Wetland Preservation and Mosquito Control: An Integrated Approach

Mosquitoes on Florida's east coast, including *Aedes taeniorhynchus* and *Aedes sollicitans*, are nuisance pests and competent disease vectors. Within the previous century, efforts have been made to reduce such populations, however most endeavors have caused deleterious effects on the surrounding environment. Rotational impoundment management has been recently established as a method that emphasizes periodic exchange and high water replication within impoundments. Culverts and pumps are utilized to artificially raise water levels, reducing exposed moist substrate available for oviposition. Yet, monitoring practices cease during the winter period of open exchange, allowing for a significant knowledge gap.

To determine discrepancies in water quality between impounded and unimpounded waters, water quality analyses were conducted for seven parameters including pH, dissolved oxygen, salinity, and nutrient concentrations. Analyses were conducted at four locations, each with an impounded and unimpounded component, per individual impoundment structure. Two separate impoundment structures in St. Lucie County, Florida were utilized in the biweekly analyses over the course of eight weeks during the winter period of open exchange.

Results from the analyses displayed no statistical significance for any parameter between impounded and unimpounded waters at Impoundment 14C (Harbor Branch). However substantial hydrological differences and variability in dissolved oxygen across the impoundment were observed. Results from analyses displayed no statistical significance for any parameter except dissolved oxygen at Impoundment 1 (Bear Point). This suggests inadequate flushing and exchange between the impoundment and peripheral lagoon. The application of additional culverts or spillways may help abate these issues and encourage more natural wetland function.

Introduction

Up until the mid-nineteenth century, St. Lucie County and surrounding areas along Florida's east coast were aptly dubbed "Mosquito County" due to the overwhelming presence of these insects. In an attempt to make the area habitable, efforts have been made to reduce mosquito populations, notably the many species of salt marsh mosquitoes (predominantly *Aedes taeniorhynchus* and *Aedes sollicitans*) that inhabit the Indian River Lagoon running vertically through the county (1).

In addition to being a nuisance, many mosquitoes of the genus *Aedes* and other

common species such as *Culex nigripalpus* are competent disease vectors (2). Viruses capable of surviving and multiplying within the mosquito can be spread to humans by mosquitos (3). The yellow fever mosquito, *Aedes aegypti*, and the Asian tiger mosquito, *Aedes albopictus*, are of major concern as the primary local vectors of yellow fever and dengue fever (4) (5) (6). Chikungunya is also readily transmitted (7).

C. nigripalpus has been implicated in the transmission of St. Louis encephalitis and West Nile virus, though domestic cases in the region are rare (8) (9). In addition, Eastern equine encephalitis can be brought into the region within the blood of several bird species, where it is then transmitted to mosquitos and can eventually infect humans (10).

To address these health concerns, organized mosquito control efforts began in the late 1920s with the earliest form of source reduction (11). Miles of parallel, hand-dug ditches were created in an attempt to connect hydrological low spots to the lagoon. These depressions in the topography collected water and provided the moist substrate necessary for mosquito and sandfly oviposition.

It was believed that this connection to the estuary would provide both the flooding necessary to decrease mud surface area and allow larvivorous fish, primarily killifish species such as *Rivulus marmoratus*, access to the breeding pools (12). However, the tides of the lagoon are primarily wind-driven, with the exception of locations in close proximity to inlets.

These ditching practices proved ineffective as the wind-driven tides were unable to elevate water levels to the point of sustained connection and larvivorous fish alone could not significantly reduce the number of insects. Sandflies were even less effected in these ditches and in many places, the ditches expanded the surface area of wet sediment exposed to the insects, exacerbating the issue.

By the early 1930s, emphasize had shifted to the impoundment of wetlands. The coastal wetlands of the Indian River Lagoon are a combination of mangrove forests, mixed herbaceous halophyte cover, and high salt marshes (13). In many areas, perimeter ditches were excavated around these structures and the removed sediment was used to form perimeter dikes. The ditches isolated the wetlands from the estuary, forming a number of lagoon microcosms scattered throughout the region. By flooding these impoundments, much of the moist substrate used for oviposition was submerged, reducing insect populations.

However, many ecological detriments ensued despite the use of lagoon water to flood the impoundments. Without connection to bodies of water, the impoundment water levels became exceedingly variable. Evaporation and seepage often resulted in elevated salinities that reduced ichthyofauna and damaged halophytes such as saltwort, *Batis maritima*, and glasswort, *Salicornia virginica* (14).

Transient species could not enter the wetland and several resident carnivorous and omnivorous fish species shifted to an herbivorous diet in impounded waters (15). During periods of prolonged rain, water levels would rise above the pneumataphores of black mangroves, cutting off oxygen intake and damaging the trees (16). This often resulted in impoundments with floral compositions of nearly monospecific stands of red mangroves. In the few impoundments flooded by artesian wells, floral and

faunal converted to being characteristic of freshwater wetland systems.

It is also believed that damage to the natural vegetation, mangrove forests in particular, within impoundments aided in the expanse of the invasive Brazilian pepper tree, *Schinus terebinthifolia* (17). Though only moderately halotolerant, *S. terebinthifolia* can withstand flooding as a sapling, allowing populations to increase in the absence of mangroves (18). The dense canopy formed by adult trees only further excludes competition and discourages the regrowth of natural vegetation (19).

By the early 1950s, these projects had been abandoned and mosquito control had become nearly entirely reliant upon pesticides (DDT, BHC, Dieldrin, etc.). However, the thick mangrove cover characteristic of the area prevented much of the aerially applied insecticides from reaching the larval habitats in which they would take effect in killing mosquitoes (20). As a result, these organo-chlorine compounds accumulated in the leaves of the mangroves which would fall into the impoundments and lagoon, decomposing as detritus and releasing the chemicals into the water column.

With mounting concerns over genetic resistance and the potentially harmful effects of chemicals in the ecosystem, the focus shifted back to impoundments.

In the 1960s the concept of rotational impoundment management (RIM) was developed as an expansion on previous impoundment management techniques with modifications to allow for increased estuary exchange. St. Lucie County currently manages nearly 4,000 acres of wetlands utilizing these techniques (21).

Culverts and pump stations were added to existing dike structures. During the summer spawning season, typically May through October, culverts are closed and lagoon water is pumped into the impoundment as a means of source reduction (22). Some culverts are fitted with bottom-flow valves to allow water from the lowermost level of the water column to be flushed and others are fitted with top-flow or spill-over valves to prevent water levels from elevating to a degree at which flora will be adversely affected.

In addition, periodic drawdowns occur during these summer months to enhance the feeding opportunities for young wading birds. Water levels are decreased for short periods of time to concentrate fish in shallow water, improving foraging opportunities (23).

Beginning ordinarily in November, in conjunction with the seasonal declines in water levels, culverts are opened and the impoundment experiences a six month period of open exchange. During this time, the impoundment structure is accessible to transient fish species and allows for a more natural hydrology.

With regards to the concern of deleterious effects on wetlands following impoundment, the St. Lucie County Mosquito Control and Coastal Management Services District has established a ninety percent water quality replication goal for all impoundments. To attain this, periodic water quality analyses are conducted on several parameters including dissolved oxygen, salinity, and nutrient concentrations.

Analyses are conducted both within and just outside of impoundment structures and compared to determine the level of water replication within the dike. Such procedures, however, are only conducted during the summer months in which the natural hydrology has been altered and is subject to unnatural conditions. No monitoring

occurs during the period of open exchange, thus allowing for a significant knowledge gap.

Of the two impoundments in which water quality was assessed, St. Lucie County Mosquito Impoundment 1 (Bear Point) is a federally permitted mitigation bank. Therefore, it is imperative that water quality standards are met at all times. In addition, St. Lucie County Mosquito Impoundment 14C (Harbor Branch) recently underwent an extensive remodel in which 21 culverts and a pump station were installed. There is currently no water quality data for this impoundment.

It is pertinent to address the lack of information with regards to winter water quality in and around these impoundments in order to promote the longevity of the structures.

It was the goal of this study to determine the quality of water within and outside of St. Lucie County mosquito impoundments and assess the impact such hydrological manipulation has rendered on the structures. All findings are intended to be applied towards the improvement and/or continued conservation of impounded wetlands through further hydrological engineering endeavors such as the addition of culverts, development of spillways, etc.

Materials and Methods

Collection Site Determination

Sixteen water collection sites were determined in total between two independent mosquito impoundment structures, St. Lucie County Mosquito Impoundment 1 (Bear Point) and St. Lucie County Mosquito Impoundment 14C (Harbor Branch). Within each of these impoundments, four locations were established, from which both river and impoundment collection sites were

A

B

C

Figures 1A and ***1B***: Photographs depicting an open culvert facing the lagoon (A) and impoundment (B) at Harbor Branch, water collection sites HBR1 and HBI1

Figure 1C: Photograph overlooking the impoundment ditch at Bear Point, water collection site BPI3

delineated (*Figures 2A* and *2B*). Collection sites were selected to provide the most holistic representation of the impoundments and thus contain attributes specific to their unique location. Special efforts were made to utilize locations in all proximities to culverts and pump stations.

The nomenclature of the collection sites is entirely dependent upon impoundment location with the first two letters corresponding to the respective impoundment, the third letter corresponding to either river or impoundment collection, and the final number corresponding to its site location determined sequentially from the entrance of the dyke.

A

Image courtesy of Google Maps

B

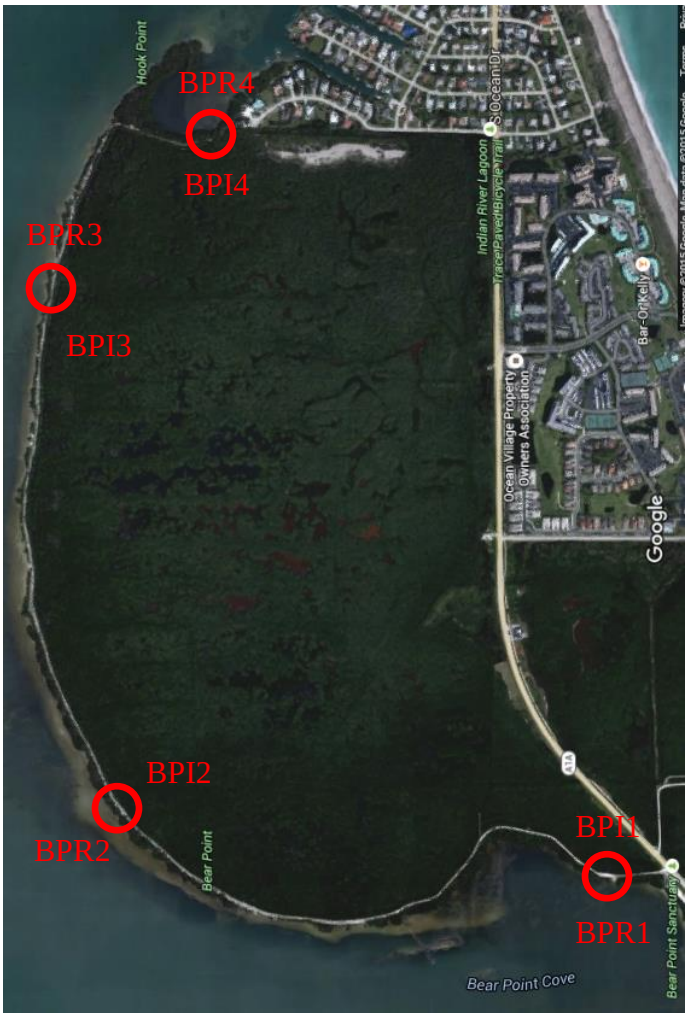


Image courtesy of Google Maps

Figure 2A: St. Lucie County Mosquito Impoundment 14C (Harbor Branch) with each of eight water collection sites labeled.
Figure 2B: St. Lucie County Mosquito Impoundment 1 (Bear Point) with each of eight water collection sites labeled.

Water Sample Collection

A large water sample was taken from each collection site using a five gallon bucket. The sample was collected by wading into the body of water. Proper safety measures were taken, including the use of closed-toe shoes and shuffling of the feet.

For both river and impoundment sites, the sample was taken beyond the initial expanse of mangroves lining the shoreline, where applicable. Efforts were made to take samples from areas with significant depth with regard to each location.

From this large sample, a 500mL sample was taken to be utilized in laboratory-based water quality analyses. The sample was filled entirely and stored in a screw-top polypropylene container to be transported to the laboratory.

Salinity Analysis

A hydrometer was utilized to determine the specific gravity of the water sample. The hydrometer was placed in the large five gallon water sample and allowed to settle. Once the bulb displayed no further movement, a measurement was taken by marking the point at which the bulb and water met.

The corresponding specific gravity measurement was recorded. Figures were then interpolated using a standard conversion equation to give salinity data.

pH and Temperature Analyses

To determine the pH level of the water sample, a Lovibond SD 50 pH meter was utilized. Prior to any readings being taken, the probe was calibrated.

Three buffers at concentrations of 4.0 pH, 7.0 pH, and 10.0 pH were poured into containers. The probe was inserted into each buffer progressing from 4.0 pH to 10.0 pH and several readings were taken for each buffer. The probe then used this three-point calibration to create a curve from which readings could be interpolated.

In order to determine pH concentrations, the probe utilizes an electrode surrounded by a glass membrane and a reference electrode. The reference electrode provides a leakage of electrons that serves as a conducting bridge to the glass electrode (24). The glass electrode then measures the electro-chemical potential of the hydrogen ions.

Once the probe had been calibrated, it was inserted into the large five gallon water sample to determine the pH concentration of the sample. At this time, the probe also determined the temperature of the sample. Both values were recorded. The electrodes were then rinsed with water and stored in electrode solution within the cap of the probe.

Dissolved Oxygen Analysis

To determine the dissolved oxygen (DO) concentration of the sample, the Hach HRDO Method 8166 was used in conjunction with a DR 900 Multiparameter Handheld Colorimeter and High Range Dissolved Oxygen AccuVac Ampules. Due to the hazardous nature of the chemicals contained in this reagent, all steps of the dissolved oxygen analysis were performed by a responsible supervisor.

A blank was prepared with water from the large five gallon sample. 10mL of the sample were added to an empty cuvette. Program 445 Oxygen, Dis HR AV was initialized on the colorimeter. The outside of the blank was wiped to prevent smudging. The blank was

inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded and the colorimeter was zeroed. This measurement was used as the baseline absorbance from which to compare the reacted sample, in order to account for stain in the water sample. The blank was removed from the sample cell receptor and the water disposed of. The empty cuvette was rinsed with deionized water and dried.

Nitrile gloves and safety goggles were adorned prior to any contact with the ampules. A 50mL polypropylene beaker was filled with water from the large 5 gallon sample. The tip of the AccuVac ampule was submerged in the water of this beaker and broken off. Water from the beaker moved into the ampule as the vacuum seal was broken. The strong inflow of the water prevented the reagent from spilling out into the beaker.

An ampule cap was placed around the point of breakage to prevent aeration from atmospheric oxygen. The ampule was then agitated for 30 seconds, during which a yellow-colored complex was formed. The ampule was then allowed to sit undisturbed for a two minute reaction time. During this reaction, any oxygen that degassed while being agitated dissolved again and reacted with the reagent (25). Once the two minutes expired, the ampule was agitated for another 30 seconds.

At this time, the yellow-colored complex had converted to a purple-colored complex, the intensity of which is proportional to the concentration of DO. The outside of the ampule was wiped to prevent smudging. The ampule was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded. The colorimeter utilized this absorbance to provide a reading of the DO concentration in the sample. The ampule was removed from the sample cell receptor and placed in a temporary storage container for transport to the laboratory. Upon arrival at the laboratory, all reacted ampules were transferred to a permanent storage container. Upon the conclusion of testing, all reacted ampules were disposed of via a chemical disposal company.

Nitrate Analysis

To determine the nitrate (NO_3^-) concentration of the sample, the Hach Cadmium Reduction Method 8039 was used in conjunction with a DR 900 Multiparameter Handheld Colorimeter and NitraVer 5 Nitrate Reagent Powder Pillows. In this method, cadmium is utilized to reduce NO_3^- into nitrite (NO_2^-) (*Figure 3A*). The created NO_2^- reacts with sulfanilic acid (*Figure 3B*) to form an intermediate diazonium salt (26). The salt then combines with gentisic acid to create an amber-colored complex (*Figure 3C*).

Due to the chemical composition of the water being tested, two special considerations were made regarding the cadmium reduction method. NO_2^- interferes at all levels as the principle of the method is to reduce NO_3^- to NO_2^-. The presence of NO_2^- in the water sample will result in artificially elevated NO_3^- readings. As a result, the NO_3^- analysis is to be treated as a total NO_3^- and NO_2^- reading. The results of the NO_2^- analysis are to be subtracted from the NO_3^- analysis results to obtain truly representative NO_3^- data.

In addition, chloride concentrations in excess of 100 mg/L inhibit the development of essential diazonium salts

and cause low results (27). Thus, chloride standards representative of the saline conditions of the lagoon were mixed using 1.6g/L NaCl DI water solution. $Ba(NO_3)_2$ was then added to the 1.6g/L NaCl DI water solution to create a solution containing 100 mg/L NO_3^-. This solution was then diluted with DI water to create standards of 1.0, 3.0, 5.0, and 10.0 mg/L NO_3^-. Each solution underwent the following procedure to create a data curve from which figures were interpolated.

A blank was prepared with water from the 500mL screw-top polypropylene container. 10mL of the sample were added to an empty cuvette. Program 355 N, Nitrate HR PP was initialized on the colorimeter. The outside of the blank was wiped to prevent smudging. The blank was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded and the colorimeter was zeroed. This measurement was used as the baseline absorbance from which to compare the reacted sample, in order to account for stain in the water sample. The blank was removed from the sample cell receptor and the water disposed of. The empty cuvette was rinsed with deionized water and dried.

Nitrile gloves were adorned prior to any contact with powder pillow reagents inside of the fume hood. 10mL of water from the 500mL screw-top polypropylene container were transferred to an empty cuvette. A NitraVer 5 Nitrate Reagent Powder Pillow was opened and its reagent contents poured into the sample cuvette. The cuvette was secured with a screw-on lid and agitated for 60 seconds. The sample was then allowed to sit undisturbed for five minutes.

During this reaction time, an amber-colored complex had formed, the intensity of which is proportional to the concentration of NO_3^-. The outside of the cuvette was wiped to prevent smudging. The cuvette was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded. The colorimeter utilized this absorbance to provide a reading of the NO_3^- concentration in the sample. The cuvette was removed from the sample cell receptor and the reacted water sample was transferred to a permanent storage container. The remaining cuvette and screw-top were rinsed and dried. Upon the conclusion of testing, all reacted water samples were disposed of via a chemical disposal company.

Formulas courtesy of Hach Company

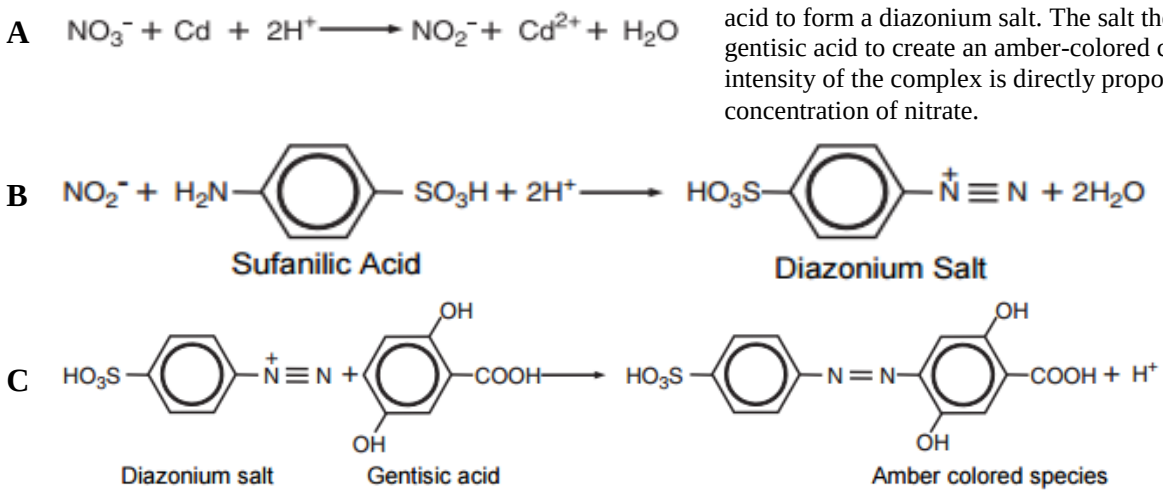


Figure 3: By means of the cadmium reduction method, nitrates are reduced to nitrites and react with sulfanilic acid to form a diazonium salt. The salt then reacts with gentisic acid to create an amber-colored complex. The intensity of the complex is directly proportional to the concentration of nitrate.

Nitrite Analysis

To determine the NO_2^- concentration of the sample, the USEPA Diazotization Method (Hach reference number 8507) was used in conjunction with a DR 900 Multiparameter Handheld Colorimeter and NitriVer 3 Reagent Powder Pillows. In this method, NO_2^- reacts with sulfanilic acid (*Figure 4A*) to form an intermediate diazonium salt (28). The salt then combines with chromotropic acid to create a pink-colored complex (*Figure 4B*). NO_3^- concentrations less than 100 mg/L do not interfere with the reaction as the NO_3^- ions cannot readily reduce.

A blank was prepared with water from the 500mL screw-top polypropylene container. 10mL of the sample were added to an empty cuvette. Program 371 N, Nitrite LR PP was initialized on the colorimeter. The outside of the blank was wiped to prevent smudging. The blank was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded and the colorimeter was zeroed (29). This measurement was used as the baseline absorbance from which to compare the reacted sample, in order to account for stain in the water sample. The blank was removed from the sample cell receptor and the water disposed of. The empty cuvette was rinsed with deionized water and dried.

Nitrile gloves were adorned prior to any contact with powder pillow reagents inside of the fume hood. 10mL of water from the 500mL screw-top polypropylene container was transferred to an empty cuvette. A NitriVer 3 Reagent Powder Pillow was opened and its reagent contents poured into the sample cuvette. The cuvette was secured with a screw-on lid and swirled for five seconds. The sample was then allowed to sit undisturbed for twenty minutes.

During this reaction time, a pink-colored complex had formed, the intensity of which is proportional to the concentration of NO_2^-. The outside of the cuvette was wiped to prevent smudging. The cuvette was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 520 nm was recorded. The colorimeter utilized this absorbance to provide a reading of the NO_2^- concentration in the sample. The cuvette was removed from the sample cell receptor and the reacted water sample was transferred to a permanent storage container. The remaining cuvette and screw-top were rinsed and dried. Upon the conclusion of testing, all reacted water samples were disposed of via a chemical disposal company.

Formulas courtesy of Hach Company

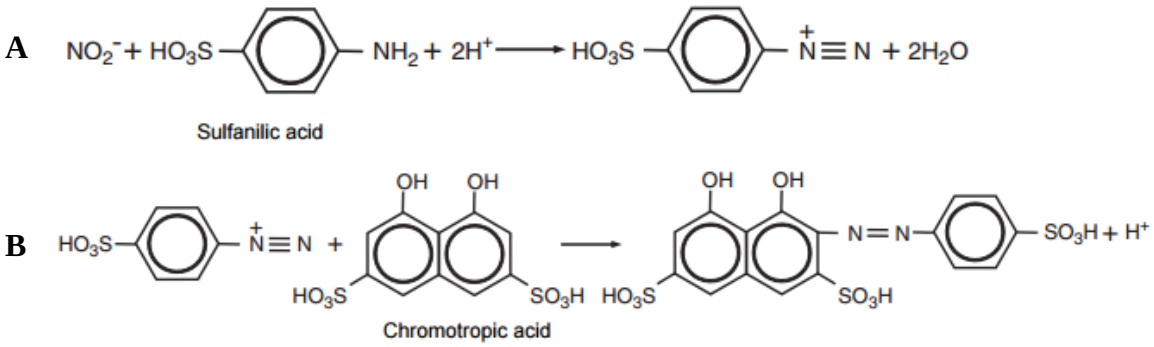


Figure 4: By means of the diazotization method, nitrites react with sulfanilic acid to form a diazonium salt. The salt then reacts with chromotropic acid to create a pink-colored complex. The intensity of the complex is directly proportional to the concentration of nitrite.

Total Reactive Phosphorus Analysis

To determine the total reactive phosphorous concentration of the sample, the USEPA PhosVer 3 (Ascorbic Acid) Method (Hach reference number 8048) was used in conjunction with a DR 900 Multiparameter Handheld Colorimeter and PhosVer 3 Phosphate Reagent Powder Pillows. In this method, orthophosphates react with molybdate to form a yellow-colored phosphomolybdate complex (30). The complex is then reduced by ascorbic acid to create a molybdenum blue species. The method provides a reading of total reactive phosphorous, which includes orthophosphates and small concentrations of condensed phosphate that may have been hydrolyzed during the test. Orthophosphates are formed by dehydrating the orthophosphate radical and include metaphosphate, pyrophosphate and polyphosphate (30).

A blank was prepared with water from the 500mL screw-top polypropylene container. 10mL of the sample were added to an empty cuvette. Program 490 P React. PP was initialized on the colorimeter. The outside of the blank was wiped to prevent smudging. The blank was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 610 nm was recorded and the colorimeter was zeroed (31). This measurement was used as the baseline absorbance from which to compare the reacted sample, in order to account for stain in the water sample. The blank was removed from the sample cell receptor and the water disposed of. The empty cuvette was rinsed with deionized water and dried.

Nitrile gloves were adorned prior to any contact with powder pillow reagents inside of the fume hood. 10mL of water from the 500mL screw-top polypropylene container were transferred to an empty cuvette. A PhosVer 3 Phosphate Reagent Powder Pillow was opened and its reagent contents poured into the sample cuvette. The cuvette was secured with a screw-on lid and agitated for thirty seconds. The sample was then allowed to sit undisturbed for two minutes.

During this reaction time, a blue-colored complex had formed, the intensity of which is proportional to the concentration of total reactive phosphorous. The outside of the cuvette was wiped to prevent smudging. The cuvette was inserted into the sample cell receptor and the instrument cap was secured overtop. The absorbance at 610 nm was recorded. The colorimeter utilized this absorbance to provide a reading of the total reactive phosphorous concentration in the sample. The cuvette was removed from the sample cell receptor and the reacted water sample was transferred to a permanent storage container. The remaining cuvette and screw-top were rinsed and dried. Upon the conclusion of testing, all reacted water samples were disposed of via a chemical disposal company.

Figure 5: Picture displaying water samples and nutrient analysis equipment within a fume hood in the laboratory.

Discussion

Rotational impoundment management (RIM) has emerged in the past 50 years as the staple of non-chemical mosquito control on Florida's East Coast (32). Prior to the onset of RIM, parallel ditches were utilized as the first form of impoundment mosquito control. Water loss through evaporation and seepage, however, reduced the viability of these ditches and they were subsequently eliminated from use.

By the late 1940s, large quantities of commercial adulticide and larvacide chemicals, predominantly DDT, were routinely accepted as the primary means of reducing mosquito populations to levels deemed tolerable by the local communities. However, this attempt to make the region habitable caused great environmental harm to the surrounding estuary and promoted genetic resistance in *A. taeniorhynchus* and *A. sollicitans*, as well as other mosquito and sandfly species (33).

In order to reduce chemical dependence and promote estuary health, new impoundment structures were created in the 1960s. These impoundments evolved into the RIM systems commonly used today.

The basis of RIM is to provide the pest-control capabilities required by local municipalities without detrimental impacts to the ecological functions of the impounded wetlands, as were caused by previous structures. Impoundments consist of an impounded wetland system, a perimeter ditch, and a perimeter dike (*Figure 6)*. In some cases the ditch and dike fully encircle the wetland, however in many shoreline structures, the upland watershed of the upland edge is utilized as a boundary instead (34).

Pump stations, culverts, and directional hoods are utilized to adjust water levels within the impoundment dike. During the summer breeding months, traditionally May through October, culverts are closed and water from the surrounding lagoon is pumped into the impoundment (35). Water levels are elevated above the tidal plane of the wetland, just submerging all available land. This reduction of exposed moist sediment severely reduces the rates of oviposition in *A. taeniorhynchus* and *A. sollicitans*.

Image courtesy of the Smithsonian Marine Station at Fort Pierce

Figure 6: Graphic representation of the key structures utilized in a wetland impoundment as a part of Rotational Impoundment Management

Conversely, between November and April the culverts are opened to allow water exchange between the impoundment and the lagoon. This flushing is imperative to the ecological health of the wetland as it prevents excessive accumulation of nutrients and salts which could lead to eutrophic and hypersaline concentrations within the impoundment.

This period of reconnection and tidal influence, absent from previous impoundment practices, also promotes the migration of non-resident fishes and crustaceans into the impoundments. Many commercially important and recreationally prized species, including tarpon, *Megalops atlanticus*, common snook, *Centropomus undecimalis*, sheepshead, *Archosargus probatocephalus*, and mangrove snapper, *Lutjanus griseus* utilize the wetlands, and the mangrove forests in particular, as nurseries and forage grounds (36).

In order to promote the ecological health and longevity of the impoundment structures, the St. Lucie County Mosquito Control and Coastal Management Services District has established guidelines and protocols outlining their acceptable maintenance, the highest of goals being a 90% level of water replication within the impoundment.

In order to attain this, optimal ratios for acres per culvert (10-16 acres/culvert), culvert per linear foot of perimeter ditch (1 culvert/500-900 linear feet), and acres per 7,000-gallon-per-minute pump (80-100 acres/pump) have been developed (37). Aerators have also been installed at pump stations and can be adjusted to supply an input of oxygen into the impoundments depending on the current conditions (38).

Monthly water quality assessments are conducted at Bear Point during the summer flooding season, however information is not gathered during the period of time in which culverts are open. The assessments, which gather information on few parameters, are conducted at the same predetermined locations along the impoundment dike each month. During the six months of open exchange, the time in which natural flushing is meant to restore any damage caused by artificial hydrological manipulation, no measures are in place to regulate the true effects of this flushing. Thus, a significant knowledge gap exists.

Bear Point is of special significance in that it is a publically-owned, credited mitigation bank holding the potential of 49.8 estuarine mangrove credits from the Florida Department of Environmental Protection and 43.3 credits from the U.S. Army Corps. of Engineers (21). Thus, additional incentives exist to promote the ecological health of the wetland. Among the criteria for credit allotment, water quality standards including temperature and salinity maximums of 35 °C and 40 ppt and pH and dissolved oxygen minimums of 6.0 and 2.0 ppm must be achieved (39).

In contrast, Harbor Branch is one of the newest impoundments managed by the District. A recent remediation project allowed for the installation of 21 culverts along the perimeter dike. Little to no water quality data has been collected at this location, spurring interest in a comprehensive analysis of the impoundment. In addition, several locations within the impoundment have been identified as suspected dead zones in which the installation of additional culverts may prove beneficial.

The flooding of this impoundment is also unique in that elevated saline water levels are beginning to show promise of exotic plant control with particular regard to Brazilian pepper trees, *Schinus terebinthifolius*. The impoundment, comprised primarily of black, *Avicennia germinans*, and red, *Rhizophora mangle*, mangrove forest along its estuary-facing edge transitions to a more elevated topography consisting primarily of white mangroves, *Laguncularia racemose*, and mixed halophyte saltwart, *Batis Maritima*, and glasswart, *Salicomia virginica*, marsh before reaching an upland boundary separating the impoundment from oak scrub (40).

S. terebinthifolius has been observed throughout each section of the impoundment, however large scale die-offs have been recorded in conjunction with annual flooding of the impoundment.

In addition to existing management protocols, a more frequent regiment of water quality analysis, both inside impoundment structures and outside in the conjoining estuary, in which a greater quantity of parameters are taken into account may provide beneficial baseline data from which impoundment management can be optimized. A direct comparison-based analysis utilizing matched pairs of impoundment and estuary sites at each of a number of locations along impoundment structures may allow for the most illustrative representation of water quality and replication in the impoundments.

A

B

Figure 7A: Photograph depicting one of two pumping stations, currently not in use at Bear Point, water collection site BPI1

Figure 7B: Photograph depicting a culvert with engaged top-flow gate at Bear Point, water collection site BPI4

Data and Data Analysis

Numerical figures were recorded for each of seven water quality parameters at all 16 water collection sites every two weeks for a duration of eight weeks. Salinity figures were calculated using specific gravity measurements attained by a hydrometer. Temperature readings given by a Lovibond SD 50 pH and temperature meter were also utilized in this calculation.

Due to chemical interference of magnesium present in the water, dissolved oxygen figures determined through a dissolved oxygen analysis were 25% less than the true concentration of the sample. Thus, all dissolved oxygen data was adjusted to account for this interference.

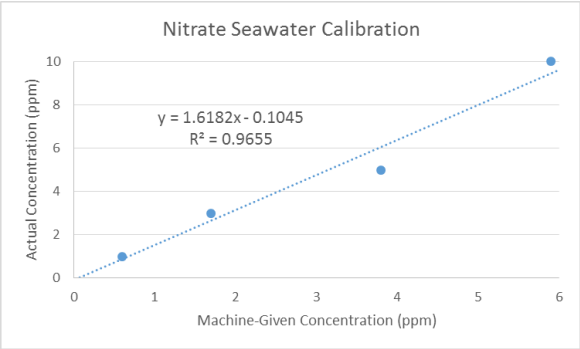
Due to chemical interference of chloride present in the water, nitrate figures determined through a nitrate analysis had been artificially reduced. To account for this discrepancy, a sodium chloride deionized water solution was mixed as to be representative of the chloride concentration of the lagoon. Barium nitrate was then added to the solution in order to create standards containing 1.0, 3.0, 5.0, and 10.0 mg/L nitrate with this elevated chloride concentrations.

Nitrate analyses were conducted on the standards and a curve was generated, from which the recorded figures from the experimental nitrate analyses were interpolated (*Figure 8*). In addition, nitrite interferes with the chemical reaction at all levels and causes elevated results, thus the figures from initial nitrate analyses were regarded as total nitrate and nitrite figures. The values of the corresponding nitrite analyses were then subtracted from these figures to attain truly representative nitrate concentrations.

On two water collection dates, total reactive phosphorus analyses yielded concentrations greater than could be accurately determined by the Hach DR900 handheld multiparameter colorimeter in conjunction with the USEPA PhosVer 3 (Ascorbic Acid) Method. The method is accurate to concentrations as high as 2.50 mg/L, which suggests the concentrations of these eleven samples, five from November 28th and six from January 9th, exceed this value. For statistical purposes, these eleven figures were assumed to be 2.50 mg/L and were treated as such in all further calculations.

T-tests were conducted to determine statistical significance for each of the seven parameters. Impoundment locations were compared against their estuary counterparts at each impoundment structure. Harbor Branch and Bear Point impoundment structures were considered independent of each other and treated as completely separate entities for all statistical purposes.

For salinity data, see Appendix A.
For pH data, see Appendix B.
For temperature data, see Appendix C.
For dissolved oxygen data, see Appendix D.
For nitrate data, see Appendix E.
For nitrite data, see Appendix F.
For total reactive phosphorus data, see Appendix G.



Machine-Given Concentration (mg/L)	0.6	1.7	3.8	5.9
Actual Concentration (mg/L)	1.0	3.0	5.0	10.0

Figure 8: Nitrate seawater calibration regression line used to interpolate nitrate figures

Results

Salinity Analysis

The salinity analyses indicated that there was no statistical significance (P = 0.9991) between salinities inside and adjacent to the Harbor Branch impoundment. Salinity averaged the same concentration within and outside of the impoundment. Salinities generally decreased in moving from south to north along the structure from HB1 to HB4. Greater average variations were recorded between HBI3 – HBR3 (-1.66 ppt) and HBI4 – HBR4 (2.00 ppt) than between HBI1 – HBRI (0.33 ppt) and HBI2 – HBR2 (-0.66 ppt).

In addition, the salinity analyses indicated that there was no statistical significance (P = 0.0755) between chloride concentrations inside and adjacent to the Bear Point impoundment. Salinity averaged 1.33 ppt lower within than outside of the impoundment. Average variations between BPI1 – BPR1 (-0.33 ppt), BPI2 – BPR2 (-1.00 ppt), and BPI3 – BPR3 (-0.67 ppt) were notably less than the average variation between BPI4 – BPR4 (-3.31 ppt).

pH Analysis

The pH analyses indicated that there was no statistical significance (P = 0.488) between pH concentrations inside and adjacent to the Harbor Branch impoundment. pH averaged 0.50 lower within than outside of the impoundment. No average variations greater than 0.13 were observed in any paired sites.

In addition, the pH analyses indicated that there was no statistical significance (P = 0.989) between pH concentrations inside and adjacent to the Bear Point impoundment. pH averaged the same concentration within and outside of the impoundment. No average variations greater than 0.12 were observed in any paired sites.

Temperature Analysis

The temperature analyses indicated that there was no statistical significance (P = 0.791) between temperature inside and adjacent to the Harbor Branch impoundment. Temperature averaged 0.2 °C higher within than outside of the impoundment. No average variations greater than 0.5 °C were observed in any paired sites.

In addition, the temperature analyses indicated that there was no statistical significance (P = 0.827) between temperature inside and adjacent to the Bear Point impoundment. Temperature averaged 0.1 °C higher within than outside of the impoundment. No average variations greater than 0.3 °C were observed in any paired sites.

Dissolved Oxygen Analysis

The dissolved oxygen analyses indicated that there was no statistical significance (P = 0.10) between dissolved oxygen concentrations inside and adjacent to the Harbor Branch impoundment. Dissolved oxygen averaged 1.5 mg/L lower within than outside of the impoundment. Greater average variations were recorded between HBI2 – HBR2 (-2.5 mg/L) and HBI3 – HBR3 (-3.6 mg/L) than between HBI1 – HBRI (0.1 mg/L) and HBI4 – HBR4 (0.3 mg/L). At both locations in which impoundment dissolved oxygen exceeded estuary dissolved oxygen, the variation was far less than the locations in which estuary dissolved oxygen exceeded impoundment dissolved oxygen.

In addition, the dissolved oxygen analyses indicated that there was statistical significance (P = 0.03)

between dissolved oxygen concentrations inside and adjacent to the Bear Point impoundment. Dissolved oxygen averaged 0.7 mg/L lower within than outside of the impoundment. Average variations between BPI1 – BPR1 (-0.8 mg/L), BPI3 – BPR3 (0.4 mg/L), and BPI4 – BPR4 (0.2 mg/L) were notably less than the average variation between BPI2 – BPR2 (-2.5 mg/L).

Nitrate Analysis

The nitrate analyses indicated that there was no statistical significance (P = 0.80) between nitrate concentrations inside and adjacent to the Harbor Branch impoundment. Nitrate averaged 0.1 mg/L higher within than outside of the impoundment. Average variations between HBI1 – HBR1 (0.4 mg/L), HBI2 – HBR2 (0.6 mg/L), and HBI3 – HBR3 (0.4 mg/L) were notably less than the average variation between HBI4 – HBR4 (-1.0 mg/L). HBR4 was the only estuary site to exceed its impoundment counterpart in average nitrate concentration at Harbor Branch.

In addition, the nitrate analyses indicated that there was no statistical significance (P = 0.68) between nitrate concentrations inside and adjacent to the Bear Point impoundment. Nitrate averaged 0.2 mg/L lower within than outside of the impoundment. Average variations between BPI1 – BPR1 (0.2 mg/L), BPI2 – BPR2 (0.0 mg/L), and BPI3 – BPR3 (-0.2 mg/L) were less than the average variation between BPI4 – BPR4 (-0.6 mg/L).

Nitrite Analysis

The nitrite analyses indicated that there was no statistical significance (P = 0.311) between nitrite concentrations inside and adjacent to the Harbor Branch impoundment. Nitrite averaged 0.001 mg/L lower within than outside of the impoundment. No average variations greater than 0.004 mg/L were observed in any paired sites.

In addition, the nitrite analyses indicated that there was no statistical significance (P = 0.458) between nitrite concentrations inside and adjacent to the Bear Point impoundment. Nitrite averaged 0.001 mg/L higher within than outside of the impoundment. An average variation of 0.003 mg/L was observed in all paired sites with the impoundment site having the higher concentration in all but BPI3 – BPR3.

Total Reactive Phosphorous Analysis

The total reactive phosphorous analyses indicated that there was no statistical significance (P = 0.61) between total reactive phosphorous concentrations inside and adjacent to the Harbor Branch impoundment. Total reactive phosphorous averaged 0.19 mg/L lower within than outside of the impoundment. Average variations between HBI1 – HBR1 (0.04 mg/L), HBI3 – HBR3 (0.19 mg/L), and HBI4 – HBR4 (-0.12 mg/L) were notably less than the average variation between HBI2 – HBR2 (-0.84 mg/L).

In addition, the total reactive phosphorous analyses indicated that there was no statistical significance (P = 0.96) between total reactive phosphorous concentrations inside and adjacent to the Bear Point impoundment. Total reactive phosphorous averaged the same concentration within and outside of the impoundment. No average variations greater than 0.10 mg/L were observed in any paired sites.

Conclusion

In order to maintain sufficient mosquito control efforts while minimizing environmental detriments, the St. Lucie County Mosquito Control and Coastal Management Services District employs modified rotational impoundment strategies to manage impounded wetland structures. In doing so, the deleterious effects of alternate management practices are greatly reduced or eliminated.

Individual analyses of each of the seven water quality parameters from Harbor Branch displayed no statistical significance between water within and along the outside of the impounded wetland structure.

However, it was found that the impounded water was not homogenous in that nutrient and dissolved oxygen concentrations were capable of varying between impoundment collection sites. Dissolved oxygen concentrations in particular were observed to be consistently lower in the impoundment sites located behind two cove structures, HBI2 and HBI3, as compared to their estuary counterparts. This gives reason to believe the installation of additional culverts at such locations may prove beneficial.

These locations also were observed to be stagnant when others demonstrated water flow and when water levels had declined sharply on December 28th, HBI2 had been reduced to little more than a stagnant puddle less than 20 cm deep.

Despite these concerns, the results suggest a predominantly unaffected state of water replication within the impoundment, with water quality deviations not uncharacteristic of natural structures. The impoundment hydrology of the structure appears to have little effect on the wetland system, with regard to water quality.

In addition, individual analyses of six of the seven water quality parameters from Bear Point displayed no statistical significance between water within and along the outside of the impounded wetland structure. Statistical significance was displayed in the dissolved oxygen analysis.

As mentioned prior, the Bear Point impoundment is also a permitted mitigation bank, upon which water quality regulations have been imposed to ensure adequate mitigation efforts. Figures were never observed outside of these bounds. However, dissolved oxygen levels were consistently lower at BPI1 and BPI2 than BPR1 and BPR2, both with and without aerator function near the pump station located at BPI1. BPI3 and BPI4 displayed a different trend, typically containing a greater concentration of dissolved oxygen than BPR3 and BPR4, though by a smaller margin.

These results indicate a predominantly unaffected state of water quality replication within the impoundment, with the exception of dissolved oxygen. Additional hydrological engineering endeavors may help abate this oxygenation issue. Supplementary perimeter culverts may allow for greater volumetric exchange while the installation of internal exchange culverts may facilitate a more fully encompassing turnover of impounded water, connecting internally isolated pockets to the perimeter ditch by mimicking the natural tidal creeks filled by detritus sedimentation.

Ultimately, the modified rotational impoundment management strategies utilized at both Harbor Branch and Bear Point provided the desired level of mosquito control though means of source reduction while limiting adverse environmental impacts. These methods show promise as a viable integrated pest control measure and pesticide alternative in Florida's microtidal Indian River Lagoon.

Both impoundments represent significant environmental and monetary importance, the value of which can be drastically altered by the determined water quality. Further research should be conducted regarding water quality assessment at both Harbor Branch and Bear Point. Due to the limited quantity of collection periods and analysis materials allocated to this study, continued assessment should be undertaken to further support these findings.

Acknowledgements

I would like to thank Joe and Lisa Scott for their endless time and support throughout the duration of this study. I would also like to thank Richard Knott, Glenn Henderson, and Sherry Burroughs from the St. Lucie County Mosquito Control and Coastal Management Services District for their cooperation.

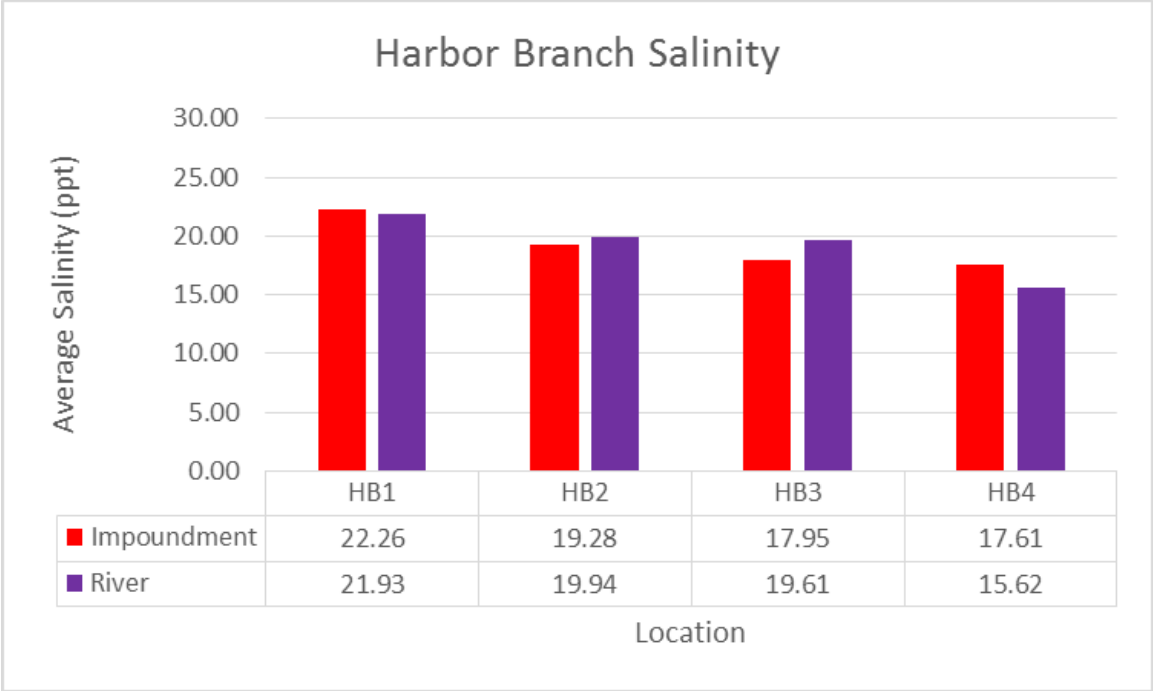
Appendix A (Salinity Data)

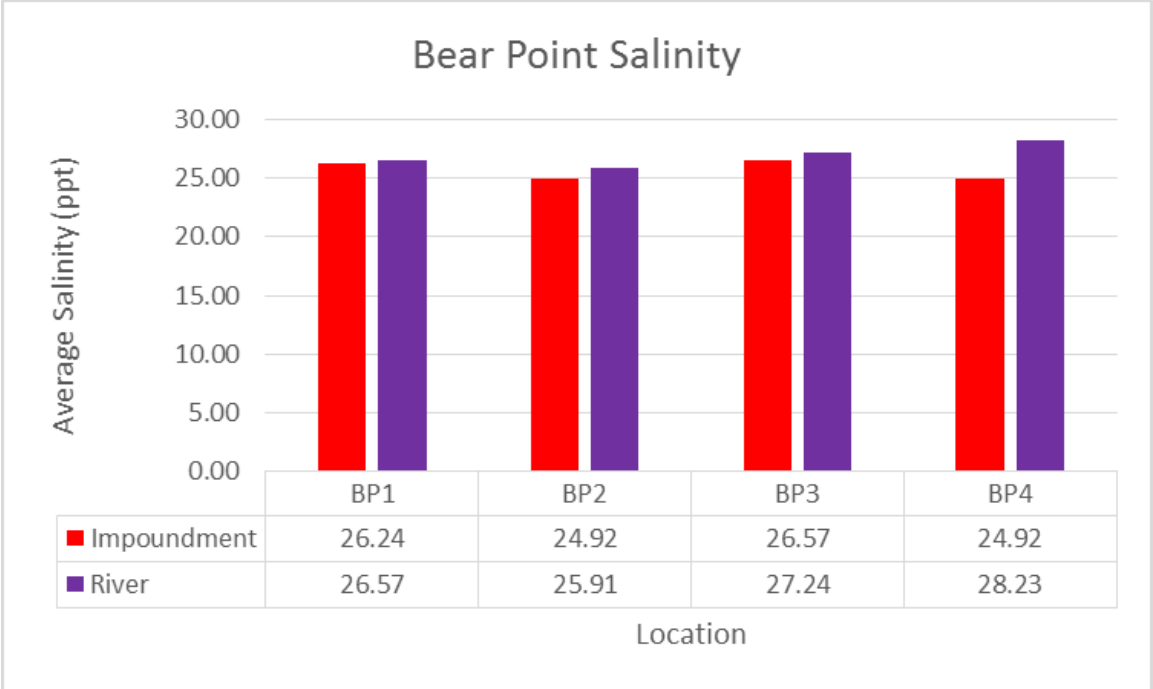
All figures in ppt

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	21.27	19.94	26.57	21.27	22.26
HBR1	21.27	18.61	25.25	22.59	21.93
HBI2	18.61	15.95	21.27	21.27	19.28
HBR2	17.28	17.28	25.25	19.94	19.94
HBI3	19.94	17.28	15.95	18.61	17.95
HBR3	19.94	15.95	23.92	18.61	19.61
HBI4	15.95	15.95	19.94	18.61	17.61
HBR4	13.29	14.62	17.28	17.28	15.62
Average	18.44	16.95	21.93	19.77	

BPI1	23.92	29.22	25.25	26.57	26.24
BPR1	25.25	26.57	26.57	27.90	26.57
BPI2	25.25	25.25	22.59	26.57	24.92
BPR2	26.57	23.92	25.25	27.90	25.91
BPI3	29.22	26.57	23.92	26.57	26.57
BPR3	26.57	25.25	27.90	29.22	27.24
BPI4	27.90	23.92	23.92	23.92	24.92
BPR4	33.19	26.57	26.57	26.57	28.23
Average	27.23	25.91	25.25	26.90	

HBI	HBR		BPI	BPR
21.27	21.27		23.92	25.25
19.94	18.61		29.22	26.57
26.57	25.25		25.25	26.57
21.27	22.59		26.57	27.90
18.61	17.28		25.25	26.57
15.95	17.28		25.25	23.92
21.27	25.25		22.59	25.25
21.27	19.94		26.57	27.90
19.94	19.94		29.22	26.57
17.28	15.95		26.57	25.25
15.95	23.92		23.92	27.90
18.61	18.61		26.57	29.22
15.95	13.29		27.90	33.19
15.95	14.62		23.92	26.57
19.94	17.28		23.92	26.57
18.61	17.28		23.92	26.57
19.27	19.27	Average	25.66	26.99


Harbor Branch Salinity
Average Salinity (ppt)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
HB1
HB2
HB3
HB4
Impoundment
22.26
19.28
17.95
17.61
River
21.93
19.94
19.61
15.62
Location

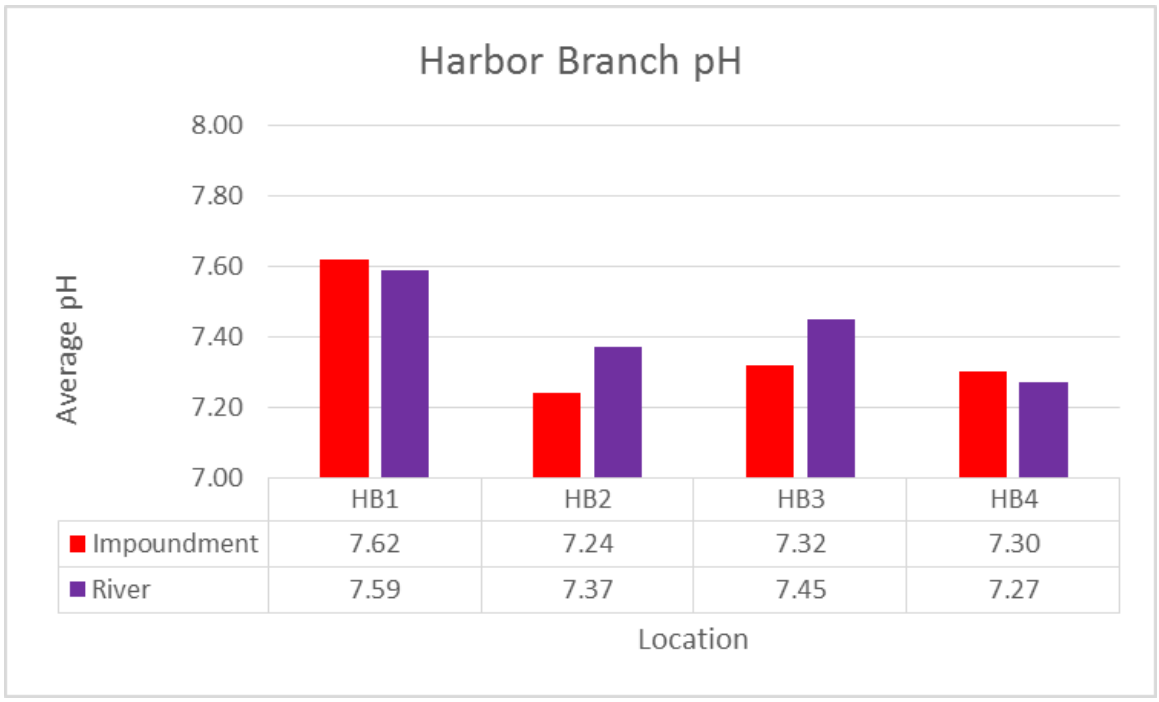

Bear Point Salinity
Average Salinity (ppt)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
BP1
BP2
BP3
BP4
Impoundment
26.24
24.92
26.57
24.92
River
26.57
25.91
27.24
28.23
Location

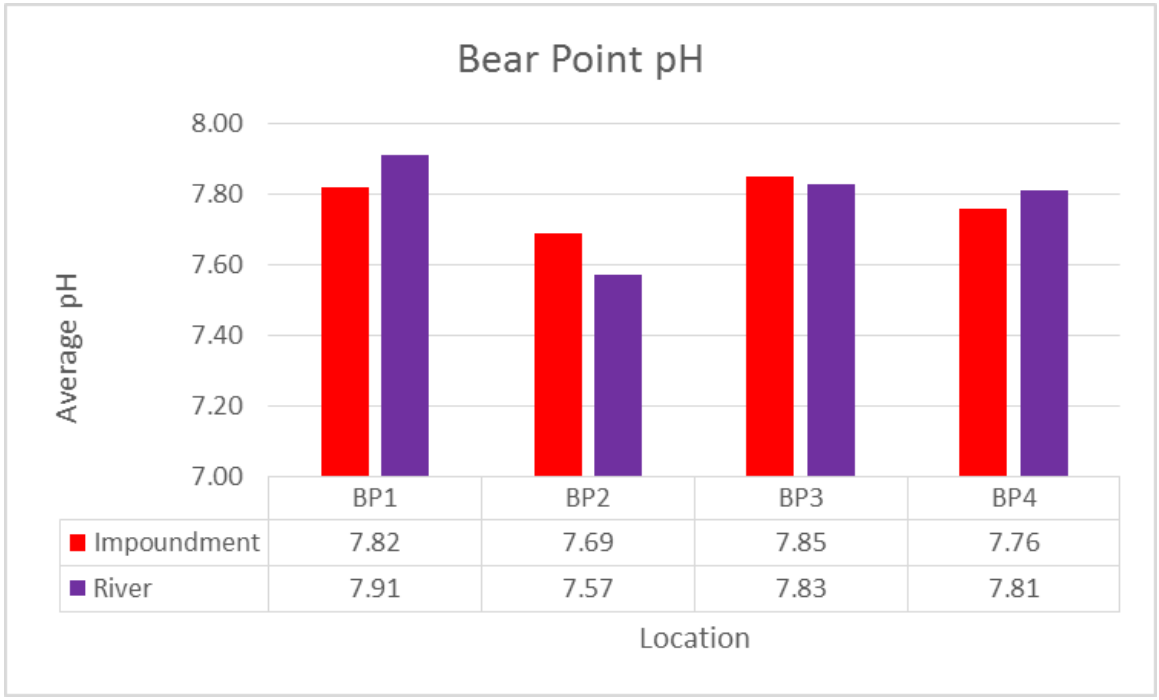
Appendix B (pH Data)

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	7.59	7.69	7.55	7.63	7.62
HBR1	7.56	7.80	7.57	7.42	7.59
HBI2	7.06	7.28	7.05	7.57	7.24
HBR2	7.29	7.49	7.29	7.41	7.37
HBI3	7.22	7.52	6.96	7.57	7.32
HBR3	7.28	7.53	7.44	7.55	7.45
HBI4	7.28	7.38	7.02	7.50	7.30
HBR4	7.24	7.33	7.24	7.25	7.27
Average	7.32	7.50	7.27	7.49	

BPI1	7.91	7.74	7.85	7.79	7.82
BPR1	7.96	7.78	8.08	7.81	7.91
BPI2	7.94	7.74	7.69	7.38	7.69
BPR2	7.59	7.45	8.03	7.20	7.57
BPI3	8.00	7.91	7.94	7.55	7.85
BPR3	8.09	7.93	8.01	7.29	7.83
BPI4	8.05	7.88	7.82	7.28	7.76
BPR4	8.04	7.79	7.92	7.48	7.81
Average	7.95	7.78	7.92	7.47	

HBI	HBR		BPI	BPR
7.59	7.56		7.91	7.96
7.69	7.80		7.74	7.78
7.55	7.57		7.85	8.08
7.63	7.42		7.79	7.81
7.06	7.29		7.94	7.59
7.28	7.49		7.74	7.45
7.05	7.29		7.69	8.03
7.57	7.41		7.38	7.20
7.22	7.28		8.00	8.09
7.52	7.53		7.91	7.93
6.96	7.44		7.94	8.01
7.57	7.55		7.55	7.29
7.28	7.24		8.05	8.04
7.38	7.33		7.88	7.79
7.02	7.24		7.82	7.92
7.50	7.25		7.28	7.48
7.37	7.42	Average	7.78	7.78


Harbor Branch pH
8.00
7.80
7.60
7.40
7.20
7.00
Average pH
HB1
HB2
HB3
HB4
Impoundment
7.62
7.24
7.32
7.30
River
7.59
7.37
7.45
7.27
Location


Bear Point pH
8.00
7.80
7.60
7.40
7.20
7.00
Average pH
BP1
BP2
BP3
BP4
Impoundment
7.82
7.69
7.85
7.76
River
7.91
7.57
7.83
7.81
Location

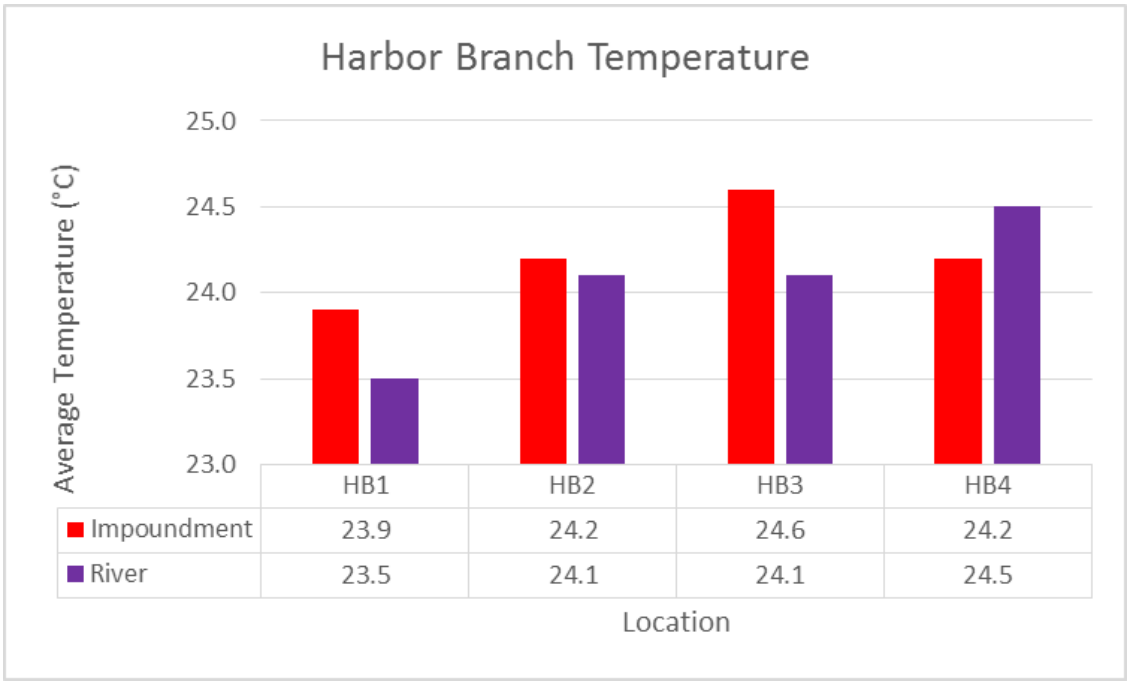
Appendix C (Temperature Data)

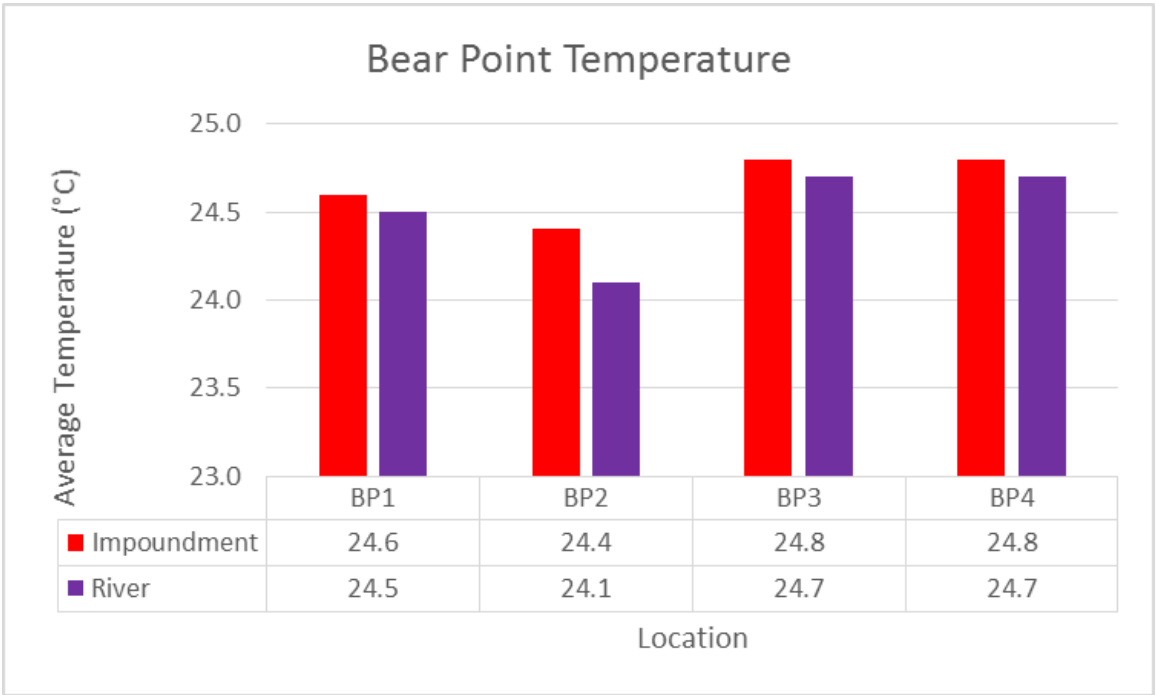
All figures in °C

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	22.8	25.0	25.7	22.0	23.9
HBR1	22.5	24.3	25.4	21.8	23.5
HBI2	24.1	24.5	26.3	21.8	24.2
HBR2	23.5	24.8	25.9	22.0	24.1
HBI3	24.7	25.0	26.5	22.0	24.6
HBR3	23.4	24.5	26.7	21.8	24.1
HBI4	22.9	25.5	26.4	22.0	24.2
HBR4	24.4	24.9	26.2	22.6	24.5
Average	23.5	24.8	26.1	22.0	

BPI1	24.0	25.0	27.2	22.2	24.6
BPR1	23.7	24.9	26.9	22.5	24.5
BPI2	24.1	24.9	26.6	21.9	24.4
BPR2	23.1	24.1	27.0	22.3	24.1
BPI3	24.7	25.0	26.9	22.6	24.8
BPR3	23.8	24.9	27.0	23.1	24.7
BPI4	24.1	24.8	27.0	23.3	24.8
BPR4	23.8	25.0	27.2	22.9	24.7
Average	23.9	24.8	27.0	22.6	

HBI	HBR		BPI	BPR
22.8	22.5		24.0	23.7
25.0	24.3		25.0	24.9
25.7	25.4		27.2	26.9
22.0	21.8		22.2	22.5
24.1	23.5		24.1	23.1
24.5	24.8		24.9	24.1
26.3	25.9		26.6	27.0
21.8	22.0		21.9	22.3
24.7	23.4		24.7	23.8
25.0	24.5		25.0	24.9
26.5	26.7		26.9	27.0
22.0	21.8		22.6	23.1
22.9	24.4		24.1	23.8
25.5	24.9		24.8	25.0
26.4	26.2		27.0	27.2
22.0	22.6		23.3	22.9
24.2	24.0	Average	24.6	24.5


Harbor Branch Temperature
Average Temperature (°C)
25.0
24.5
24.0
23.5
23.0
HB1 HB2 HB3 HB4
Impoundment 23.9 24.2 24.6 24.2
River 23.5 24.1 24.1 24.5
Location


Bear Point Temperature
Average Temperature (°C)
25.0
24.5
24.0
23.5
23.0
BP1 BP2 BP3 BP4
Impoundment 24.6 24.4 24.8 24.8
River 24.5 24.1 24.7 24.7
Location

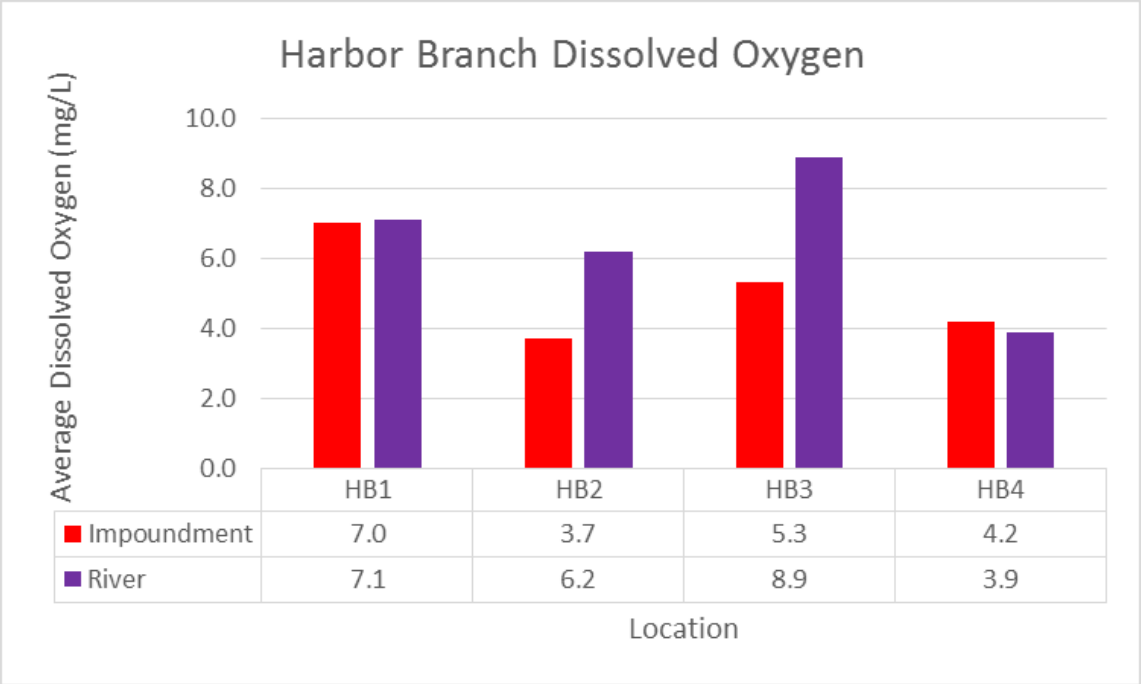
Appendix D (Dissolved Oxygen Data)

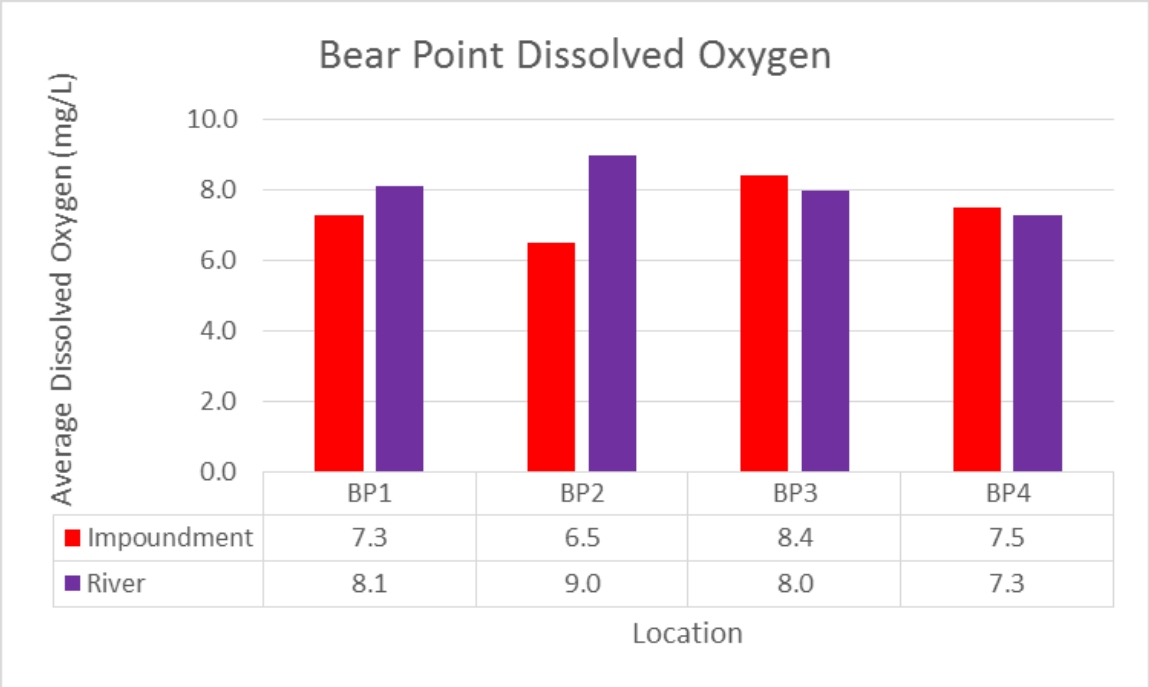
All figures in mg/L

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	6.9	8.0	5.6	7.3	7.0
HBR1	6.0	8.1	6.1	8.3	7.1
HBI2	3.3	1.7	1.6	8.1	3.7
HBR2	5.2	5.5	5.6	8.3	6.2
HBI3	3.5	6.3	1.2	10.0	5.3
HBR3	7.7	9.2	10.1	8.4	8.9
HBI4	3.9	3.7	1.6	7.5	4.2
HBR4	2.7	3.3	3.7	5.9	3.9
Average	4.9	5.7	4.4	8.0	

BPI1	7.3	6.7	7.7	7.5	7.3
BPR1	8.5	7.3	8.4	8.1	8.1
BPI2	8.0	6.4	6.0	5.6	6.5
BPR2	9.7	8.4	9.6	8.4	9.0
BPI3	8.1	7.9	8.4	9.2	8.4
BPR3	8.1	7.6	8.4	8.0	8.0
BPI4	8.0	7.6	7.1	7.2	7.5
BPR4	7.7	7.2	7.7	6.7	7.3
Average	8.2	7.4	7.9	7.6	

HBI	HBR		BPI	BPR
6.9	6.0		7.3	8.5
8.0	8.1		6.7	7.3
5.6	6.1		7.7	8.4
7.3	8.3		7.5	8.1
3.3	5.2		8.0	9.7
1.7	5.5		6.4	8.4
1.6	5.6		6.0	9.6
8.1	8.3		5.6	8.4
3.5	7.7		8.1	8.1
6.3	9.2		7.9	7.6
1.2	10.1		8.4	8.4
10.0	8.4		9.2	8.0
3.9	2.7		8.0	7.7
3.7	3.3		7.6	7.2
1.6	3.7		7.1	7.7
7.5	5.9		7.2	6.7
5.0	6.5	Average	7.4	8.1


Harbor Branch Dissolved Oxygen
Average Dissolved Oxygen (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
HB1
HB2
HB3
HB4
Impoundment
7.0
3.7
5.3
4.2
River
7.1
6.2
8.9
3.9
Location


Bear Point Dissolved Oxygen
Average Dissolved Oxygen (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
BP1
BP2
BP3
BP4
Impoundment
7.3
6.5
8.4
7.5
River
8.1
9.0
8.0
7.3
Location

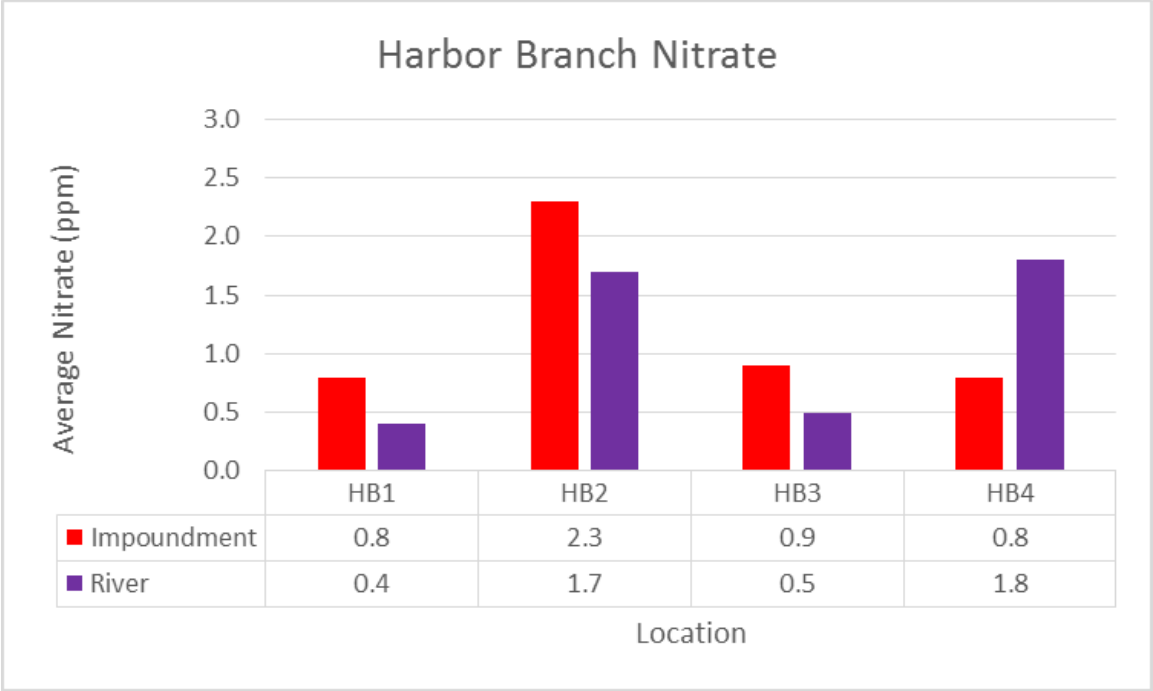
Appendix E (Nitrate Data)

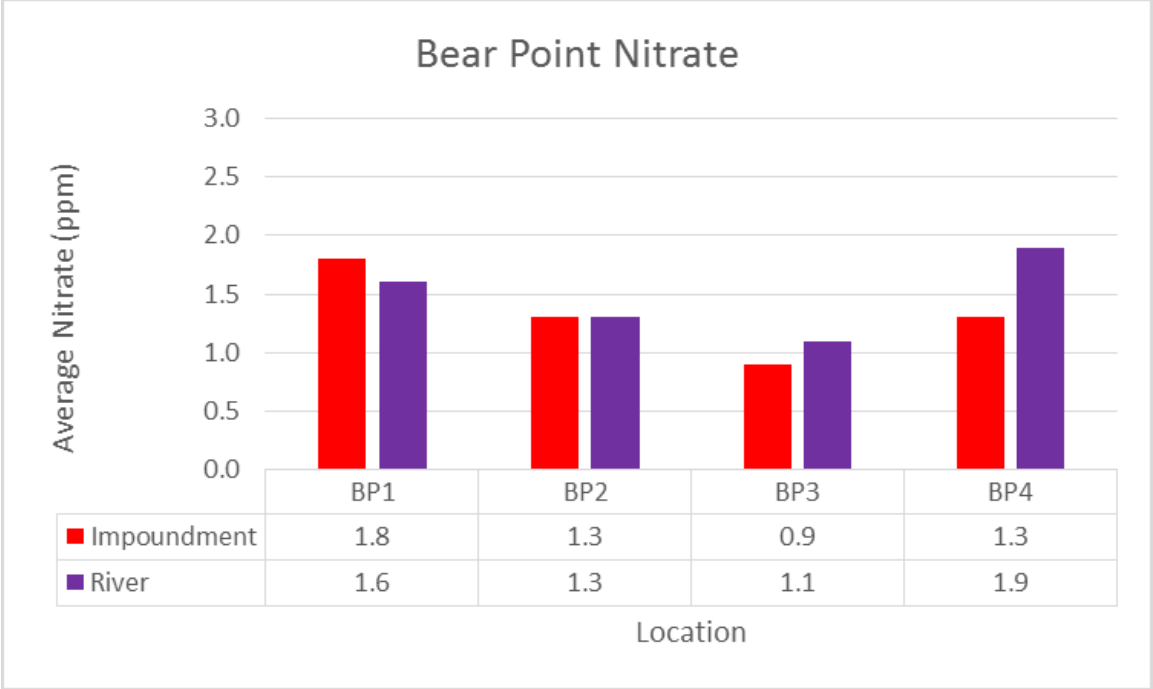
All figures in mg/L

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	0.5	1.5	0.0	1.0	0.8
HBR1	0.5	0.0	0.9	0.2	0.4
HBI2	7.0	0.0	1.2	1.0	2.3
HBR2	3.9	1.2	0.5	1.0	1.7
HBI3	0.0	1.0	0.9	1.8	0.9
HBR3	0.0	0.0	1.4	0.4	0.5
HBI4	1.5	0.0	0.7	0.9	0.8
HBR4	1.0	2.2	2.0	1.8	1.8
Average	1.8	0.7	1.0	1.0	

BPI1	2.0	0.2	4.4	0.5	1.8
BPR1	2.8	0.0	0.7	3.0	1.6
BPI2	2.0	0.1	1.5	1.5	1.3
BPR2	2.6	0.0	1.0	1.5	1.3
BPI3	1.4	0.0	2.0	0.0	0.9
BPR3	2.0	0.0	0.0	2.3	1.1
BPI4	1.4	0.0	2.5	1.2	1.3
BPR4	1.8	0.0	3.0	2.8	1.9
Average	2.0	0.0	1.9	1.6	

HBI	HBR		BPI	BPR
0.5	0.5		2.0	2.8
1.5	0.0		0.2	0.0
0.0	0.9		4.4	0.7
1.0	0.2		0.5	3.0
7.0	3.9		2.0	2.6
0.0	1.2		0.1	0.0
1.2	0.5		1.5	1.0
1.0	1.0		1.5	1.5
0.0	0.0		1.4	2.0
1.0	0.0		0.0	0.0
0.9	1.4		2.0	0.0
1.8	0.4		0.0	2.3
1.5	1.0		1.4	1.8
0.0	2.2		0.0	0.0
0.7	2.0		2.5	3.0
0.9	1.8		1.2	2.8
1.2	1.1	Average	1.3	1.5


Harbor Branch Nitrate
Average Nitrate (ppm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
HB1
HB2
HB3
HB4
Impoundment
0.8
2.3
0.9
0.8
River
0.4
1.7
0.5
1.8
Location


Bear Point Nitrate
Average Nitrate (ppm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
BP1
BP2
BP3
BP4
Impoundment
1.8
1.3
0.9
1.3
River
1.6
1.3
1.1
1.9
Location

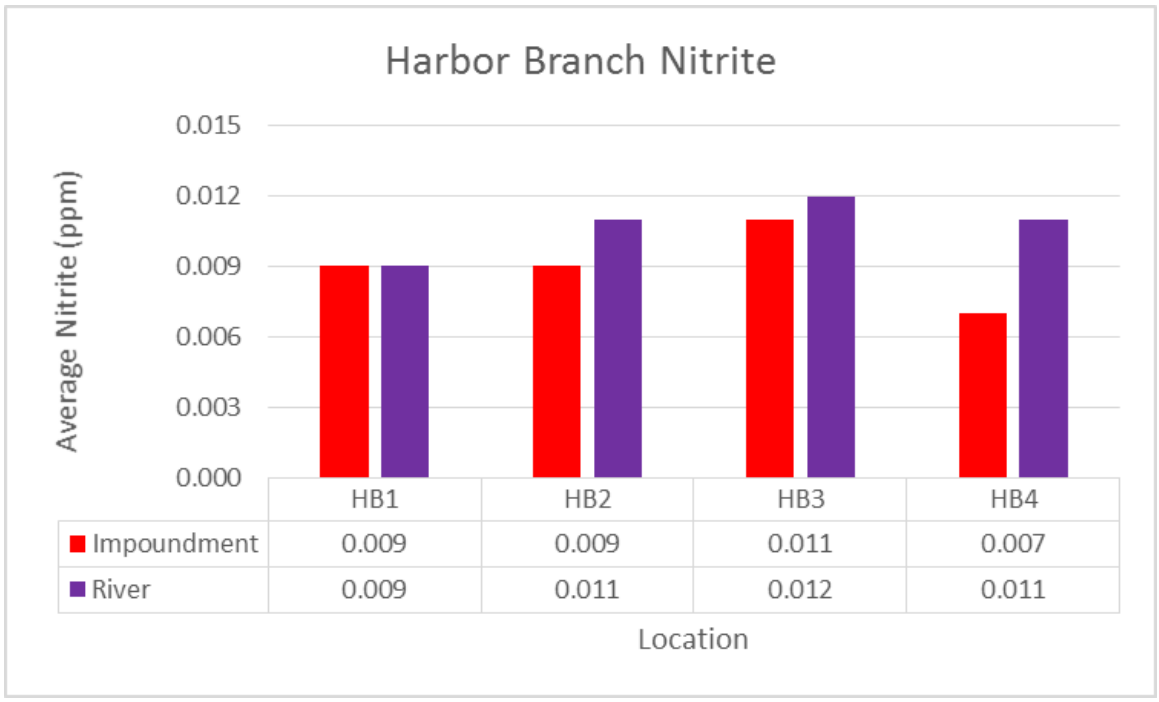
Appendix F (Nitrite Data)

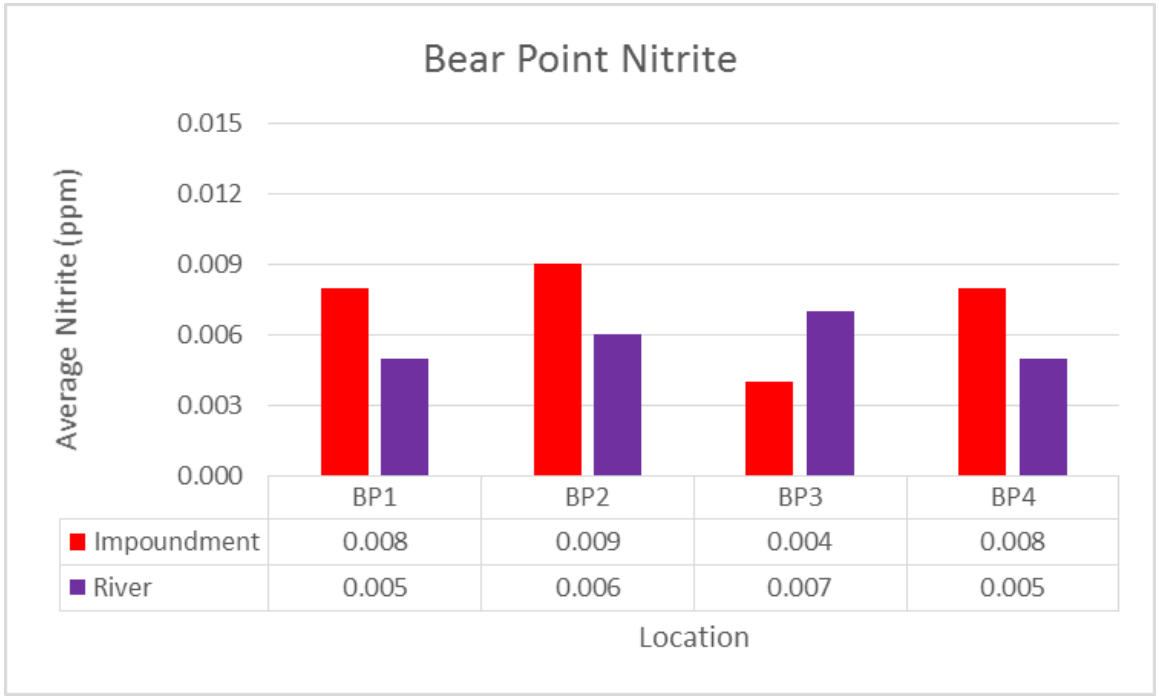
All figures in mg/L

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	0.015	0.014	0.000	0.007	0.009
HBR1	0.016	0.009	0.001	0.008	0.009
HBI2	0.011	0.013	0.010	0.002	0.009
HBR2	0.017	0.008	0.010	0.008	0.011
HBI3	0.011	0.017	0.003	0.011	0.011
HBR3	0.015	0.014	0.009	0.008	0.012
HBI4	0.006	0.006	0.006	0.008	0.007
HBR4	0.012	0.009	0.006	0.017	0.011
Average	0.013	0.011	0.006	0.009	

BPI1	0.017	0.006	0.009	0.000	0.008
BPR1	0.006	0.008	0.000	0.005	0.005
BPI2	0.011	0.011	0.008	0.005	0.009
BPR2	0.008	0.000	0.000	0.016	0.006
BPI3	0.007	0.007	0.000	0.003	0.004
BPR3	0.021	0.000	0.000	0.008	0.007
BPI4	0.020	0.006	0.007	0.000	0.008
BPR4	0.010	0.005	0.001	0.004	0.005
Average	0.013	0.005	0.003	0.005	

HBI	HBR		BPI	BPR
0.015	0.016		0.017	0.006
0.014	0.009		0.006	0.008
0.000	0.001		0.009	0.000
0.007	0.008		0.000	0.005
0.011	0.017		0.011	0.008
0.013	0.008		0.011	0.000
0.010	0.010		0.008	0.000
0.002	0.008		0.005	0.016
0.011	0.015		0.007	0.021
0.017	0.014		0.007	0.000
0.003	0.009		0.000	0.000
0.011	0.008		0.003	0.008
0.006	0.012		0.020	0.010
0.006	0.009		0.006	0.005
0.006	0.006		0.007	0.001
0.008	0.017		0.000	0.004
0.009	0.010	Average	0.007	0.006


Harbor Branch Nitrite
Average Nitrite (ppm)
0.015
0.012
0.009
0.006
0.003
0.000
HB1 HB2 HB3 HB4
Impoundment 0.009 0.009 0.011 0.007
River 0.009 0.011 0.012 0.011
Location


Bear Point Nitrite
Average Nitrite (ppm)
0.015
0.012
0.009
0.006
0.003
0.000
BP1 BP2 BP3 BP4
Impoundment 0.008 0.009 0.004 0.008
River 0.005 0.006 0.007 0.005
Location

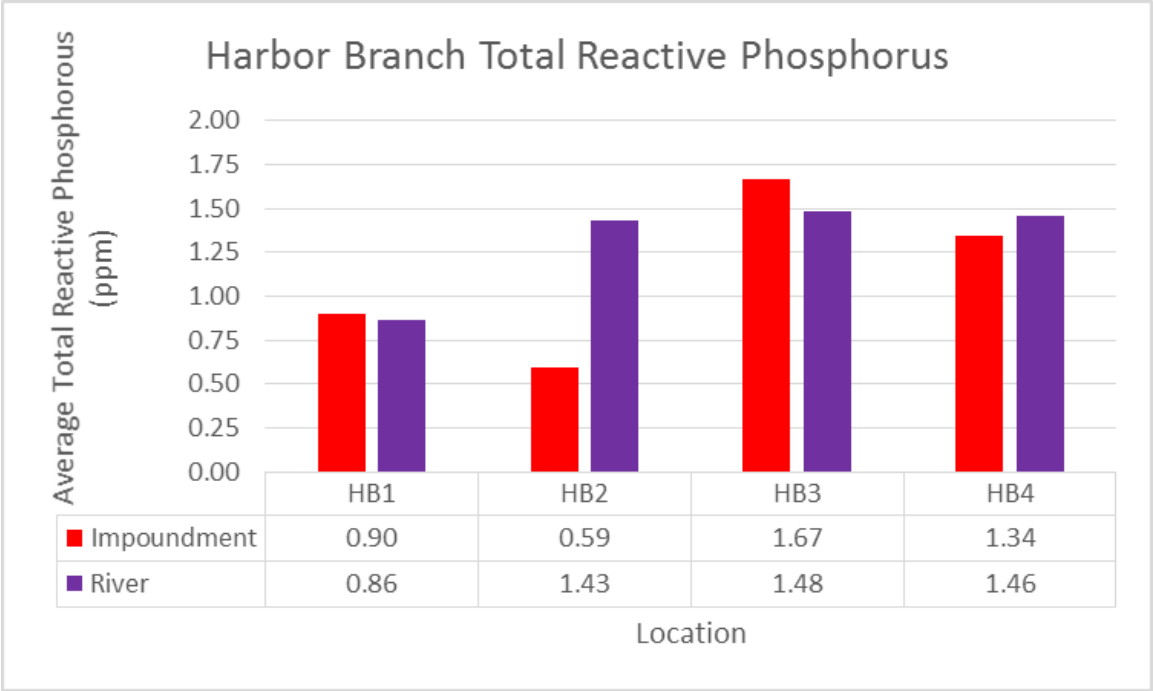
Appendix G (Total Reactive Phosphorus Data)

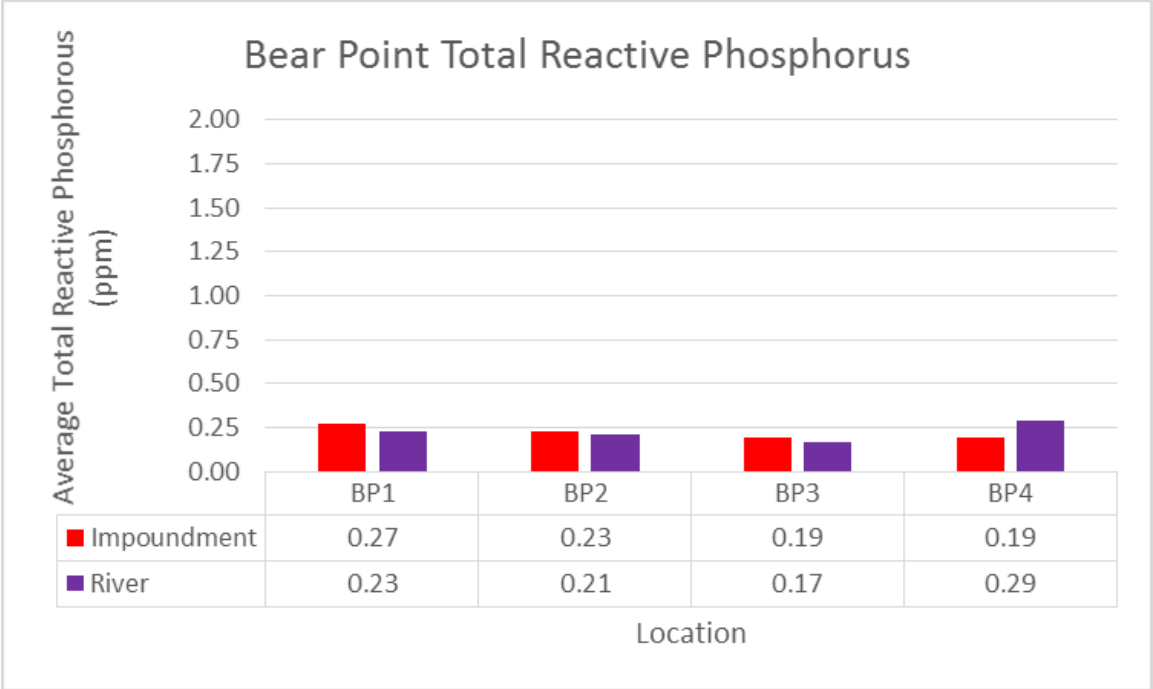
All figures in mg/L

	11/28/2015	12/13/2015	12/28/2015	1/9/2016	Average
HBI1	0.37	0.32	0.39	2.50	0.90
HBR1	0.38	0.31	0.25	2.50	0.86
HBI2	0.72	0.65	0.70	0.28	0.59
HBR2	2.50	0.40	0.32	2.50	1.43
HBI3	2.50	0.88	0.80	2.50	1.67
HBR3	2.50	0.47	0.46	2.50	1.48
HBI4	2.50	0.47	0.29	2.08	1.34
HBR4	2.50	0.42	0.41	2.50	1.46
Average	1.75	0.49	0.45	2.17	

BPI1	0.34	0.52	0.11	0.10	0.27
BPR1	0.67	0.21	0.04	0.00	0.23
BPI2	0.44	0.13	0.04	0.32	0.23
BPR2	0.40	0.27	0.02	0.13	0.21
BPI3	0.46	0.17	0.04	0.08	0.19
BPR3	0.36	0.12	0.07	0.12	0.17
BPI4	0.23	0.15	0.13	0.25	0.19
BPR4	0.57	0.38	0.06	0.14	0.29
Average	0.43	0.24	0.06	0.14	

HBI	HBR		BPI	BPR
0.37	0.38		0.34	0.67
0.32	0.31		0.52	0.21
0.39	0.25		0.11	0.04
2.50	2.50		0.10	0.00
0.72	2.50		0.44	0.40
0.65	0.40		0.13	0.27
0.70	0.32		0.04	0.02
0.28	2.50		0.32	0.13
2.50	2.50		0.46	0.36
0.88	0.47		0.17	0.12
0.80	0.46		0.04	0.07
2.50	2.50		0.08	0.12
2.50	2.50		0.23	0.57
0.47	0.42		0.15	0.38
0.29	0.41		0.13	0.06
2.08	2.50		0.25	0.14
1.12	1.31	Average	0.22	0.22


Harbor Branch Total Reactive Phosphorus
Average Total Reactive Phosphorous (ppm)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HB1 HB2 HB3 HB4
Impoundment 0.90 0.59 1.67 1.34
River 0.86 1.43 1.48 1.46
Location


Bear Point Total Reactive Phosphorus
Average Total Reactive Phosphorous (ppm)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
BP1 BP2 BP3 BP4
Impoundment 0.27 0.23 0.19 0.19
River 0.23 0.21 0.17 0.29
Location

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