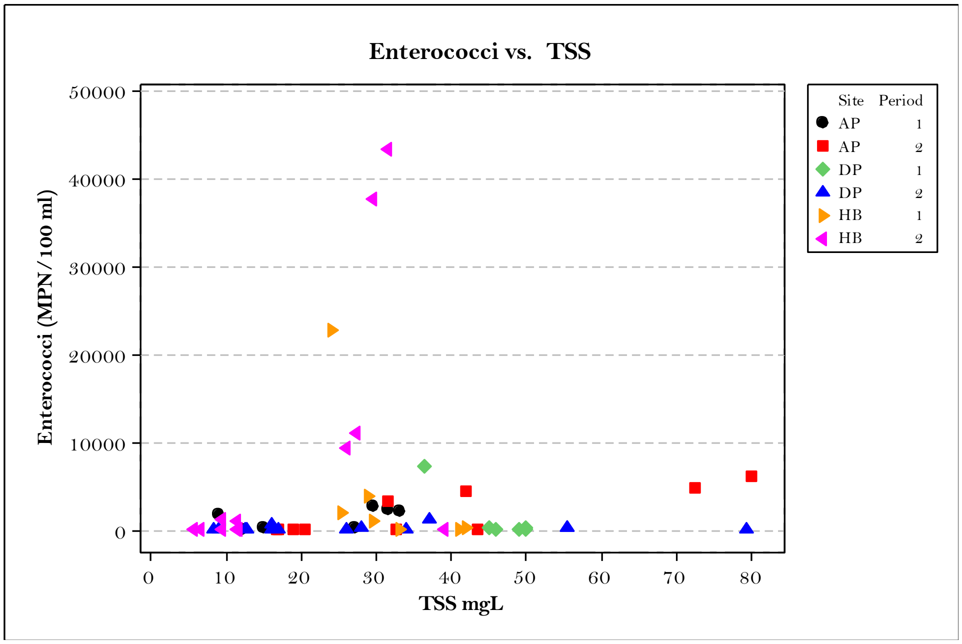

Figure 108. Enterococci versus suspended solids concentrations at the ponds and Horsepen Bayou.

Time of Travel and Reclaimed Water Sampling

To determine the time of travel of a controlled water release in the UHCL created wetland we used a rhodamine WT dye release. Dyes mimic the movement of water molecules. A measure of the movement of a dye (i.e., Rhodamine WT) effectively measures the movement of the water and, therefore, substances transported by the water in which it is introduced. Substance mixing and dispersion occur in all dimensions of a water body (Wilson et al. 1986). For example, in linear flow systems, vertical mixing typically occurs first. Subsequently, and depending on current, channel configuration and flow characteristics, lateral mixing and longitudinal mixing follow. Dye was released at the reclaimed water release point (Spigot), and dye detecting sondes were placed at site 8 and site 10 downstream of the water release point (Table 7). The dye release time and the time at initial detection was recorded at each of the subsequent sampling sites. With an average controlled water release of 0.237 cfs at the top of the primary wetland, the time of travel for those water molecules to reach site 8 was 3.5 hours, and to reach site 10 (the outfall of the wetland system) was 6.0 hrs after the dye release. The water release would be similar to a constant light to moderate rainfall event in the UHCL created wetland watershed. The time of travel data was used to time water collection for the controlled reclaimed water special study.

Table 7. Time of travel data for reclaimed water release. Shows the time the dye was detected at each checkpoint.

Site #	Site Description	Time Dye Detected	Date	Interval (hrs)	Example Time
S	Spigot	9:30	3/26/2012	0.00	12:00
8	Outfall of Primary Wetland	13:01	3/26/2012	3.50	15:30
10	Outfall of Secondary Wetland	15:31	3/26/2012	6.00	18:00

Water Quality Samples from Controlled Reclaimed Water Special Study.

Controlled water releases using the reclaimed waste water from the Clear Lake City water treatment facility were sampled on three separate (replicate) events. Three replicate water samples were collected at each of the three sites per event using the time laps calculated during the time of travel study of the controlled reclaimed water release (Table 8). Water samples were analyzed for nutrients and a clear decreasing trend was observed (Table 8 & Figure 109). The elevated nutrient levels observed in the spigot samples are exemplary of nutrient enriched stormwater inflow to our wetland treatment system. Decreases in nutrient concentrations can be observed by extreme (in some cases 3 orders of magnitude) in which a combination of factors are contributing to this decline. Primarily dilution is responsible for the concentration decrease observed throughout the system. In addition, suspended sediment with bound nutrients settled out as a result of the pool-run design of the wetland complex as well as the sediment check dams installed in the primary wetland complex. Finally there is most likely some nutrient uptake by the wetland vegetation.

Table 8. Water samples from controlled reclaimed water releases, values averaged from three events, triplicate samples taken at each site during each event, n=9.

Site	Date	Nitrate+Nitrite	TP	Ortho Phosphate	TKN	Ammonia
S	4/9/2012	12.40	4.35	3.13	2.5	0.2
	5/7/2012	8.70	3.78	1.57	5.1	4.2
	5/22/2012	18.37	3.50	3.22	3.1	3.0
8	4/9/2012	0.14	0.41	0.31	1.8	0.2
	5/7/2012	1.73	0.71	0.39	4.1	0.1
	5/22/2012	0.14	0.61	0.45	2.0	0.1
10	4/9/2012	0.14	0.27	0.18	1.3	0.2
	5/7/2012	0.11	0.30	0.21	2.5	0.1
	5/22/2012	0.17	0.46	0.28	2.9	0.1
12	4/10/2012	0.22	0.34	0.24	2.8	0.2
	5/8/2012	1.30	0.65	0.34	3.0	0.1
	5/23/2012	1.01	0.87	0.53	3.9	0.3

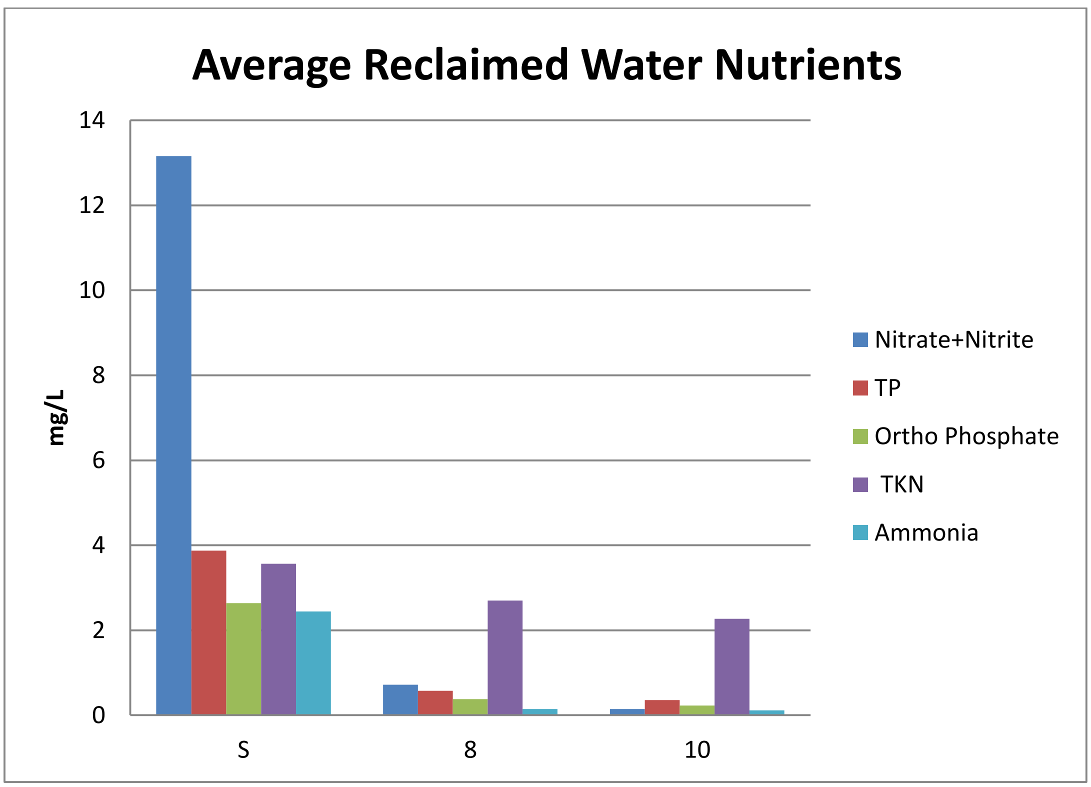

Figure 109. Nutrient level water samples from controlled reclaimed water releases, values averaged from three events, triplicate samples taken at each site during each event, n=9.

Periphyton

Periphyton collectors were deployed at four sites one and two years following construction of the wetland complex. Three replicate samplers were deployed at each site, with up to 4 splits (slides) collected per replicate (Table 9). Periphyton biomass growth was greatest in the fall samples taken in 2012 at the site in the primary wetland complex (Site 4), 20.65 mg/m^2/hr. The site with the highest periphyton biomass in the summer sampling event in 2013 was Duck Pond (Site 2) with an average biomass of 27.40 mg/m^2/hr Figure 111 and 112. Although samples were collected during different times of the year, both sampling periods occurred during warm weather conditions. This is reflected by the higher amount of photosynthetic pigments observed during warmer months (Table 10 and 11).

Table 9. Average periphyton biomass growth in mg/m^2/hr collected at four sites as part of the UHCL created wetland project. Replicates A, B, and C consist of a minimum of 3 split sample slides which are averaged. Date corresponds to information presented in Figure 110.

Site	Date	A	B	C	Grand Total
2	10/19/2012	1.31	2.53	2.23	2.09
	06/07/2013	28.67	29.21	24.33	27.40
4	10/19/2012	23.33	20.11	18.52	20.65
	06/07/2013	20.02	20.84	15.31	18.72
10	10/19/2012	9.64	9.82	16.40	12.38
	06/07/2013	4.53	5.80	4.80	5.05
12	10/19/2012	10.13	10.28	9.48	9.96
	06/07/2013	22.93	19.57	23.02	21.84

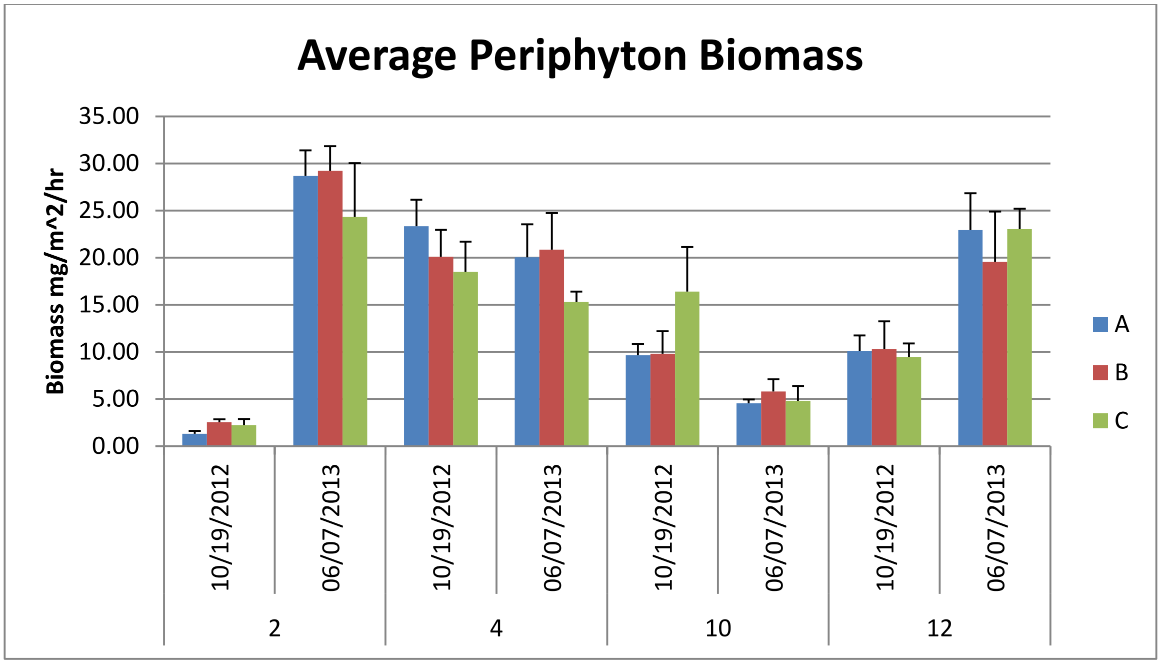

Figure 110. Average Periphyton Biomass growth rate in mg/sqm/hr collected at four sites as part of the UHCL created wetland project. Standard deviation bars incorporate the 4 field splits taken at each rep. Reps represented by A, B, and C, within each replicate a minimum of 3 splits are averaged. Data corresponds to Table 9.

Table 10. Average Periphyton Chlorophyll-*a* in mg/kg/day collected at four sites as part of the UHCL created wetland project. Replicates represented by A, B, and C. Within each replicate a minimum of 3 splits are averaged. Data corresponds to Figure 111.

		Rep			
Site	Date	A	B	C	Grand Total
2	10/19/2012	0.05	0.03	0.09	0.06
	06/07/2013	0.70	0.08	0.01	0.26
4	10/19/2012	2.27	4.24	4.45	3.65
	06/07/2013	3.46	2.44	1.26	2.38
10	10/19/2012	1.78	1.40	2.68	1.95
	06/07/2013	0.06	0.00	0.06	0.04
12	10/19/2012	1.64	0.38	1.34	1.12
	06/07/2013	0.71	1.20	0.74	0.89

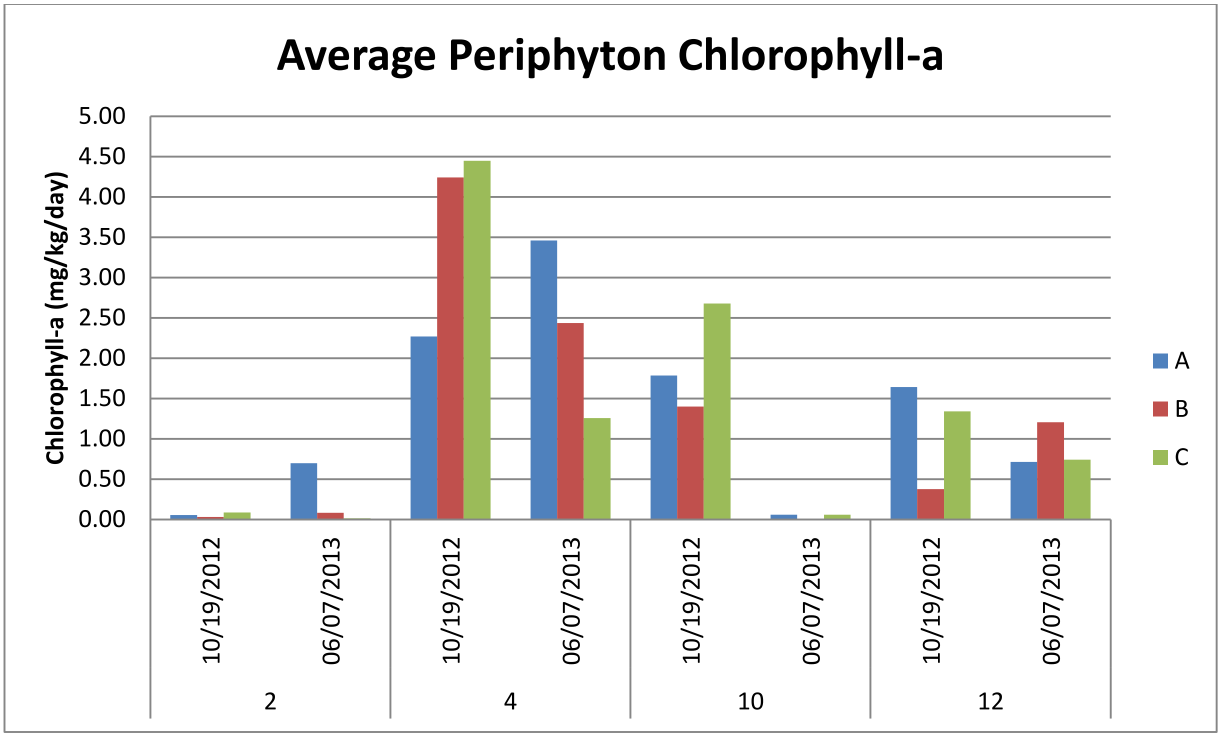

Figure 111. Average Periphyton Chlorophyll-a in mg/kg/day collected at four sites as part of the UHCL created wetland project. Standard Deviation Bars incorporate the 4 field splits taken at each rep. Reps represented by A, B, and C, within each replicate a minimum of 3 splits are averaged. Data corresponds to Table 10.

Table 11. Average Periphyton Pheophytin a in mg/kg/day collected at four sites as part of the UHCL created wetland project. Reps represented by A, B, and C, within each replicate a minimum of 3 splits are averaged. Corresponds to Figure 111.Figure 112.

Site	Date	A	B	C	Grand Total
2	10/19/2012	0.01	0.53	0.19	0.24
	06/07/2013	4.07	4.01	4.12	4.07
4	10/19/2012	1.96	6.26	4.16	4.12
	06/07/2013	4.98	4.31	4.32	4.53
10	10/19/2012	0.64	0.99	1.21	0.94
	06/07/2013	2.32	3.25	1.57	2.38
12	10/19/2012	0.53	0.20	0.60	0.44
	06/07/2013	2.69	0.86	1.77	1.77

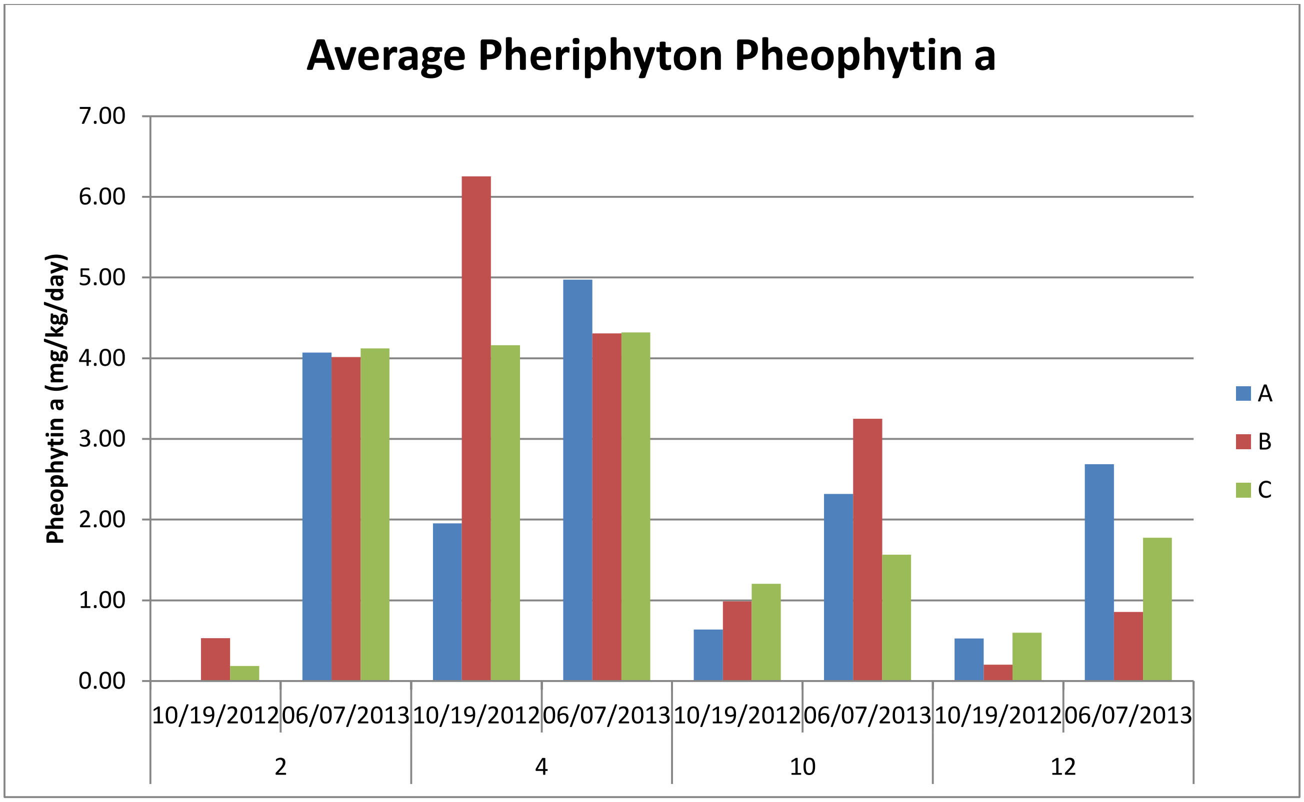

Figure 112. Average Periphyton Pheophytin a in mg/kg/day collected at four sites as part of the UHCL created wetland project. Standard Deviation Bars incorporate the 4 field splits taken at each rep. Reps represented by A, B, and C, within each replicate a minimum of 3 splits are averaged. Data corresponds to Table 11.

Sediment Sampling

Sediment sampling revealed relatively low heavy metal concentrations within the sediment of the wetland complex (Table 12). There did not appear to be a consistent trend between dates or sites. The accumulation of sediment metals is a long-term process and will be monitored as part of ongoing classes and special studies at the site. There was however a general temporal decline in metal levels during the study period (Figure 113).

Table 12. Heavy Metal levels measured in the top 3cm of sediment at the UHCL wetland complex. Values averaged from replicates taken at each site.

Site	Date	Cadmium mg/kg	Lead mg/kg	Mercury mg/kg
2	7/6/2011	0.10	18.70	0.101
	9/5/2012	0.80	4.70	0.037
	5/30/2013	0.15	7.20	0.028
4	9/5/2012	1.00	59.40	0.053
	5/29/2013	0.10	17.20	0.012
10	9/5/2012	1.20	11.15	0.074
	5/29/2013	0.35	11.55	0.030

12	7/6/2011	0.10	16.93	0.094

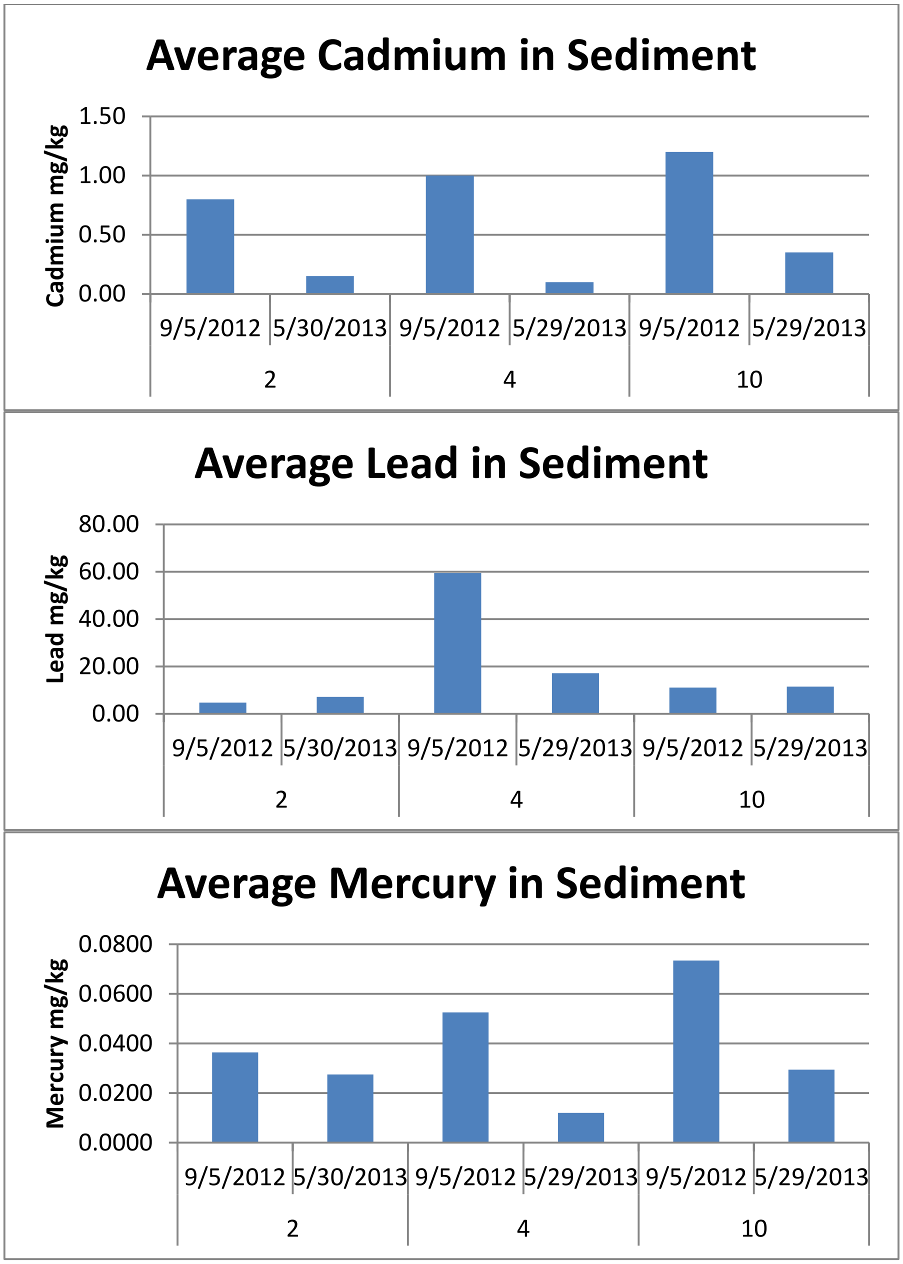

Figure 113. Heavy Metal levels measured in the top 3cm of sediment at the UHCL wetland complex. Values averaged from replicates collected at each site.

Sediment nitrogen levels generally declined through time, but phosphorus levels increased suggesting that the wetland was sequestering phosphorus into the sediment (Figure 114). This pattern is consistent with the general decline in phosphorus levels within the water column as discussed earlier.

Table 13. Nutrient concentrations measured in the top 3 cm of the sediment at the UHCL wetland complex. Values averaged from replicates collected at each site.

Site	Date	Phosphorus mg/kg	Total Nitrogen mg/kg	Total Organic Carbon mg/kg
2	9/5/2012	53.950	1895.4	24450
	5/30/2013	39.550	1432.5	13150
4	9/5/2012	11.183	1496.6	64250
	5/29/2013	40.950	803.0	15405
10	9/5/2012	39.300	2657.6	16700
	5/29/2013	62.850	1588.0	31500

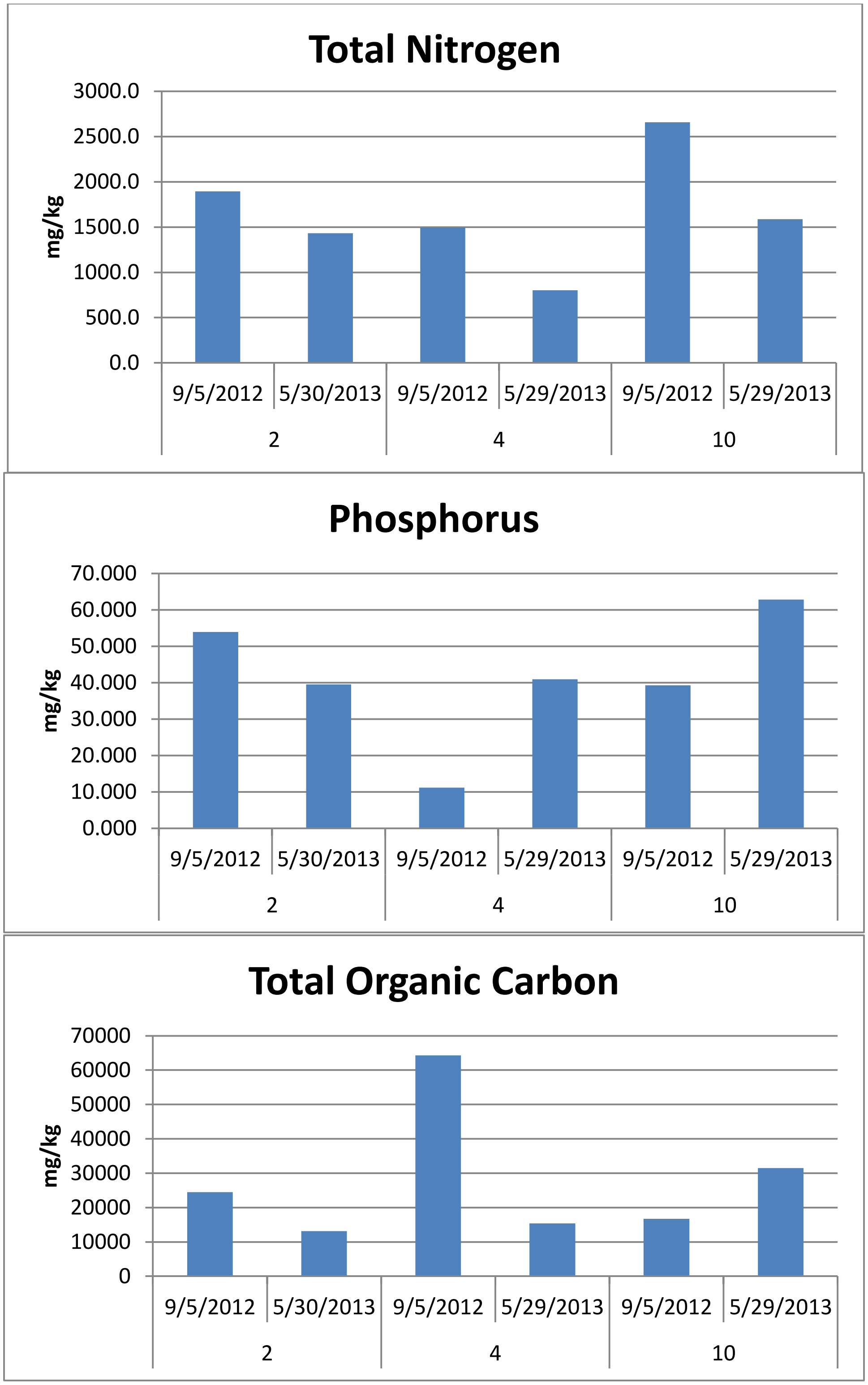

Figure 114. Nutrient concentrations measured in the top 3 cm of the sediment at the UHCL wetland complex. Values represent averages from replicates collected at each site.

Plant Tissue Sampling

All heavy metals samples from the plants were below the detection limit. This suggests that within the period of the study, wetland plants did not accumulate detectable levels of the metals listed above under the sediment section. This may be due to naturally low levels occurring within the watershed and the longer term period needed for sediment bound chemicals to become bioavailable to plants.

Chlorophyll-a levels were monitored in the field and laboratory. Data from these tests suggest all plants were exhibiting normal seasonal fluctuations in metabolism and did not seem to exhibit a distinct spatial or interspecific pattern in the pigment (Table 14 and Figure 115).

Table 14. Plant Tissue samples from two species of wetland plants at the UHCL created wetland complex. Values averaged using replicates for each event.

		SPAD		Chlorophyll a (mg/kg)		Pheophytin a (mg/kg)	
Site	Date	Sagittaria	Scirpus	Sagittaria	Scirpus	Sagittaria	Scirpus
4	9/5/2012	31.25	56.62	108.35	299.96	438.57	302.31
	5/29/2013	47.97	58.42	148.44	191.12	538.05	38.05
10	9/5/2012	34.48	63.45	188.75	211.41	369.65	272.60
	5/29/2013	68.03	57.50	197.35	228.87	365.42	24.64

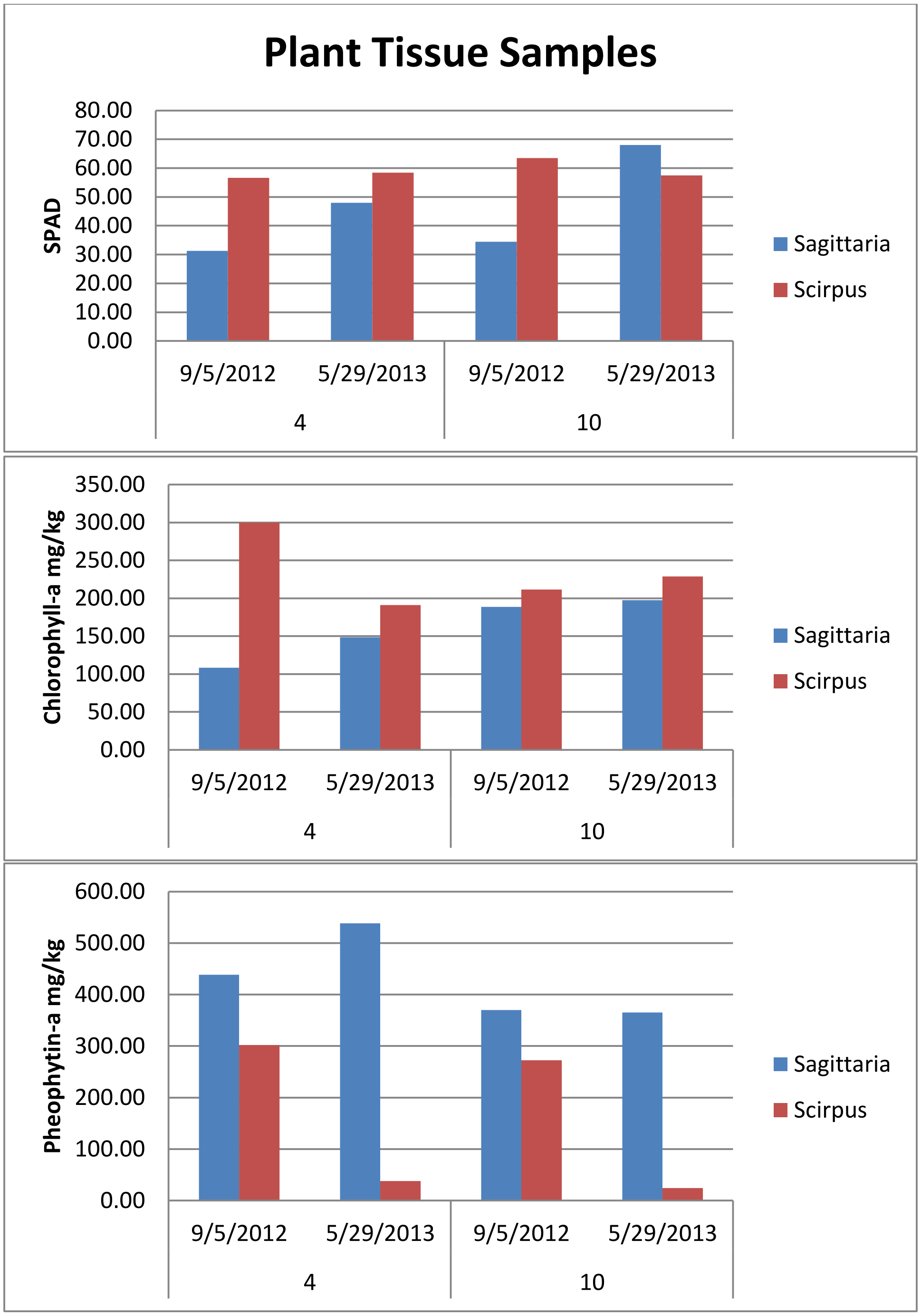

Figure 115. Plant Tissue samples from two species of wetland plants at the UHCL created wetland complex. Values averaged using replicates for each event.

Solar Pump Study

A pilot scale demonstration project to evaluate the feasibility of the use of solar powered pump systems to enhance water quality in Horsepen Bayou was constructed at the UHCL created wetland site. The solar powered pump system was composed of two solar panels with a direct power line to a pump located in Horsepen Bayou. The pumped water runs uphill through a 1 inch PVC pipe approximately 90 m to the outfall point located at the top of the secondary wetland (Site 7). The feasibility determination of the solar pump involved multiple parameters including pumping from a tidal waterbody, pump capacity and flow rates, solar power intensity, and assessing overall treatment potential.

Pump Intake and Debris

As mentioned, the intake pump is located in Horsepen Bayou, a tidal waterbody adjacent to the created wetland complex. Since the created wetland is a freshwater wetland, the salinity of the bayou had to be closely monitored in order to insure that saltwater was not pumped into the created freshwater wetland system. As a result, a HOBO® conductivity data logger - U24-001 meter which measures conductivity (µS/cm) was deployed at the site of the pump intake to monitor the salinity of Horsepen Bayou (Figure 116). The solar pump was only used when the conductivity in Horsepen Bayou at the site of the pump intake was <1000 µS/cm. This occurred regularly during dry weather, but only for short periods of time. Generally speaking the only time conductivity was below 1000 µS/cm long enough to insure no saline water was pumped into the wetland was when heavy rain events occurred which resulted in lower salinities within in Horsepen Bayou. However, during or immediately following rain events irrigation water is not needed in the created wetland, as it is already receiving freshwater runoff from the UHCL campus.

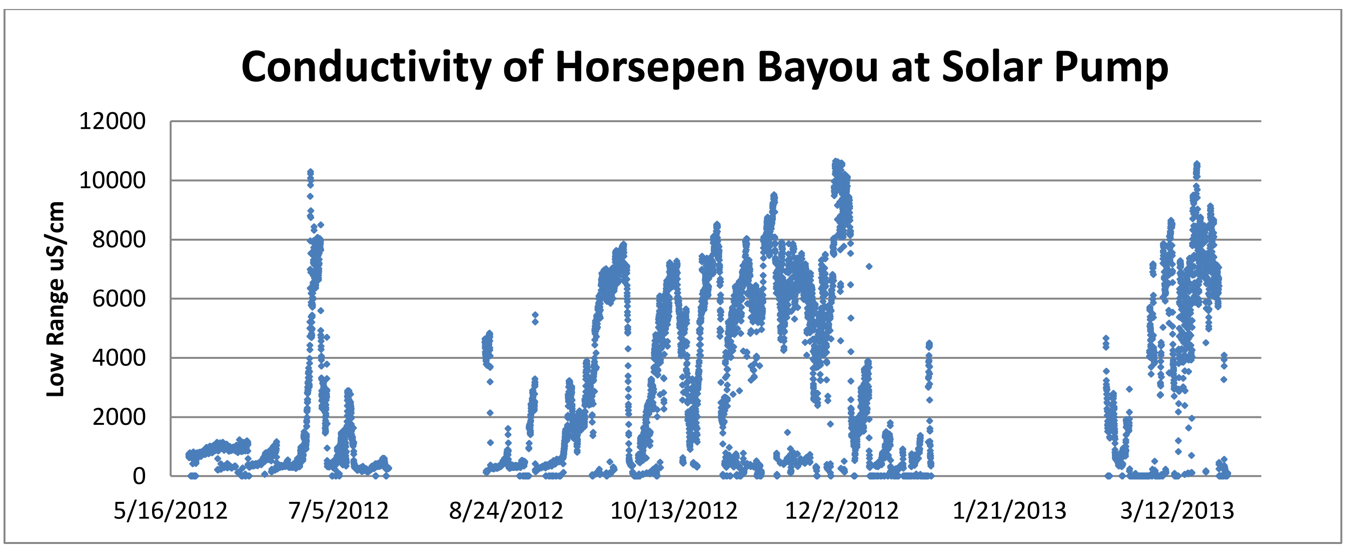

Figure 116. Conductivity (low range µS/cm) measured every 30 minutes by HOBO® conductivity data logger deployed at the Solar Pump Intake in Horsepen Bayou.

In addition to the necessary conductivity monitoring, maintenance on the pump intake was a constant issue. The pump was installed in a small indention of the bank immediately below the outfall from the pond in order to protect it from high flow events, but this indention also collector of small debris. The debris (aquatic vegetation, trash, etc) would clog the pump intake and would have to be manually cleared before each time the pump was started (Figure 117).

Figure 117. EIH Staff removing debris from around the solar pump intake in order to turn on the pump.

Pump Capacity and Flow Rates

Our pump was powered by a solar panel. It is a direct current system without a battery charging system, which means it does not produce power when there is no sunlight (at night or on an overcast day), and on partly cloudy days, or early in the morning or evening the power output is minimal. This resulted in a direct relationship between the pump output and the solar radiation (Figure 118). The pump reached its maximum output at about 1600uA which was a flow of around 0.265 L/sec (0.0094 cfs). With the volume of the secondary wetland being 1000's of liters, it would take many hours to fill the secondary wetland at constant maximum output levels. This flow was insignificant in terms of providing meaningful water treatment for Horsepen Bayou. However, this was a pilot feasibility study on the use of solar power to provide energy necessary to pump water and provide tertiary water quality treatment. In this case the size of the system necessary to treat the volume of water in a bayou as large as Horsepen Bayou was not feasible, mainly due to drought conditions, reduced freshwater flows, and flood tides resulting in elevated salinities throughout most of the study period within the bayou. Using a solar pump and created wetland complex to provide tertiary water quality treatment would be feasible in smaller freshwater streams. However, other systems such as created wetlands installed in-line or off channel at the same or less elevation would likely be more cost effective under those conditions (Biebighauser 2011). The greatest utility of the solar pump system would be in the treatment of freshwater where perched wetlands can only be built along the river banks and no other option is available.

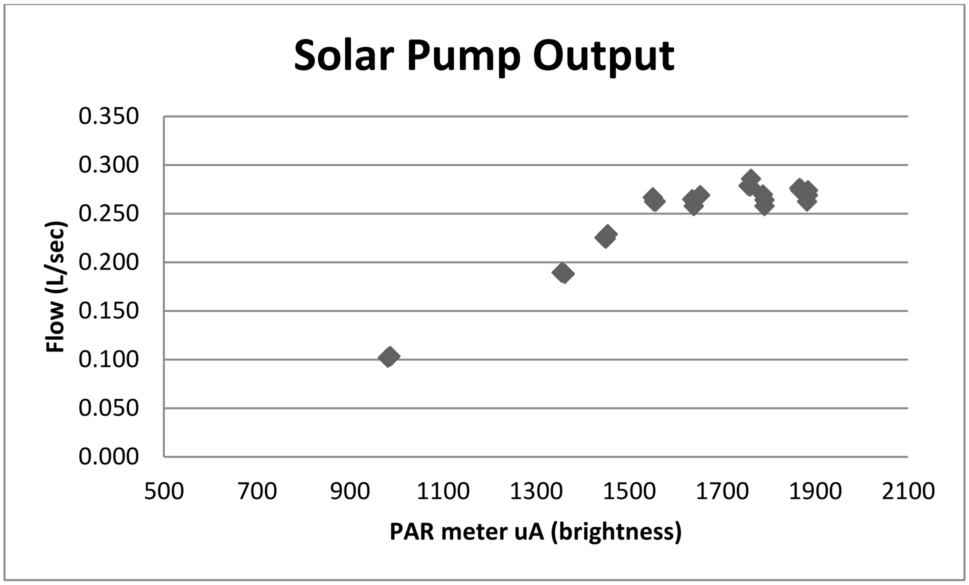

Figure 118. Output of Solar Pump as Flow in liters per second by the solar radiation level µA measured by a LiCor PAR.

Habitat for Wildlife Sampling

Vegetation Surveys

We characterized the plant community by collecting data on species composition and cover before, immediately following, and one year after construction. One of our objectives was to compare vegetation composition pre and post wetland construction, using the frequency of occurrence and percent cover. The frequency of occurrence was calculated by dividing the number plots where a species was found by the total number of plots (Howard et al. 2011). In addition, the percent cover of each species present in each quadrat was estimated to the nearest 1 percent, and the total % cover was calculated by the sum of each of the percent covers of each quadrat (Howard et al. 2011).

First to compare the pre-construction vegetation surveys completed in the summer of 2011 to the post construction vegetation surveys completed in the summer of 2012 (Table 15). The three most frequently occurring species pre construction with a frequency of occurrence of >0.25 were: *Ludwigia sp*., *Phyla nodiflora*, and *Polygonum hydropiperoides*. The three most frequently occurring species one year after construction with an occurrence of >1.45 were: *Calyptocarpus vialis*, *Plyla nodiflora*, and *Ulmus crassifolia*. In comparison, the species with the highest total percent cover pre-construction was *Echinochloa sp*., (413) while after construction it was *Vigna luteola* (1961). Both species composition and richness changed pre and post construction, with a total of 41 species observed during pre-construction sampling, and a total of 122 species observed one year post construction.

Our second objective was to compare the “clean slate” immediate post construction planting with the post construction vegetation surveys completed in the summer of 2012 (Table 16). A total of 10 species were planted as part of the initial planting immediately following the construction of the wetland site. Of these ten species, all but one were observed during the transect surveys conducted one year post-construction. One species of wetland vegetation which was planted but was not observed later was the watershield (*Brasenia schreberi*). Therefore of the 122 species observed one year post construction, 113 of them naturally recruited to the site. Finally, using fine scale topographic mapping corresponding to the vegetation quadrat plots, we created a descriptive visual showing exactly of what the UHCL created wetland looked like one year following construction.

Nekton

Nekton (fish and large mobile macroinvertebrates) sampling was conducted at Alligator pond pre-construction and post-construction to evaluate the fish community structure. In addition, post-construction nekton sampling was conducted at the primary and secondary wetland complexes (Table 17). Nekton was also sampled at Duck Pond to serve as a reference site throughout the course of this study.

During construction, Alligator Pond was drained, and EIH staff enumerated and identified all fish, invertebrates, and reptiles that were removed from the pond. All biota was relocated to either Duck Pond on campus or into Horsepen Bayou. Due to the rigorous amount of exhaustive sampling that occurred during construction (primarily during the pond draining), the area formerly known as Alligator Pond and the new primary and secondary wetland complexes were essentially barren of fish and other nektonic species. This allowed for a unique scenario in which natural recruitment to the wetland complex in year two post-construction could be measured prior to the subsequent stocking of Alligator Pond with known counts of fish species in early 2013.

The only fish species that naturally recruited to the wetland complex and Alligator Pond was the western mosquitofish (*Gambusia affinis*). On February 28, 2013 Alligator pond was also stocked with 9 species of fish, primarily consisting of largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) (Table 18). Three months later when Alligator pond was sampled again we found young of the year largemouth bass and sunfish *Lepomis* spp. in high numbers suggesting that our stocked fish had spawned, and were establishing a resident population. We plan to continue stocking the pond and wetland system in order to develop a healthy nekton community and to support a small recreational fishery and outdoor workshop lab for various student workshops. Future plans include developing better access to the pond through the installation of a small floating pier dock. Since stocking of the pond, several outdoor summer classes for elementary, intermediate and high school students have been held at the wetland complex. Many of these students also participated in our urban fishing program held at Horsepen Bayou and Alligator Pond.

Table 15. Frequency and total cover of plant species identified in Pre and Post vegetation surveys along random transects at the UHCL Created Wetland Site. Frequency = Frequency of occurrence, so like presence/absence. It is calculated by counting the number of plots the species was found in and dividing that by the total number of plots. Total % cover % = the sum of all of the % covers from each plot by species. The number of plots in Pre sampling was 62 and in Post sampling was 851.

			Frequency		Total Cover (%)	
Species Name	**Common name**	**Wetland Class**	Pre	Post	Pre	Post
Acacia angustissima	Prairie acacia		0.00	0.27	0	82
Acmella oppositifolia	Oppositeleaf spotflower		0.00	0.01	0	1
Agalinis heterophylla	Prairie false foxglove	FACU	0.00	0.11	0	84
Alternanthera philoxeroides	Alligatorweed	OBL	0.00	0.63	0	438
Amaranthus australis	Southern amaranth	OBL	0.00	0.04	0	12
Amaranthus sp.	Pigweed or Amaranth		0.00	0.04	0	11
Ambrosia psilostachya	Cuman ragweed	FAC	0.13	0.90	51	1120
Ammannia coccinea	Valley redstem	OBL	0.00	0.24	0	66
Ampelopsis arborea	Peppervine	FAC	0.03	0.00	2	0
Andropogon virginicus	Broomsedge bluestem	FAC	0.03	0.00	2	0
Anagallis arvensis	Scarlet pimpernel	FACU	0.00	0.07	0	6
Aster spp.	Aster		0.03	0.00	25	0
Baccharis halimifolia	Eastern baccharis	FAC	0.00	0.17	0	79
Bacopa monnieri	Herb of grace	OBL	0.05	0.28	90	28
Bacopa sp.	Water hyssop	OBL	0.00	0.00	0	0
Brasenia schreberi	Watershield	OBL	0.00	0.00	0	0
Calyptocarpus vialis	Staggler daisy	FAC	0.10	1.46	2	1281
Campsis radicans	Trumpet creeper	FAC	0.03	0.27	25	176
Carex cherokeensis	Cherokee sedge	FACW	0.05	0.00	55	0
Carex debilis	Sedge	FACW	0.00	0.03	0	15
Chamaecrista fasciculata	Partridge pea	FACU	0.00	0.25	0	115
Chamaecrista sp.	Sensitive pea		0.00	0.06	0	2
Chamaesyce maculata	Spotted sandmat	FACU	0.00	0.08	0	3
Chloracantha spinosa	Spiny chloracantha	FACW	0.00	0.54	0	262
Cirsium horridulum	Canadian horseweed	FAC	0.00	0.01	0	10
Cissus spp.	Golden tickseed		0.03	0.00	5	0
Conyza canadensis	Bermuda grass	FACU	0.00	0.32	0	348
Coreopsis tinctoria	Fragrant flatsedge	FAC	0.00	0.14	0	26
Cynodon dactylon	Flatsedge	FACU	0.05	0.87	42	1542
Cyperus odoratus	Fragrant flatsedge	FACW	0.00	0.24	0	72
Cyperus pseudovegetus	Marsh flatsedge	FACW	0.05	0.08	95	19
Cyperus ochraceus	Pond flatsedge	FACW	0.00	0.07	0	48
Cyperus iria	Ricefield flatsedge	FACW	0.00	0.11	0	35
Cyperus sp.	Faltsedge		0.00	0.69	0	240
Cyperus virens	Green flatsedge	FACW	0.03	0.72	30	456
Dichondra carolinensis	Carolina ponysfoot	FAC	0.00	0.55	0	77
Dichondra sp.	Ponysfoot		0.00	0.65	0	467
Digitaria filiformis	Slender crabgrass		0.05	0.00	28	0
Digitaria sanguinalis	Hairy crabgrass	FACU	0.00	0.23	0	221
Diodia virginiana	Virginia buttonweed	FACW	0.05	0.82	25	154
Dracopis amplexicaulis	Clasping coneflower	FAC	0.00	0.18	0	28
Echinochloa colona	Jungle rice	FACW	0.00	0.44	0	173
Echinochloa crus-galli	Barnyard grass	FACW	0.00	0.37	0	224
Echinochloa polystachya	Creeping river grass	OBL	0.00	0.03	0	10
Echinochloa sp.	Cockspur or barnyard grass		0.23	0.03	413	2
Echinochloa walteri	Coast cockspur grass	OBL	0.00	0.06	0	50
Eclipta prostrata	False daisy	FACW	0.05	0.97	30	251

Table 15 Cont. Frequency and total cover of plant species identified in Pre and Post vegetation surveys along random transects at the UHCL Created Wetland Site.

			Frequency		Total Cover (%)	
Species Name	**Common name**	**Wetland Class**	Pre	Post	Pre	Post
Eleocharis montevidensis	Sand spikerush	FACW	0.00	0.18	0	141
Eleocharis parvula	Dwarf spikerush	OBL	0.00	0.04	0	2
Eleocharis quadrangulata	Squarestem spikerush	OBL	0.00	0.11	0	198
Eleocharis sp.	Spikerush		0.05	0.20	45	148
Elymus virginicus	Virginia wildrye	FAC	0.00	0.03	0	4
Eupatorium spp.	Boneset, or Snakeroot		0.03	0.04	0	6
Euphorbia serpens	Matted sandmat	FAC	0.00	0.03	0	28
Gaillardia pulchella	Indian blanket	UPL	0.00	0.03	0	3
Gnaphalium sp.	Cudweed		0.00	0.03	0	3
Hydrocotyle sp.	Pennywort		0.05	0.04	85	17
Hydrocotyle umbellata	Manyflower marshpennywort	OBL	0.00	0.03	0	6
Ilex vomitoria	Yaupon	FAC	0.00	0.01	0	20
Ipomoea cordatotriloba	Tievine	FACU	0.00	0.03	0	7
Iris virginica	Virginia iris	OBL	0.00	0.11	0	50
Iva annua	Annual marsh elder	FAC	0.05	0.37	26	346
Juncus brachycarpus	Whiteroot rush	FACW	0.00	0.10	0	20
Juncus interior	Inland rush	FACU	0.00	0.01	0	1
Juncus marginatus	Grassleaf rush	FACW	0.00	0.04	0	20
Juncus sp.	Rush		0.00	0.03	0	3
Juncus tenuis	Poverty rush	FAC	0.00	0.01	0	5
Juncus validus	Roundhead rush	FACW	0.00	0.14	0	62
Kummerowia striata	Japanese clover	FACU	0.00	0.30	0	191
Kyllinga brevifolia	Shortleaf spikesedge	FACW	0.00	0.15	0	26
Lantana spp.	Lantana		0.03	0.00	10	0
Ligustrum sinense	Chinese privet	FAC	0.00	0.01	0	10
Ludwigia octovalvis	Mexican primrose-willow	OBL	0.00	0.46	0	740
Ludwigia peploides	Floating primrose-willow	OBL	0.00	0.34	0	98
Ludwigia sp.	Primrose-willow	OBL	0.26	0.30	241	40
Lygodium japonicum	Japanese climbing fern	FAC	0.00	0.03	0	11
Malvastrum coromandelianum	Three-lobed false mallow	FACU	0.00	0.04	0	3
Mecardonia procumbens	Baby jump-up	OBL	0.00	0.07	0	6
Mikania scandens	Climbing hempvine	FACW	0.08	0.23	7	353
Modiola caroliniana	Carolina bristlemallow	FACU	0.00	0.08	0	23
Monarda citriodora	Lemon beebalm		0.00	0.13	0	31
Neptunia lutea	Yellow puff	FACU	0.00	0.01	0	1
Nymphaea mexicana	Yellow waterlily	OBL	0.00	0.21	0	506
Nymphaea odorata	American white waterlily	OBL	0.00	0.14	0	151
Oxalis dillenii	Slender yellow woodsorrel	FACU	0.00	0.54	0	59
Panicum hemitomon	Maidencane	OBL	0.00	0.21	0	380
Panicum sp.	Panicgrass		0.00	0.03	0	8
Parthenocissus quinquefolia	Virginia creeper	FACU	0.00	0.01	0	1
Paspalum denticulatum	Logtom	OBL	0.10	0.00	193	0
Paspalum dilatatum	Dallisgrass	FAC	0.03	0.39	2	237
Paspalum notatum	Bahiagrass	FACU	0.00	0.90	0	1888
Paspalum plicatulum	Brownseed paspalum	FAC	0.00	0.00	0	0
Paspalum sp.	Crowngrass or paspalum		0.00	0.07	0	8
Paspalum urvillei	Vasey's grass	FAC	0.15	0.46	105	537
Paspalum vaginatum	Seashore paspalum	OBL	0.00	0.13	0	68

Table 15. Cont. Frequency and total cover of plant species identified in Pre and Post vegetation surveys along random transects at the UHCL Created Wetland Site.

			Frequency		Total Cover (%)	
Species Name	**Common name**	**Wetland Class**	Pre	Post	Pre	Post
Phyla nodiflora	Turkey tangle frogfruit	FAC	0.36	1.80	261	1124
Phyllanthus urinaria	Chamber bitter	FAC	0.00	0.08	0	4
Polygonum hydropiperoides	Swamp smartweed	OBL	0.23	1.11	196	1367
Polygonum pensylvanicum	Pennsylvania smartweed	FACW	0.00	0.03	0	5
Pontederia cordata	Pickerelweed	OBL	0.00	0.35	0	1070
Ptilimnium nuttallii	Laceflower	FAC	0.00	0.03	0	3
Rhynchospora sp.	Beaksedge		0.00	0.04	0	30
Rubus sp.	Blackberry or dewberry		0.00	0.03	0	10
Rubus trivialis	Southern dewberry	FACU	0.15	0.31	8	505
Rumex crispus	Curly dock	FAC	0.03	0.07	2	5
Rumex sp.	Dock or sorrel		0.00	0.01	0	3
Sagittaria lancifolia	Bulltongue arrowhead	OBL	0.00	0.08	0	28
Sagittaria platyphylla	Delta arrowhead	OBL	0.00	0.27	0	147
Sagittaria sp.	Arrowhead	OBL	0.00	0.48	0	108
Schoenoplectus californicus	California bulrush	OBL	0.00	0.32	0	553
Setaria texana	Texas bristlegrass		0.00	0.01	0	2
Sida rhombifolia	Cuban jute	FACU	0.05	0.30	8	105
Smilax bona-nox	Saw greenbrier	FAC	0.00	0.01	0	1
Solidago canadensis	Canada goldenrod	FACU	0.10	0.01	64	2
Sorghum halepense	Johnsongrass	FACU	0.00	0.63	0	891
Sorghastrum nutans	Indiangrass	FACU	0.18	0.00	211	0
Spirodela polyrrhiza	Common duckmeat	OBL	0.00	0.01	0	1
Stenotaphrum secundatum	St. Augustine grass	FAC	0.10	0.45	18	1429
Symphyotrichum tenuifolium	Perenniel saltmarsh aster	OBL	0.00	0.15	0	66
Taxodium distichum	Bald cypress	OBL	0.00	0.24	0	1213
Toxicodendron radicans	Eastern poison ivy	FAC	0.00	0.01	0	1
Triadica sebifera	Chinese tallow	FAC	0.03	0.07	100	5
Trifolium repens	White clover	FACU	0.00	0.68	0	378
Typha latifolia	Broadleaf cattail	OBL	0.00	0.03	0	3
Ulmus crassifolia	Cedar elm	FAC	0.03	1.37	0	203
Ulmus spp.	Elm		0.03	0.00	0	0
Unidentifiable species			0.00	0.11	0	5
Unidentifiable grasses			0.00	1.76	0	1798
Urochloa reptans	Sprawling signalgrass	UPL	0.00	0.17	0	239
Urochloa platyphylla	Broadleaf signalgrass	FAC	0.00	0.32	0	169
Vallisneria americana	American eelgrass	OBL	0.00	0.01	0	2
Verbena brasiliensis	Brazilian vervain		0.03	0.85	1	326
Verbena rigida	Tuberous vervain		0.00	0.01	0	4
Verbena xutha	Gulf vervain		0.08	0.00	0	0
Vigna luteola	Hairypod cowpea	FACW	0.15	0.83	16	1961
Vitis mustangensis	Mustang grape		0.03	0.06	10	8

Table 16. List of the plant species planted at the UHCL wetland immediately following construction on 8/27/2011.

Species	Common Name	Number Planted
Brasenia schreberi	Watershield	18
Eleocharis montevidensis	Sand spikerush	25
Eleocharis quadrangulata	Squarestem spikerush	52
Iris virginica	Virginia iris	31
Nymphaea sp.	Water Lily	44
Panicum hemitomon	Maidencane	115
Polygonum hydropiperoides	Swamp Smartweed	26
Pontederia cordata	Pickerelweed	105
Sagittaria sp.	Arrowhead	59
Schoenoplectus californicus	Bullrush	132

Table 17. Presence/absence of fish species caught using all sample methods at all sites during the UHCL wetland construction study.

Site	Date	Construction Phase	*Atractosteus spatula*	*Lepomis gulosus*	*Lepomis macrochirus*	*Dorosoma petenense*	*Gambusia affinis*	*Menidia beryllina*	*Ictalurus punctatus*	*Micropterus salmoides*	*Lepomis spp. (juv)*	*Notemigonus crysoleucas*
Duck Pond	8/10/2011	Pre	X	X	X	X						
	5/29/2013	Post: Year 2	X	X	X		X	X				
Alligator Pond	5/24/2011	Pre	X		X		X		X			
	8/8/2011	Pond Draining	X	X	X		X			X		X
	6/8/2012	Post: Year 1					X					
	5/30/2013	Post: Year 2					X			X	X	
Primary wetland	6/8/2012	Post: Year 1					X					
	5/29/2013	Post: Year 2					X					
Secondary Wetland	6/8/2012	Post: Year 1					X					
	5/29/2013	Post: Year 2					X					

Table 18. Fish stocked into Alligator Pond on 2/28/2012.

Species	Number
Atractosteus spatula	1
Mugil cephalus	1
Ictaluris punctatus	3
Micropterus salmoides	17
Lepomis gulusus	2
Lepomis macrochirus	18
Lepomis microlophus	1
Lepoms auritus	1
Lepomis megalotis	3

Benthics

The following data represents a summary of all benthic sampling results at the site (Table 19). None of the sites surveyed yielded consistently high benthic IBI scores. This is not surprising since the benthic IBI methodology was primarily designed to evaluate the biological condition of flowing streams. Currently TCEQ and EPA have not adopted a consistent method to evaluate wetland biotic integrity (USEPA 2011). We will be conducting ongoing studies to evaluate the functional relationship between benthic communities and healthy plant communities.

Zooplankton

Only limited zooplankton samples were collected during the study. The data are presented below in (Table 20). Although catch rates declined after construction of the wetland, the number of taxa increased. Additional monitoring is needed to determine the ultimate influence of the wetland community on the zooplankton. The presence of zooplankton and benthic other invertebrates is essential for support of the wetland and lotic food chains that include fish, larger invertebrates, amphibians, reptiles, and fish eating birds (Batzer and Sharitz 2006, Sabo et al. 2009).

Table 19 Benthic Index of Biotic Integrity (IBI) evaluation for selected sites within the wetland complex; including pre-and post-construction sampling events. Rows highlighted in light blue represent pre-construction levels. Calculations based on specifications outlined in (TCEQ 2007). Note: on 8 June 2012, only one replicate was collected at site 12.

Site	Date	Rep.	Total # individuals in sample	Total Taxa Richness	IBI Score	IBI Rating
2	12/8/10	A	223	13	26	Intermediate
		B	205	10	20	Limited
	7/22/11	A	330	25	26	Intermediate
		B	266	23	26	Intermediate
	9/7/12	A	263	15	23	Intermediate
		B	256	5	15	Limited
	5/30/13	A	256	20	26	Intermediate
		B	421	22	30	High
4	6/8/12	A	220	25	20	Limited
		B	209	25	23	Intermediate
	9/5/12	A	151	4	12	Limited
		B	11	5	17	Limited
	5/29/13	A	215	21	24	Intermediate
		B	144	8	16	Limited
10	6/7/12	A	269	17	22	Intermediate
		B	207	19	24	Intermediate
	9/6/12	A	354	3	15	Limited
		B	217	5	15	Limited
	5/29/13	A	80	16	19	Limited
		B	218	28	23	Intermediate
12	12/8/10	A	228	14	20	Limited
		B	191	11	19	Limited
	5/25/11	A	385	29	24	Intermediate
		B	216	26	23	Intermediate
	7/22/11	A	199	23	22	Intermediate
		B	225	30	27	Intermediate
	6/8/12		117	13	21	Limited
	9/7/12	A	7	2	17	Limited
		B	56	2	17	Limited
	5/29/13	A	420	16	19	Limited
		B	271	13	19	Limited

Table 20. Results of zooplankton sampling at Alligator Pond and Duck Pond prior to and after construction of the wetland.

Site Information			Invertebrates							Fish		Community Metrics		
Site	Date	Rep	Sididae	Daphinidae	*Leptodora kindtii*	Chydoridae	Calanoida	Chironomidae	Caenidae	*Gambusia affinis*	Centrachidae	Total	NoTaxa	CumTaxa
2	9/7/2012	1	0.08	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.93	2	3
2	9/7/2012	2	0.08	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.51	3	3
2	9/7/2012	3	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11	1	3
2	5/30/2013	1	0.00	0.00	0.57	0.07	1.98	0.00	0.07	0.00	0.00	2.69	4	4
2	5/30/2013	2	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.79	1	4
2	5/30/2013	3	0.00	0.00	0.00	0.00	2.49	0.00	0.00	0.00	0.00	2.49	1	4
12	9/7/2012	1	0.21	0.00	0.00	0.00	6.89	0.00	0.00	0.01	0.00	7.11	3	3
12	9/7/2012	2	0.38	0.00	0.00	0.00	4.84	0.00	0.00	0.00	0.00	5.22	2	3
12	9/7/2012	3	0.13	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.89	2	3
12	5/30/2013	1	0.00	0.11	0.00	0.00	0.91	0.00	0.00	0.00	0.00	1.02	2	5
12	5/30/2013	2	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.07	4	5
12	5/30/2013	3	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	1	5

Birds

Numerous species of birds have been sighted at the wetland complex. Since the site was disturbed during construction it has taken some time for new species of birds to recruit to the area. More recent surveys have shown a steady increase in the number of taxa. In some categories the secondary wetland now exceeds the undisturbed Duck Pond control site. In addition, more wading birds have begun to recruit to the area. The increase in vegetation density and cover will lead to greater utilization of the site.

Table 21 Total avian counts by species groupings in each wetland location surveyed. Data compiled from surveys performed between 8 June 2012 and 24 May 2013 (*n* surveys = 14). Appendix A contains full species list for bird counts.

Grouping	Primary Wetland	Secondary Wetland	Duck Pond
Birds of prey	13	6	7
Wading birds	11	24	122
Ducks and divers	0	5	29
Passerines	105	196	114
Doves	0	17	8
Woodpeckers	21	1	2
Swallows	0	1	0
Shorebirds	0	1	0
Total number of observations	150	249	282
Total species count per site	21	30	33

Game Cameras – Other Wildlife

The game camera was invaluable for monitoring and documenting both wildlife and human use of the sight. An electronic supplement of the majority of photographs is available upon request. A summary of the major points associated with the use of camera monitoring is listed below.

- Depending on date, vegetation made some animals hard to detect (esp. turtles, low lying animals)
- Depending on time of year, more hours of visibility vs. less (summer/winter)
- Arbor camera view had to be adjusted to final sampling position on 1/4/2012;
- Night time hours = harder to detect animals (especially at arbor) due to low light
- Not all animals triggered cameras (esp. at arbor); many counts came from animals included in photographs triggered by humans or on hourly photos
- Thousands of visitors have come to the wetland complex of the last 2 years.

Numerous species of wildlife was seen at the wetland complex using the camera traps. These included:

- Turtle
  - Red eared slider
  - Possibly spiny softshell
- Duck
  - Black-bellied whistling duck
- Raptor
  - Red-tailed hawk
  - Red-shouldered hawk
- Wading birds
  - Black crowned night heron
  - Cattle/Snowy egret
  - Great blue heron
  - Great egret
  - Green heron
  - Little blue heron (breeding and non)
  - Reddish egret (?)
  - Roseate spoonbill
  - White ibis (juvenile and adult)
  - Yellow crowned night heron
- Bird, other
  - Belted (?) kingfisher
  - Laughing (?) gull

- Northern cardinal
- Common (?) grackle

We are in the process of analyzing this data and vegetation data as part of a long-term monitoring program to determine how physical attributes such as plant communities and physical cover affect the associated aquatic and semi-terrestrial fauna.

On a closing note, the wetland complex has been utilized by over 400 school students during EIH's youth summer camp, and the high school Texas Envirothon programs to teach wetland ecology and aquatic biology. In addition, Dr. Guillen routinely uses the wetland for his graduate Wetlands Ecology and Limnology courses. The complex has become one of the greatest treasures of the UHCL campus. The President of UHCL and others in University Advancement have been exploring ways to increase access and are interested in seeing additional wetlands constructed along our riparian corridor. Numerous presentations on the constructed wetland complex have been given to various groups such as the Rotary Club of Clear Lake and other interest groups.

DISCUSSION

By all measures the UHCL created wetland has been an overwhelming success. Although we were only able to collect a small suite of indicator variables due to the limited budget for monitoring, the results to date suggest that the system which includes the various wetland cells and associated retention pond are very effective for the removal of phosphorus and indicator bacteria depending on flow regime and bank stability. As the wetland continues to mature, additional plant growth will stabilize bottom sediments. In addition, more extensive plant growth will lead to increase nitrogen and phosphorus removal. In addition, the "pre-polishing' effect of the wetland has likely lead to the reduction in eutrophic conditions (e.g. algal mats) in Alligator pond. The water which discharges from Alligator Pond to Horsepen Bayou is now cleaner due to in-situ biological and mechanical treatment of the discharge water.

Our limited data suggest that after construction of the wetlands the levels of phosphorus and indicator bacteria declined leading to reduced frequency of algal blooms which the overall level of dissolved oxygen increased. The temporal patterns displayed by the RFU and dissolved oxygen, when combined with the pH and turbidity data supports the hypothesis that less algal blooms including a reduction in the variability of extreme oxygen levels ranging from supersaturated to hypoxia occurred after construction of the wetland. This is in contrast to the Duck Pond which continues to exhibit elevated pH levels which is an indication this waterbody continues to exhibit eutrophic conditions. This pattern is consistent with the observed algal blooms consisting of blue green algal mats that occur there each year. The highest levels of pH usually occurred during dry weather sampling. This is likely due to reduced turbidity that allows light to penetrate the water column and stimulate algal growth.

Also, based on automated turbidity monitoring it appears that the intensity and frequency of high turbidity events has also declined. The greatest decline in any nutrient occurred in the reduction of orthophosphates and total phosphorus at the Alligator Pond after construction of the wetland. This reduction in phosphorus most likely led to the decline in algal blooms.

The total organic carbon content of the water column declined at Alligator Pond after installation of the wetland during both wet and dry weather conditions. However, this decline was also observed at both the Duck Pond and to a lesser extent Horsepen Bayou. The cause of this general decline is unknown, but the greatest difference or reduction occurred at the Alligator Pond after construction of the wetland.

The controlled water releases using the reclaimed waste water from the Clear Lake City Water Authority treatment facility provided us with an ideal controlled source of pollutants (nutrients) to examine the efficacy of the wetland treatment system. Using estimated time of travel data we were able to track a “slug” of water to evaluate nutrient removal. We observed a clear decreasing spatial trend in nutrient levels extending from upstream to downstream, when the only source of water was the wastewater irrigation system. Decreases in nutrient concentrations were observed and in some cases by 3 orders of magnitude. A combination of factors contributed to this decline in nutrients in the water column. This included precipitation, uptake by plants and mechanical uptake, which has been observed in freshwater wetlands (Reddy and Delaune 2008). Supporting sediment nitrogen and phosphorus data indicated that nitrogen levels generally declined through time, but phosphorus levels increased suggesting that the wetland was sequestering phosphorus into the sediment under anoxic surface water conditions. This pattern was consistent with the general decline in phosphorus levels within the water column as discussed earlier.

Enterococci and *E. coli* bacteria showed significant declines in density during dry weather sampling at the Alligator pond following construction of the wetland. This pattern did not occur during all wet weather events. The Duck Pond and Horsepen Bayou did not exhibit this pattern in reduction. This provides strong evidence that the wetland was effective in reducing levels from 100-880 MPN/100 ml down to less than 50 MPN/100 of *E. col*i and/or Enterococci indicator bacteria.

We examined the relationship of various nutrients and pollutants and rainfall amounts. We found that this relationship was not consistent. It appeared that Horsepen Bayou was the least sensitive to increased flows and resulting increases in selected pollutants such as TSS, nitrogen and phosphorus. However, Alligator Pond tended to exhibit a more sensitive response, although in general the level of these pollutants was lower than the other sites at comparable flows, especially after construction of the wetland. Interestingly, high TSS values occurred at Alligator Pond in response to increased rainfall after construction of the wetland. This again suggests that during the first two years erosion of the levee and other unstable soils may have been occurring.

Part of our project included the evaluation of a solar powered intake pump to irrigate our wetland during low rainfall periods or to supplement runoff. Unfortunately this approach did not appear to be logistically feasible in the long term for our area. Horsepen Bayou, the source of water, is a tidal waterbody. Since the created wetland is a perched freshwater wetland, the salinity of the bayou was closely monitored in order to be sure that saltwater was not pumped into the created freshwater wetland system. Because we did not want to pump saline water into the wetland, the solar pump was only used when the conductivity in Horsepen Bayou at the site of the pump intake was <1000 µS/cm. This occurred regularly during dry weather, but only for short periods of time. Conductivity was only below 1000 μS/cm for prolonged periods only after large or frequent rain event which reduced salinities in Horsepen Bayou. Unfortunately during or immediately following rain events extra water is not needed in the created wetland, since it is receiving runoff from the UHCL campus and is already saturated with storm water. In addition to the necessary conductivity monitoring, maintenance on the pump intake was a major issue. We did consider the feasibility of using more salt tolerant plants. However, during many periods the conductivity would be so low as to eventually lead to the establishment of a predominantly freshwater system. The bottom line is it is much easier to maintain a freshwater system given the local meteorology and hydrology then an estuarine wetland. The pump was installed in a small indention of the bank in order to protect it from high flow events, but as a result this indention was also a collector of small debris. The debris (aquatic vegetation, trash, etc) would clog the pump intake and would have to be manually cleared before each time the pump was started.

However, based on this pilot feasibility study, the use of solar power to provide energy necessary to pump water and provide tertiary water quality treatment would be feasible in more favorable freshwater systems. Using a solar pump and created wetland complex to provide tertiary water quality treatment would be feasible in smaller freshwater streams and bayous. The greatest utility of the solar pump system would be in the treatment of freshwater where perched wetlands can only be built along the river banks and no other option is available. We would also recommend the incorporation of a screen to remove large debris and careful design of the streambank to reduce obstruction of the intake line. In addition, the inclusion of storage batteries to prolong operation during evening hours and overcast days would be useful. Other automated systems using wind power to generate electricity for battery storage should also be explored.

The plant community in the wetland established itself rapidly. The three most frequently occurring species pre construction with a frequency of occurrence of >0.25 were: *Ludwigia sp*., *Phyla nodiflora*, and *Polygonum hydropiperoides*. The three most frequently occurring species one year after construction with an occurrence of >1.45 were: *Calyptocarpus vialis, Plyla nodiflora*, and *Ulmus crassifolia*. In comparison, the species with the highest total percent cover pre-construction was *Echinochloa sp*., (413) while after construction it was *Vigna luteola* (1961). Both species composition and richness changed pre and post construction, with a total of 41 species observed during pre-construction sampling, and a total of 122 species observed one year post construction. A total of 113 of the 122 species of plants observed one year post construction, naturally recruited to the site.

The wetland site has attracted numerous terrestrial and aquatic wildlife species. It is also utilized by students and faculty for classes and as a rest stop during the day. The wetland complex will continue to serve as a multifunction asset to the campus providing water quality improvement, wildlife habitat, aesthetically pleasing areas to rest and a unique teaching and research tool.

Based on data collected during this study we conclude that the construction of wetlands similar to the design used in this project that are associated with detention basins or borrow pits are a viable option in many urban watersheds along the Gulf coast. The design of the primarily surface flow treatment wetland is both practical, provides effective treatment for common pollutants (e.g. bacteria, sediment, nutrients), is cost effective and aesthetically pleasing (Persyn et al. 2005). Very often these urban waterways in Texas have been channelized and are separated from the riparian zone by elevated berms and levees. The primary connection with them is through below ground overflow drains. However, the remaining oxbows and man-made depressions provide an ideal location for construction of an intercept surface flow wetland. The strategic placement of logs and rocks provides both a hydrological barrier to reduce velocity, increase storage time and provides habitat for benthic organisms and algae. The project can be scaled to any size property. The major drawback is the need for property for construction of the facility. This type of wetland represents best management practices for construction of riparian wetlands in heavily developed urban areas within the Galveston Bay watershed. The promotion of this technology will both reduce pollutant loading and provide additional green space and natural surroundings in an urban landscape and also expand habitat for waterbirds, amphibians and wetland plants, many of which are currently at risk. Improvements in water quality would occur with the wider adoption of these types of constructed wetlands by large landowners and as neighborhood/subdivision projects. A local candidate site includes the former Clear Lake City golf course. Schools, universities, and regional parks are also excellent sites that provide opportunities for educational outreach.

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Appendices

Appendix A: Species Lists from Biological Surveys

Table A1. Plant species documented at the wetland site.

Species Name	Common Name	Wetland Class	Old (species) name
Acacia angustissima	Prairie acacia	NA	
Acmella oppositifolia	Oppositeleaf spotflower	NA	
Agalinis heterophylla	Prairie false foxglove	FACU	*Gerardia heterophylla* Nutt.
Alternanthera philoxeroides	Alligatorweed	OBL	
Amaranthus australis	Southern amaranth	OBL	
Amaranthus sp.	Pigweed or Amaranth	NA	
Ambrosia psilostachya	Cuman ragweed	FAC	*Ambrosia cumanensis*
Ammannia coccinea	Valley redstem	OBL	
Ampelopsis arborea	Peppervine	FAC	
Andropogon virginicus	Broomsedge bluestem	FAC	
Anagallis arvensis	Scarlet pimpernel	FACU	
Aster spp.	Aster	NA	
Baccharis halimifolia	Eastern baccharis	FAC	
Bacopa monnieri	Herb of grace	OBL	
Bacopa sp.	Water hyssop	OBL	
Calyptocarpus vialis	Staggler daisy	FAC	
Campsis radicans	Trumpet creeper	FAC	
Carex cherokeensis	Cherokee sedge	FACW	
Carex debilis	Sedge	FACW	
Chamaecrista fasciculata	Partridge pea	FACU	
Chamaecrista sp.	Sensitive pea	NA	
Chamaesyce maculata	Spotted sandmat	FACU	
Chloracantha spinosa	Spiny chloracantha	FACW	*Leucosyris spinosus*
Cirsium horridulum	Canadian horseweed	FAC	
Cissus spp.	Golden tickseed	NA	
Conyza canadensis	Bermuda grass	FACU	
Coreopsis tinctoria	Fragrant flatsedge	FAC	
Cynodon dactylon	Flatsedge	FACU	
Cyperus odoratus	Fragrant flatsedge	FACW	
Cyperus pseudovegetus	Marsh flatsedge	FACW	
Cyperus A	Flatsedge	Most likely FACW	
Cyperus ochraceus	Pond flatsedge	FACW	
Cyperus iria	Ricefield flatsedge	FACW	
Cyperus D	Flatsedge	Most likely FACW	
Cyperus sp.	Faltsedge	Most likely FACW	
Cyperus virens	Green flatsedge	FACW	
Dichondra carolinensis	Carolina ponysfoot	FAC	
Dichondra sp.	Ponysfoot	NA	
Digitaria filiformis	Slender crabgrass	NA	
Digitaria sanguinalis	Hairy crabgrass	FACU	
Diodia virginiana	Virginia buttonweed	FACW	
Dracopis amplexicaulis	Clasping coneflower	FAC	
Echinochloa colona	Jungle rice	FACW	*Echinochloa colonum*
Echinochloa crus-galli	Barnyard grass	FACW	
Echinochloa polystachya	Creeping river grass	OBL	
Echinochloa sp.	Cockspur grass or barnyard grass	NA	

Species Name	Common Name	Wetland Class	Old (species) name
Echinochloa walteri	Coast cockspur grass	OBL	
Eclipta prostrata	False daisy	FACW	
Eleocharis montevidensis	Sand spikerush	FACW	
Eleocharis parvula	Dwarf spikerush	OBL	
Eleocharis quadrangulata	Squarestem spikerush	OBL	
Eleocharis sp.	Spikerush	NA	
Elymus virginicus	Virginia wildrye	FAC	
Eupatorium spp.	Boneset, Thoroughwort, or Snakeroot	NA	
Euphorbia serpens	Matted sandmat	FAC	
Gaillardia pulchella	Indian blanket	UPL	
Gnaphalium sp.	Cudweed	NA	
Hydrocotyle sp.	Pennywort	NA	
Hydrocotyle umbellata	Manyflower marshpennywort	OBL	
Ilex vomitoria	Yaupon	FAC	
Ipomoea cordatotriloba	Tievine	FACU	*Ipomoea trichocarpa*
Iris virginica	Virginia iris	OBL	
Iva annua	Annual marsh elder	FAC	
Juncus brachycarpus	Whiteroot rush	FACW	
Juncus interior	Inland rush	FACU	
Juncus marginatus	Grassleaf rush	FACW	
Juncus sp.	Rush	NA	
Juncus tenuis	Poverty rush	FAC	
Juncus validus	Roundhead rush	FACW	
Kummerowia striata	Japanese clover	FACU	Unk. Woody base, branching, 3 leaflets
Kyllinga brevifolia	Shortleaf spikesedge	FACW	
Lantana spp.	Lantana	NA	
Ligustrum sinense	Chinese privet	FAC	
Ludwigia octovalvis	Mexican primrose-willow	OBL	
Ludwigia peploides	Floating primrose-willow	OBL	
Ludwigia sp.	Primrose-willow	OBL	
Lygodium japonicum	Japanese climbing fern	FAC	Fern vine
Malvastrum coromandelianum	Three-lobed false mallow	FACU	
Mecardonia procumbens	Baby jump-up	OBL	
Mikania scandens	Climbing hempvine	FACW	
Modiola caroliniana	Carolina bristlemallow	FACU	
Monarda citriodora	Lemon beebalm	NA	
Neptunia lutea	Yellow puff	FACU	
Nymphaea mexicana	Yellow waterlily	OBL	
Nymphaea odorata	American white waterlily	OBL	
Oxalis dillenii	Slender yellow woodsorrel	FACU	
Panicum hemitomon	Maidencane	OBL	
Panicum sp.	Panicgrass	NA	
Parthenocissus quinquefolia	Virginia creeper	FACU	
Paspalum denticulatum	Logtom	OBL	
Paspalum dilatatum	Dallisgrass	FAC	
Paspalum notatum	Bahiagrass	FACU	
Paspalum plicatulum	Brownseed paspalum	FAC	
Paspalum sp.	Crowngrass or paspalum	NA	

Species Name	Common Name	Wetland Class	Old (species) name
Paspalum urvillei	Vasey's grass	FAC	
Paspalum vaginatum	Seashore paspalum	OBL	
Phyla nodiflora	Turkey tangle frogfruit	FAC	
Phyllanthus urinaria	Chamber bitter	FAC	Chamaecrista-like or mimosa-like
Polygonum hydropiperoides	Swamp smartweed	OBL	
Polygonum pensylvanicum	Pennsylvania smartweed	FACW	
Pontederia cordata	Pickerelweed	OBL	
Ptilimnium nuttallii	Laceflower	FAC	
Rhynchospora sp.	Beaksedge	NA	
Rubus sp.	Blackberry or dewberry	NA	
Rubus trivialis	Southern dewberry	FACU	
Rumex crispus	Curly dock	FAC	
Rumex sp.	Dock or sorrel	NA	
Sagittaria lancifolia	Bulltongue arrowhead	OBL	
Sagittaria platyphylla	Delta arrowhead	OBL	
Sagittaria sp.	Arrowhead	OBL	
Schoenoplectus californicus	California bulrush	OBL	*Scirpus californicus*
Setaria texana	Texas bristlegrass	NA	
Sida rhombifolia	Cuban jute	FACU	
Smilax bona-nox	Saw greenbrier	FAC	
Solidago canadensis	Canada goldenrod	FACU	
Sorghum halepense	Johnsongrass	FACU	
Sorghastrum nutans	Indiangrass	FACU	
Spirodela polyrrhiza	Common duckmeat	OBL	
Stenotaphrum secundatum	St. Augustine grass	FAC	
Symphyotrichum tenuifolium	Perenniel saltmarsh aster	OBL	*Aster tenuifolius*
Taxodium distichum	Bald cypress	OBL	
Toxicodendron radicans	Eastern poison ivy	FAC	
Triadica sebifera	Chinese tallow	FAC	*Sapium sebiferum*
Trifolium repens	White clover	FACU	
Typha latifolia	Broadleaf cattail	OBL	
Ulmus crassifolia	Cedar elm	FAC	Cedar Elm
Ulmus spp.	Elm	NA	
Unidentifiable species		NA	Unidentifiable species
Unknown Grass #1		NA	
Unknown Grass		NA	
Unkown unidentifiable grasses		NA	Unk. Unidentifiable grasses
Unknown spp.		NA	
Urochloa reptans	Sprawling signalgrass	UPL	
Urochloa platyphylla	Broadleaf signalgrass	FAC	*Brachiaria platyphylla*
Vallisneria americana	American eelgrass	OBL	
Verbena brasiliensis	Brazilian vervain	NA	
Verbena rigida	Tuberous vervain	NA	
Verbena xutha	Gulf vervain	NA	
Vigna luteola	Hairypod cowpea	FACW	
Vitis mustangensis	Mustang grape	NA	

Table A2. List of nekton and other aquatic/semiaquatic organisms observed at the wetland.

Type	Species Name	Common Name
Fish	*Atractosteus spatula*	Alligator gar
	Lepomis gulosus	Warmouth
	Lepomis macrochirus	Bluegill
	Lepomis spp. *(juv)*	Sunfish species
	Dorosoma petenense	Threadfin shad
	Ictalurus punctatus	Channel catfish
	Gambusia affinis	Western mosquitofish
	Micropterus salmoides	Largemouth bass
	Menidia sp.	Silverside
Invert.	*Procambarus* spp.	Crayfish
Herp.	Unidentified spp.	Tadpole
	Rana catesbeiana	Bullfrog
	Hyla cinerea	Green tree frog
	Rana utricularia	Leopard frog
	Trachemys scripta elegans	Red eared slider
	Apalone spinifera	Spiny softshell

Table A3. List of benthic macroinvertebrates collected.

Phylum	Class	Order	Family	Genus	Reported to:
Annelida	Branchiobdellida				Class
	Hirudinea				Class
	Oligochaeta				Class
Arthropoda	Crustacea	Amphipoda	Gammaridae	*Gammarus*	Genus
		Amphipoda	Taltridae	*Hyalella*	Genus
		Cladocera			Order
		Copepoda			Genus
		Decapoda	Cambaridae	*Cambarus*	Genus
		Decapoda	Palaemonidae	*Palaemontes*	Genus
		Isopoda			Genus
		Mysidacea	Mysidae	*Taphromysis*	Genus
		Ostracoda			Genus
	Hydracarina				Class
	Insecta	Coleoptera	Carabidae		Family
			Chrysomelidae		Family
			Curculionidae		Family
			Dytiscidae	*Hydrovatus*	Genus
				Neobidessus	Genus
				Oreodytes	Genus
			Haliplidae	*Peltodytes*	Genus
			Hydrophilidae	*Berosus*	Genus
				Cymbiodyta	Genus
				Enochrus	Genus
				Paracymus	Genus
				Tropisternus	Genus
					Family
			Scirtidae	*Scirtes*	Genus
			Staphylinidae		Family
		Collembola	Isotomidae	*Isotomurus*	Genus
			Poduridae	*Podura*	Genus
			Sminthuridae	*Sminthurides*	Genus
		Diptera	Ceratopogonidae	*Bezzia*	Genus
				Dasyhelea	Genus
				Forcipomyia	Genus
				Probezzia	Genus
				Stilobezzia	Genus
			Chaoboridae	*Chaoborus*	Genus
			Chironomidae		Family
			Empididae	*Clinocera*	Genus
			Ephydridae	*Hydrellia*	Genus
			Psychodidae	*Pericoma*	Genus
			Stratiomyidae	*Nemotelus*	Genus

Arthropoda	Insecta	Diptera	Stratiomyidae	*Odontomyia*	Genus
				Stratiomys (Stratiomyia)	Genus
			Tabanidae	*Chrysops*	Genus
			Tipulidae	*Geranomyia*	Genus
				Limnophila	Genus
		Ephemeroptera	Baetidae	*Callibaetis*	Genus
			Caenidae	*Caenis*	Genus
		Hemiptera	Belostomatidae	*Lethocerus*	Genus
			Cicadellidae		Family
			Corixidae	*Trichocorixa*	Genus
					Family
			Hebridae	*Hebrus*	Genus
			Mesoveliidae	*Mesovelia*	Genus
			Nepidae	*Curicta*	Genus
				Nepa	Genus
		Lepidoptera	Pyralidae		Family
		Odonata	Coenagrionidae	*Enallagma*	Genus
				Ischnura	Genus
			Gomphidae	*Arigomphus*	Genus
			Libellulidae	*Brechmorhoga*	Genus
				Erythemis	Genus
				Orthemis	Genus
				Pachydiplax	Genus
				Perithemis	Genus
				Sympetrum	Genus
					Family
		Trichoptera	Hydroptilidae	*Oxyethira*	Genus
			Leptoceridae	*Nectopsyche*	Genus
Mollusca	Bivalvia	Unionoida	Unionidae		Family
		Veneroida	Corbiculidae	*Corbicula*	Genus
			Sphaeriidae	*Sphaerium*	Genus
	Gastropoda	Caenogastropoda	Ampullariidae	*Pomacea*	Genus
		Limnophila	Ancylidae	*Ferrissia*	Genus
			Lymnaeidae	*Fossaria*	Genus
			Physidae	*Physella*	Genus
			Planorbidae	*Biomphalaria*	Genus
				Gyraulus	Genus
				Helisoma	Genus
		Mesogastropoda	Hydrobiidae		Family
			Thiaridae	*Melanoides*	Genus
Nematoda					Phylum
Platyhelminthes	Turbellaria			*Macrostomum*	Genus

Table A4. List of birds observed at the wetland complex.

Bird Code	Bird Name
AMCR	American Crow
AMRO	American Robin
BASW	Barn Swallow
BBWD	Black-bellied Whistling duck
BCNH	Black crowned Night Heron
BEKI	Belted Kingfisher
BLJA	Blue Jay
CACH	Carolina Chickadee
CAEG	Cattle Egret
CAWR	Carolina Wren
CEWA	Cedar Waxwing
CLSW	Cliff Swallow
CONI	Common Nighthawk
DOWO	Downy Woodpecker
EAKI	Eastern Kingbird
EAPH	Eastern Phoebe
GCFL	Great Crested Flycatcher
GFWO	Golden-fronted Woodpecker
GREG	Great Egret
GRHE	Green Heron
HAWO	Hairy Woodpecker
LAGU	Laughing Gull
LBHE	Little Blue Heron
NECO	Neotropic Cormorant
NOCA	Northern Cardinal
NOHA	Northern Harrier
NOMO	Northern Mockingbird
PBGR	Pied-billed Grebe
PIWA	Pine Warbler
PIWO	Pileated Woodpecker
RBWO	Red-bellied Woodpecker
RCKI	Ruby-crowned Kinglet
RSHA	Red-shouldered Hawk

Bird Code	Bird Name
SNEG	Snowy Egret
SOSA	Solitary Sandpiper
TRHE	Tricolored Heron
TUTI	Tufted Titmouse
TUVU	Turkey Vulture
YCNH	Yellow crowned Night-Heron
YRWA	Yellow Rumped Warbler
WWDO	White-winged Dove
WOTH	Wood Thrush
BGGN	Blue-gray Gnatcatcher
HETH	Hermit Thrush
MODO	Mourning Dove
MUDU	Muscovy Duck
OSPR	Osprey

Table A5. List of zooplankton species collected.

Cladocera	*Leptodora kindtii*
	F. chydoridae
Copepoda	Calanoida
	Chironomidae
Epheromoptera	Caenidae
Fish	*Gambusia affinis*
	Centrachidae

Appendix B: Raw 24-Hour Sonde Data

(Electronic Supplement)