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Characterizing a Small-scale, Constructed Wetland for Stormwater Treatment

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Abstract:

Because of the efficient treatment processes of wetlands, engineered treatment wetlands are increasingly being used to treat stormwater and wastewater, and especially combined sewer overflows (CSO). Constructed treatment wetlands are low-cost, require minimal maintenance, can be implemented in a decentralized fashion, and contribute to ecosystem preservation. All of these reasons have brought treatment wetlands to the forefront for consideration by communities working to reduce CSOs and improve water quality, especially in small cities with limited resources.

Goals of this study were to compare the removal of stormwater pollutants including total suspended solids (TSS), biochemical oxygen demand (BOD), and nutrients (nitrogen and phosphorus) through subsurface flow (SSF) and free-water surface (FWS) wetland configurations. Additionally, each wetland system was composed of multiple basins optimized to remove certain stormwater contaminants. Stormwater, pond and synthetic waters were used to test the efficiency of contaminant removal. Over the course of two years, undergraduate students built wetlands and performed experiments to investigate contaminate removal efficiency. Overall, we found that both wetlands were effective in removing TSS, BOD and nitrate. BOD removal (up to 47%) occurred in the basins with highest organic content, and TSS (up to 82%), nitrate (58-88%) and nitrite (up to 50%) removal occurred in the basins with the highest sand content. The FWS configuration was advantageous for nitrate and nitrite removal, but was not significantly more effective than the SSF. We did not observe significant phosphate removal. Follow up studies will consider additional wetland configurations and operational methods.

Introduction:

Natural wetlands are composed of diverse ecosystems that perform important functions such as improving water quality, allowing for absorption of rainwater for flood storage, cycling of nutrients, and providing wildlife habitat (1,2). A wetland is a transitional area located between a waterbody and land, and is powered by the energy stored in organic content found in wastewater (2). In a wetland system, the soils and plants work as filters. Sedimentation along with plant interception reduces the amount of total suspended solids (TSS). Plant and microbial life can utilize organic materials and nutrients as well as absorb, transform, or break down harmful pathogens and chemicals (3).

"Using a technique of biomimicry these beneficial functions can be replicated by constructed wetlands. Many institutions, businesses, and communities have utilized constructed wetlands for the purpose of treating and purifying stormwater and/or wastewater because of wetlands' effective, low-cost, natural method of removing pollutants. Summer of 2014, a small-scale engineered treatment wetland was designed and constructed in RHIT's Cook Laboratory (Figures 1 and 2)" (7).

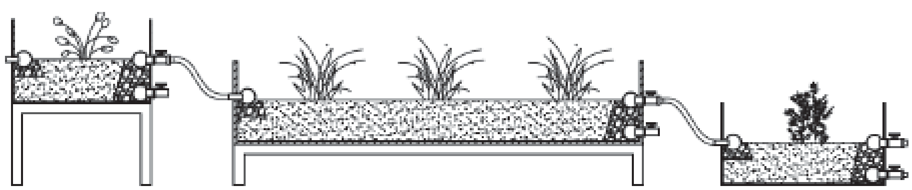

Figure 1: Subsurface System with filter media and plants

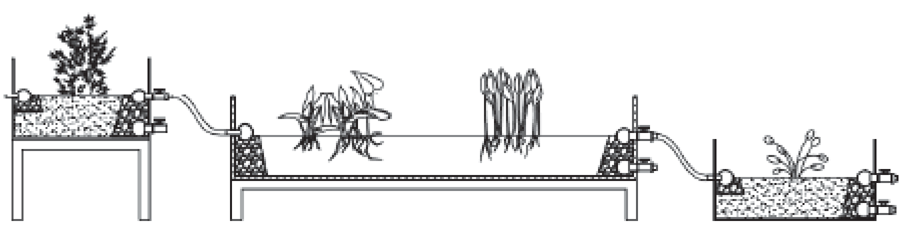

Figure 2: Free Water System with filter media and plants

There are over 100 communities in Indiana that use an outdated combined sewer system (stormwater and wastewater conveyed in a combined pipe network), according to the U.S. Environmental Protection Agency (4); Terre Haute is one of these communities. Whenever Terre Haute receives a quarter inch or more of rain, they dump runoff directly into the Wabash River. This contaminates the ecosystem with harmful Combined Sewer Overflow (CSO) (5). In many European countries, vertical flow treatment wetlands have been developed as very useful tools for treatment of combined sewage overflow (6).

One sustainable alternative to the treat the CSO before expelling it to the Wabash River is to build constructed wetlands in Indiana. One such wetland has already been constructed in Washington, IN. The project successfully reduced the sewer construction plan by $26.5 million and continues to save $1.6 million annually. This system creates a higher sewer capacity and improves water quality, as well as saving energy, reducing chemical usage, requiring less maintenance, and providing a wildlife habitat (7,8).

In 2014, a research team at Rose-Hulman Institute of Technology developed two small-scale wetlands. Each wetland was designed to have three separate basins made of plexiglass. The first and third of these basins in each wetland train were to be identical. The second basin in one train was designed to replicate a wetland experiencing subsurface flow (SSF). This basin was filled with the soil description in Table 1. The second basin the other train was designed to replicate a wetland with a free water surface (FWS). This basin was filled with the soil described in Table 2. The majority of this basin hold free standing water. The plants in this basin were those that thrive in submerged conditions. Using these two small-scale wetland trains, we will test the two different types of wetlands in their ability to remove key nutrients: total suspended solids, nitrate, phosphate, biochemical oxygen demand, and dissolved oxygen.

Table 1: Subsurface (SSF) System Soil Media Components

SUBSURFACE SYSTEM

First Basin

Volume (cubic in)						
	Total	Clay	Organic	Sand	Silt	Gravel
20x20	2400	0	120	480	600	1200

Second Basin (Subsurface)

Volume (cubic in)						
	Total	Clay	Organic	Sand	Silt	Gravel
24x60	8640	518.4	3110.4	518.4	1036.8	2592

Last Basin

Volume (cubic in)						
	Total	Clay	Organic	Sand	Silt	Gravel
24x24	3456	777.6	518.4	518.4	777.6	864

Table 2: Free Water Surface (FWS) System Soil Media Components

FREE WATER SURFACE SYSTEM						
First Basin						
Volume (cubic in)						
		Clay	Organic	Sand	Silt	Gravel
20x20	2400	0	120	480	600	1200
Second Basin (Free Water Surface)						
Volume (cubic in)						
		Clay	Organic	Sand	Silt	Gravel
24x60	2880	0	1728	0	1152	0
Last Basin						
Volume (cubic in)						
		Clay	Organic	Sand	Silt	Gravel
24x24	3456	777.6	259.2	518.4	1036.8	864

The plexiglass basins used to create the wetland trains were created in 2014 and disassembled. During the summer of 2016 the basins were reassembled to test the wetlands for these projects. When the basins were reassembled, they were unable to hold water. In order to waterproof the basins, they were once again disassembled and lined with pond liners. The connections (two washers and screws) had been glued to plexiglass sides. Once the pond liner had been laid the connection had to be re-glued, but the washers no longer laid flush with the surface of the plexiglass wall. The washers were wrapped in a silicone adhesive in order to waterproof the connections. Finding and sealing all of the leakage locations in the connections took two to three weeks to accomplish. This process, while necessary, slowed the research process and prevented early plant establishment before testing began.

Background:

The wetland will be used to treat a series of nutrients, including total suspended solids, nitrate, phosphate, biochemical oxygen demand, and dissolved oxygen. Each of these nutrients can cause harm to a surrounding ecosystem and all (with the exception of dissolved oxygen) are regulated in order to obtain NPDES permits in treated wastewater (9).

As total suspended solids increase in a body of water, it decreases the ability for that water to support aquatic life by absorbing heat from sunlight. This affects temperature, dissolved oxygen levels, and photosynthesis – all of which impact both fish and aquatic plant life in an ecosystem. Settling of solids also has the potential to smother young fish eggs, and clog gills (10).

Dissolved oxygen is the source of oxygen for aquatic life. Bacteria that consume organic matter also consume this oxygen. Thus, a buildup of decaying matter will increase the consumption by bacteria, and decrease the amount remaining for aquatic life. This reduced amount of oxygen in the water can cause aquatic life to die in the water – a process called eutrophication (11). The capacity of water to hold oxygen is low enough that there are not negative effects on the environment when there is above average levels of oxygen.

BOD, Biochemical Oxygen Demand, is the amount of dissolved oxygen required for bacteria or aerobic biological organisms to break down oxidize organic wastes in water sample. Microorganisms in water need dissolved oxygen (DO) to degrade the organic compounds as food recourse for growth and reproduction (12). The Environmental Protection Agency used BOD level as an indicator of nutrient pollution, a measurement of the readily decomposable organic content of a waste water (13, 14). The BOD5 test helps to test the change of DO concentration and measure BOD-removal efficiency of both constructed wetland treatment systems. The more pollutants are in the water sample, the more dissolved oxygen will be required. So if the BOD is higher, the lower quality the water will be.

Nitrogen and phosphorus are required for plant life, but too much of these nutrients can cause problems for an ecosystem. An excess of nutrients in water can lead to overgrowth of plant matter and create algae blooms (15). This can lead to eutrophication of the water bodies and deprive the water at depth of sunlight and dissolved oxygen. The growth can also clog waterway systems with plant matter and prevent the use of the waterway for recreational use (16). Excess nitrogen in drinking water can also lead to health effects for humans and livestock as it decrease the ability of the blood to transport oxygen to necessary organs. Infants with this condition develop and illness called “blue baby syndrome,” which often causes a blueish discoloration of the skin (17).

Nitrate, which is frequently measured as mg/L N, is regulated by the Environmental Protection Agency as a contaminant in drinking water such that the concentration cannot exceed 10 mg/L (18).There are three primary processes through which nitrogen is transformed are nitrogen fixation, nitrification, and denitrification. The natural cycle of denitrification can follow a variety of different pathways, but follows the basic stepwise reduction as follows: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ (19). Various bacteria and microorganisms that exist in a healthy wetland can help to consume and transform nitrogen. This transformation and movement through what is known as the nitrogen cycle indicate healthy wetland activity and accomplishes the EPA standards for nitrate levels.

3.0 Methods

Tests done on the constructed wetland included Total Suspended Solids (TSS), pH, Temperature, Dissolved Oxygen (DO), Biochemcial Oxygen Demand (BOD5) Nitrate, Nitrite, Ammonia, and Phosphate. Nitrite and Ammonia were not measured until there was evidence of nitrogen removal. Phosphate was measured in all water types excluding the high nitrate sample as there had not been evidence of removal previously and the water type was focusing on the nitrogen cycle specifically.

3.1 Wetland Setup

The basins shown below were designed by a research team in order to replicate the natural functions of a wetland. The basins were composed of plexiglass and acrylic cement. The two trains imitate the two types of wetlands: subsurface flow (SSF) and free water surface (FWS). In each train the first basin was filled with soils and plants designed for the removal of total suspended solids. The second basins were designed for the purpose of nutrient uptake. The third basins were intended to removal smaller particles. The high clay content in the third basins was intended to be used in the removal of phosphorous.

When loaded with soil and water, however, the seams of the basins failed under the lateral load and began to leak. In order to stop the leaking, the basins were lined with a pond liner. The liner had to be cut at connection points in order to insert the pipe and fixtures. These connection points were layered with rubber washers and wrapped in silicone to prevent leaking at these points as well.

3.2 Wetland Operation

The source water for the wetland was stored in a large 50 gallon reservoir and was pumped into the first basin. The pump was initially too fast for a representative flow rate. Valves were attached to the pump to create a diversion system to decrease the volume of water being pumped into the reservoir (see images below). The remainder of the wetland operated using gravity.

Figure 3: Subsurface System (20)

Figure 4: Free Water Surface System (20)

Initial tests were run through the wetland using tap water. Tap water tests were used to estimate a baseline retention time (roughly six hours). Between testing different water types, the basins would be drained such that only the tap water was used to maintain the plants in the basins when a test was begun. This was much harder to guarantee in the FWS train, as the water in basin two likely became a mixture of all the water types as testing continued.

Aside from tap water, three other types were tested. These included collected stormwater samples from Lost Creek on Rose-Hulman's campus (one test), wetland water from the J.I. Case Wetland in Hawthorn Park (one test), and a synthetic water composed of tap water with added Potassium Nitrate (two tests). The sample collected in Lost Creek was taken on July 26, 2016 and was collected from the drainage outlet from the Student Recreation Center parking lot. The samples were taken at the beginning of the storm in order to collect the first flush. Due to insufficient rainfall, two samples were taken from the J.I. Case wetland in Hawthorn Park instead of Lost Creek. Data from these locations showed nitrate removal. In order to better capture this removal, an artificial water was created with potassium nitrate. Each of these tests was comprised of two sets of samples: one at a complete retention time (six hours after pumping began) and an overnight sample (18 hours after samples were taken and pumping stopped; 24 hours after pumping began).

3.3 Sample Collection

Samples were taken from the initial water source and from the outlet at basin three initially. Upon seeing some nitrogen removal, additional samples were taken at outlets at each basin in order to track chemical changes in the water as it flowed through the wetland. All samples were taken at the bottom outlet of the basins in order to collect water that had seeped through the soil and would have experienced maximum treatment in the wetland.

3.4 Chemical Testing Methods

a. Total Suspended Solids (TSS): Testing done to measure turbidity were done with a Hach 2100P Portable Turbidimeter. A sample would be stirred, poured into the sample bottle, and inserted into the turbidimeter. This measured Turbidity directly in NTU.

b. pH and Temperature: Testing for pH and Temperature were performed using a Beckman pH/Temp/mV/ISE Meter. The probe was placed into a sample. The sample would be stirred during measurements. The probe made these measurements directly.

c. Dissolved Oxygen: A YSI Pro0DO meter was used to measure DO in mg/L. A probe stirred the sample and displayed measurements on the attached screen.

d. Biochemical Oxygen Demand: BOD5 for each sample was calculated according to $BOD5 = \frac{DOi - DOf}{P}$ were DO_i is the initial DO of the diluted sample, DO_f is the DO of the diluted sample after the 5-day incubation, and P is the volumetric fraction of sample used where P is the sample volume divided by the total volume of 300 mL. Different sample volumes were used for different tests based on the baseline testing results, and ranged from 50 ml to 300 ml.

e. Nitrate: The concentration of nitrate was measured using a Hach DR 2800 spectrometer. Hach Method 8171 was used for this measurement. A NitraVer 5 powder pillow was poured into 10 mL of sample and shaken until dissolved. A five-minute reaction time transpired before the sample was inserted into the device which measured nitrate in mg/L.

f. Nitrite: The concentration of nitrite was measured using a Hach DR 2800 spectrometer. Hach Method 8507 was used for this measurement. A NitraVer 3 powder pillow was poured into 10 mL of sample and shaken until dissolved. A twenty-minute reaction time transpired before the sample was inserted into the device which measured nitrate in mg/L.

g. Ammonia: The concentration of ammonia was measured using a Hach DR 2800 spectrometer. Hach Method 8155 was used for this measurement. Ammonia Salicylate powder pillow was poured into 10 mL of sample, shaken until dissolved, and then exposed to a three-minute reaction time. Ammonia Cyanurate Reagent powder pillow was then poured into that mixture, shaken, and allowed to react for fifteen minutes. The sample was then placed into the device where ammonia was measured in mg/L.

h. Phosphate: The concentration of phosphate was measured used a Hach DR 2800 spectrometer. Hach Methods 8114 and 8178 were used for this measurement. For concentrations of 0.3 to 45.0 mg/L PO_4^{3-}, Method 8114 was used. In this method, 0.5 mL of Molybdovandate Reagent was added to 10 mL samples. The samples were swirled and exposed to a seven-minute reaction time before being read in the spectrometer. For concentrations of 0.23 to 30.00 mg/L PO_4^{3-}, Method 8178 was used. In this method, 1 mL of Molybdate Reagent and 1 mL of Amino Acid Reagent Solution were added to a 25 mL sample. The sample was then shaken and exposed to a ten-minute reaction time before being read in the spectrometer.

4.0 Results:

Turbidity:

The design of the basins was such that the majority of the TSS removal would take place in Basin 1. Looking at this basin specifically for TSS removal, the wetland was successful in removing up to 82% of total suspended solids. The soils used in other basins in order to treat other pollutants caused an increase in the turbidity (such as the high clay content soil in the third basin to remove phosphates). The samples were allowed to sit overnight (eighteen hours) and were measured again. There were no significant changes in turbidity values when the samples were allowed to sit in the basins overnight (18 hours after initial samples were taken). In order to maximize the ability of the wetland to remove solids, it may be recommended that the basin that was used here as Basin 1 be moved to the end of each train, thus removing solids directly before exiting the wetland and minimizing the chance for an increase in the concentration of additional suspended solids.

pH:

pH remained relatively constant throughout each train and consistent with the expectations for a wetland. pH values remained within a 6-8 range. Most healthy wetlands (excluding peat bogs which are filled with decaying plant matter) will converge to a neutral pH over time, regardless of the acidity of the soil in the wetland. This range is usually from 6.5-7.5 (21).

Temperature:

The temperatures from all sample locations were from 22.5 – 30.9 °C. Temperature fluctuations throughout each train correlated with sample point, cloud cover, and time of day. When these factors are considered, the temperature values are within reason. Although there is a trend for temperature to increase throughout the basins, this is likely due to the effects of a small scale model rather than a result of plant growth or chemical changes. There is no direct data for comparison as wetland temperatures are climate dependent.

Dissolved Oxygen:

The removal of dissolved oxygen ranged from 21.7% to 68.6%. The subsurface flow train consistently performed better than the free water surface train. The samples that were taken after the water had settled overnight (the 18-hour samples) tended to have higher removal rates. The average DO removal for all basins is 49.3 ± 9.84%. The figure below shows the DO values in each basin in mg/L and shows the overall removal in each basin. The values shows are the averages of all the water types and all sample times (six hours after pumping began and 18 hours after pumping stopped).

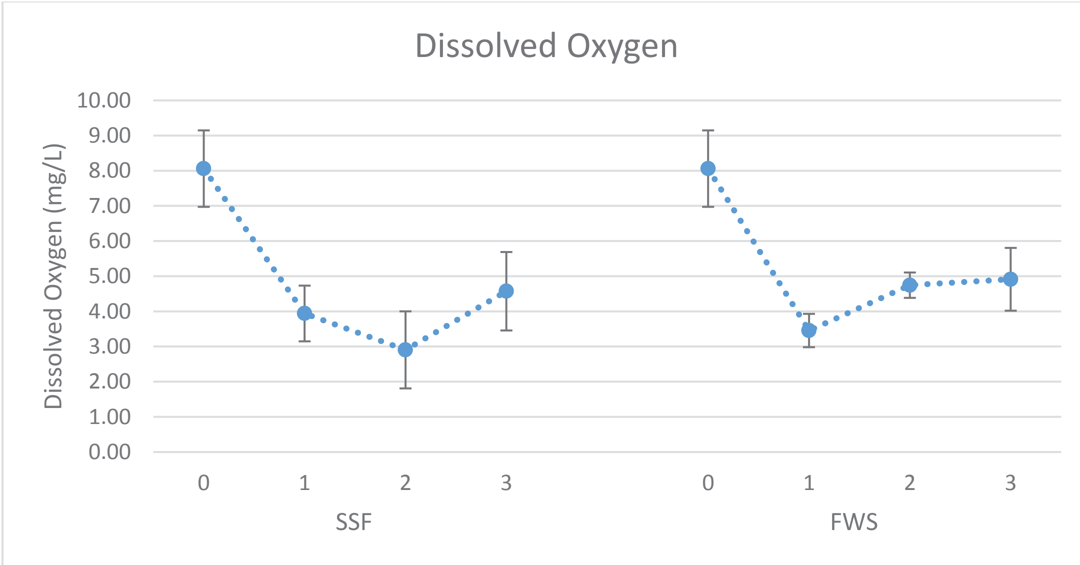

Figure 5: Dissolved Oxygen Removal in all basins

BOD:

Tap Water:

Since both constructed wetlands were in small size, the baseline test was conducted to check the BOD-removal efficiency of the both constructed wetlands. The tap water was introduced to basin 1 for each systems with 18 hours detention time. For this test, four different BOD5 sample volumes collected at both bottom ports of basin 3 were tested and compared between inlet tap water.

According to Figures 6 and 7 which provide the recorded DO concentrations of samples from both the SSF and FWS wetlands, DO is consumed between the inlet and outlets. The average BOD5 in the FWS wetland was 4.14±1.35 mg/L and the average BOD5 in the SSF wetland was 3.47±1.16 mg/L. Comparing both of the outlet BOD5 values to the Inlet BOD5 value of 6.53 mg/L, there was 36.6% BOD removal in the FWS wetland and 46.9% BOD removal in the SSF wetland. The baseline test results show that both SSF and FWS constructed wetlands have the ability.

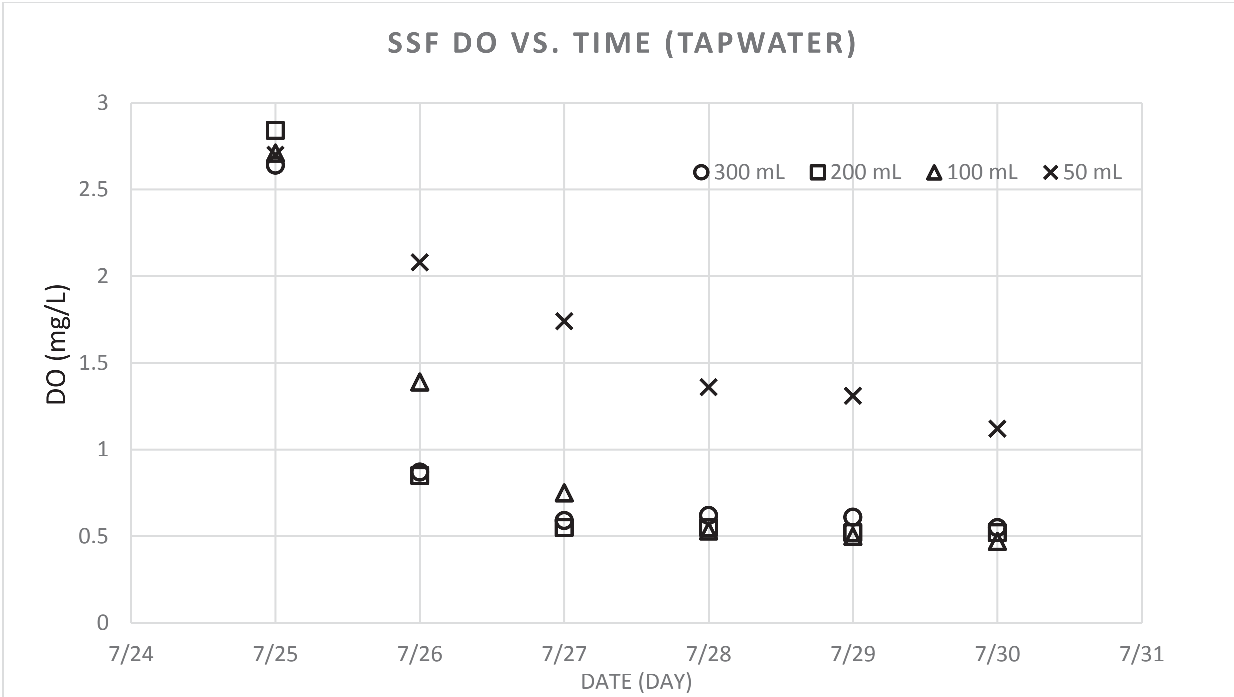

Figure 6. 5-day SSF basin 3 water sample DO (mg/L) concentrations for Tap water baseline test (300 ml, 200 mL, 100 mL, and 50mL are treated water sample volumes)

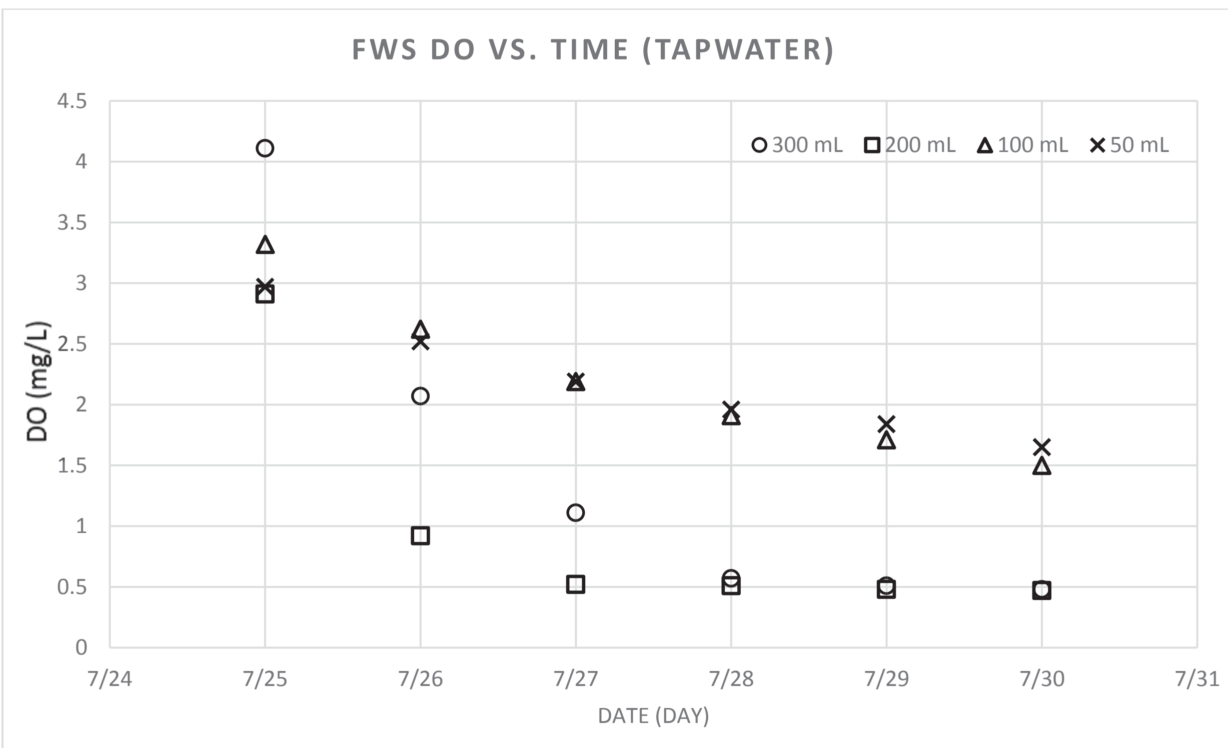

Figure 7. 5-day FWS basin 3 water sample DO (mg/L) concentrations for Tap water baseline test (300 ml, 200 mL, 100 mL, and 50mL are treated water sample volumes)

Stormwater Test:

In the FWS Wetland System, DO readings for each sample volumes from basin 3 bottom port with 5 hr and 18 hr retention times are recorded and collected. Figure 3 provided average DO readings of four sample volumes during 5 days durations. From Figure 3, the DO readings were decreasing gradually along the 5-day period. We observe that the longer retention time in the FWS wetland, the more DO was consumed. Table 1 shows the BOD5 values and percentage of BOD removal for each sample volumes from stormwater test. The average BOD removal from stormwater test in the FWS systems with a 5 hr detention time was 57.10±7.34%, and the average BOD5 removal in the FWS with an additional incubation time (no flow after 5 hr) was 57.45±22.01% as shown in Table 1.

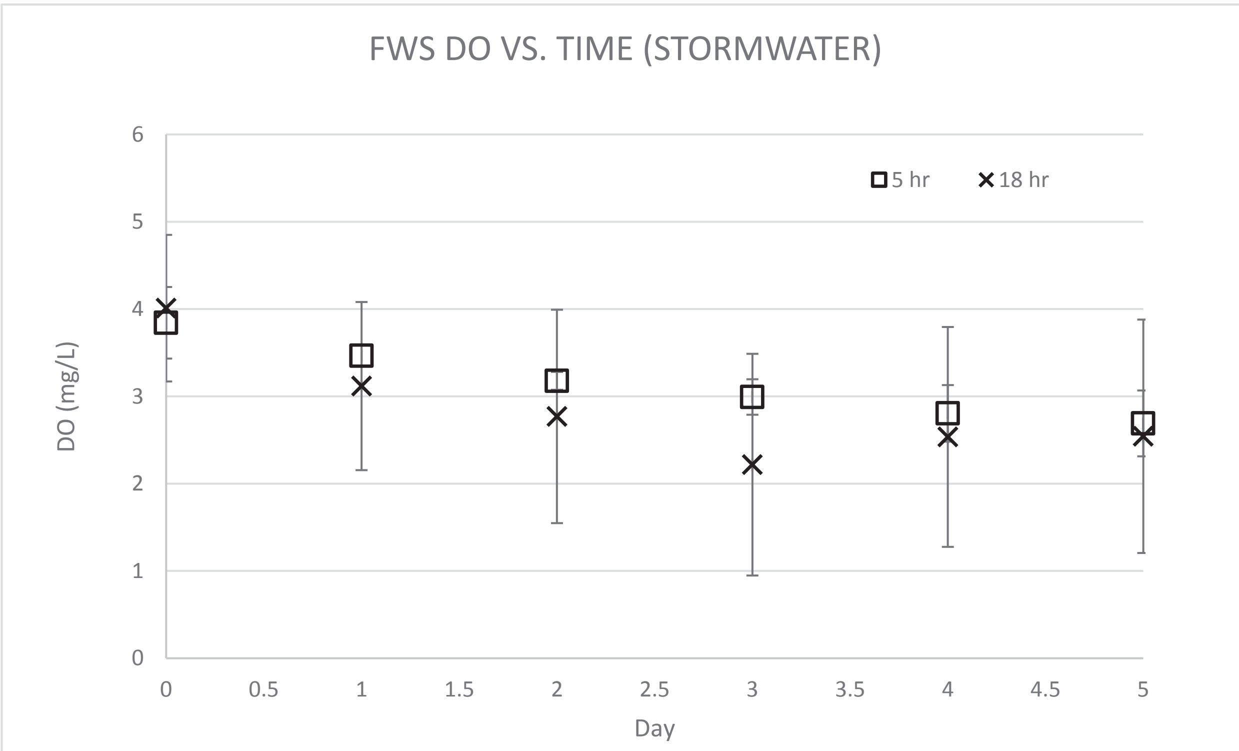

Figure 8. DO readings (mg/L) for stormwater test in the FWS wetland

Table 3. BOD5 values and % of BOD removal from stormwater test in the FWS wetland

Sample volume	**20 mL**	**50 mL**	**150 mL**	**300 mL**	**Avg**
Inlet water sample BOD5 (mg/L)	11.55	9.24	6.08	6.53	8.96±2.75
BOD5 (5 hr) (mg/L)	5.25	4.26	2.92	2.09	4.14±1.17
BOD5 (18 hr) (mg/L)	2.40	2.88	4.34	3.06	3.21±1.01
%BOD Removal (5 hr)	54.55 %	53.90%	51.97%	67.99%	57.10±7.34%
%BOD Removal (18 hr)	53.14 %	28.62%	68.83%	79.22%	57.45±22.01 %

*20 mL means 20 mL of water sample with 280 mL Dilution Water (Total 300mL solution for BOD5 test).

The SSF constructed wetland was effective and reliable for removing BOD in all waters tested. Figure 4 shows average DO readings for two detention times. And according to the plot, more DO was consumed when the time is longer. The average BOD removal from stormwater test in SSF system with a 5 hr detention time was 24.11±22.57%, and the average BOD removal in the SSF with an additional 18 hr incubation time (no flow after 5 hr) was 45.26±12.54%, as shown in Table 2.

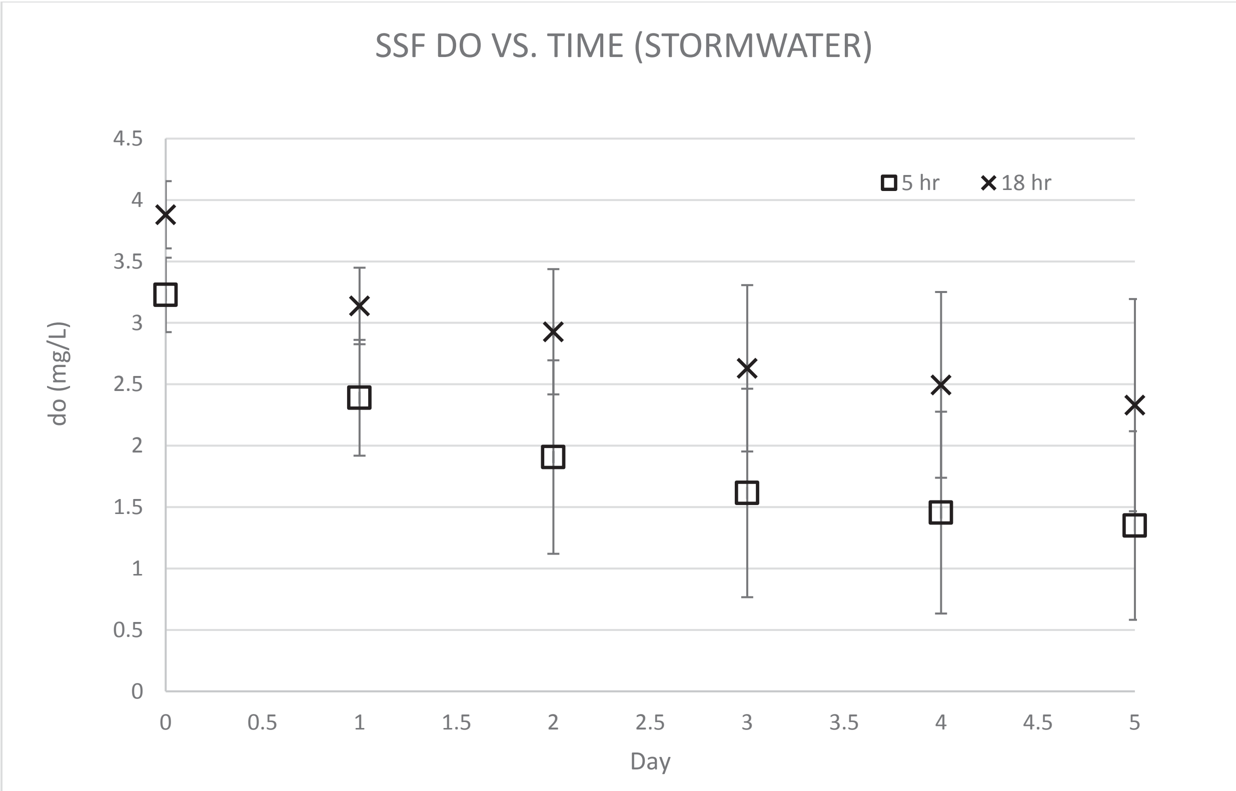

Figure 9. DO readings (mg/L) for stormwater test in the SSF wetland

Table 4. BOD5 values and % of BOD removal from stormwater test in the SSF wetland

Sample volume	**20 mL**	**50 mL**	**150 mL**	**300 mL**	**Average**
Inlet BOD5 (mg/L)	11.55	9.24	6.08	6.53	8.35±2.55
BOD5 (6 hr) (mg/L)	9.15	9.12	4.92	2.92	6.53±3.12
BOD5 (18 hr) (mg/L)	5.40	5.46	4.28	2.79	4.48±1.25
%BOD Removal (6hr)	20.78%	1.30%	19.08%	55.28%	24.11±22.57%
%BOD Removal (18hr)	53.25%	40.91%	29.61%	57.27%	45.26+12.54%

*20 mL means 20 mL of water sample with 280 mL Dilution Water (Total 300mL solution for BOD5 test).

J.I. Case Wetland:

Table 3 shows the BOD5 and BOD removal from J.I. Case water of FWS wetland. The average BOD removal in the FWS wetland with 6 hr detention time was 12.145±0.88% and with 18 hours detention time, it was 44.32±44.66%, as shown in Table 3. The DO reading in wetland test is relatively lower than stormwater test, so the percentage of BOD removal is lower than the test results before.

Table 5. BOD5 values and % of BOD removal from J.I. Case wetland water test in FWS wetland

Sample volume	**100 mL**	**200 mL**	**300 mL**	**Avg**
Inlet BOD5 (mg/L)	10.2	9.75	5.47	8.47±2.61
BOD5 6hr (mg/L)	12.09*	8.505	4.84	8.48±3.63
BOD5 18hr (mg/L)	9.99	5.865	0.49	5.45±4.76
%BOD Removal (6hr)	-18.53%*	12.77%	11.52%	12.15±0.88%
%BOD Removal (18hr)	2.059%	39.85%	91.04%	44.32±44.66%

The incubator was not working well during the last three days for BOD5 test. The temperature inside the incubator was not stay at 20°C constantly. This situation was discovered after the data was collected. Based on the data from J.I. Case water wetland test, provide in Table 4 as well, there are significant removal of BOD observed in SSF wetland system. The average BOD removal from wetland test in SSF system with a 6 hr detention time was 31.31±15.70%, and the average BOD removal in the SSF with an additional 18 hr incubation time (no flow after 6 hr) was 61.01±49.72%.

Table 6. BOD5 values and % of BOD removal from J.I. Case wetland water test in SSF wetland

Sample volume	**100 mL**	**200 mL**	**300 mL**	**Average**
Inlet BOD5 (mg/L)	10.2	9.75	5.47	8.47±2.61
BOD5 (6 hr) (mg/L)	9.82	7.78	3.15	6.92+3.42
BOD5 (18 hr) (mg/L)	11.13*	7.23	0.21	6.19+5.53
%BOD Removal (6 hr)	3.73%	20.21%	42.41%	31.31+15.70%
%BOD Removal (18 hr)	-9.12%*	25.85%	96.16%	61.01+49.72%

*The incubator in the lab was broken for the last three days during 5-day BOD test; this may have affected the 18hr 100 mL sample (avg did not include negative value)

Impact of basin soil and water composition on BOD removal for both the FWS and SSF systems

The three basins comprising different soil content and volumes. To understand the removal of BOD throughout the wetland system, BOD removal was determined for each individual basin in both the FWS and SSF wetland systems. The wetland water test was performed for those tests. Average BOD5 values based on three different sample volumes for each basin in both systems are shown in Figure 5. We speculate that the clay content impeded their ability to thrive. According to Table 5 and Figure 6, BOD value was largely removed in Basin 1 of the FWS wetland (27.65%), and in Basin 2 of the SSF wetland (43.35%). % of BOD Removal was calculated by averaging BOD5 values for three sample volumes in each basin in both wetland systems and comparing to the inlet BOD5, as shown in Table 5.

Table 7. BOD5 (mg/L) value and % of removal in each basin in FWS and SSF wetlands from wetland test

Sample volume	300 mL	200 mL	100 mL	Average	% of BOD Removal
Inlet water sample	5.47	9.75	10.20	8.47±2.61	-
Basin 1 in FWS	3.48	7.91	14.73	8.71±5.67	27.65%
Basin 2 in FWS	5.18	9.75	10.08	8.34±2.74	3.24%
Basin 3 in FWS	5.86	7.86	11.46	8.39±2.84	19.38%
Basin 1 in SSF	4.21	8.03	10.77	7.67±3.29	20.36%
Basin 2 in SSF	1.99	7.50	11.88	7.12±4.96	43.35%
Basin 3 in SSF	3.25	7.82	6.81	5.96±2.40	31.22%

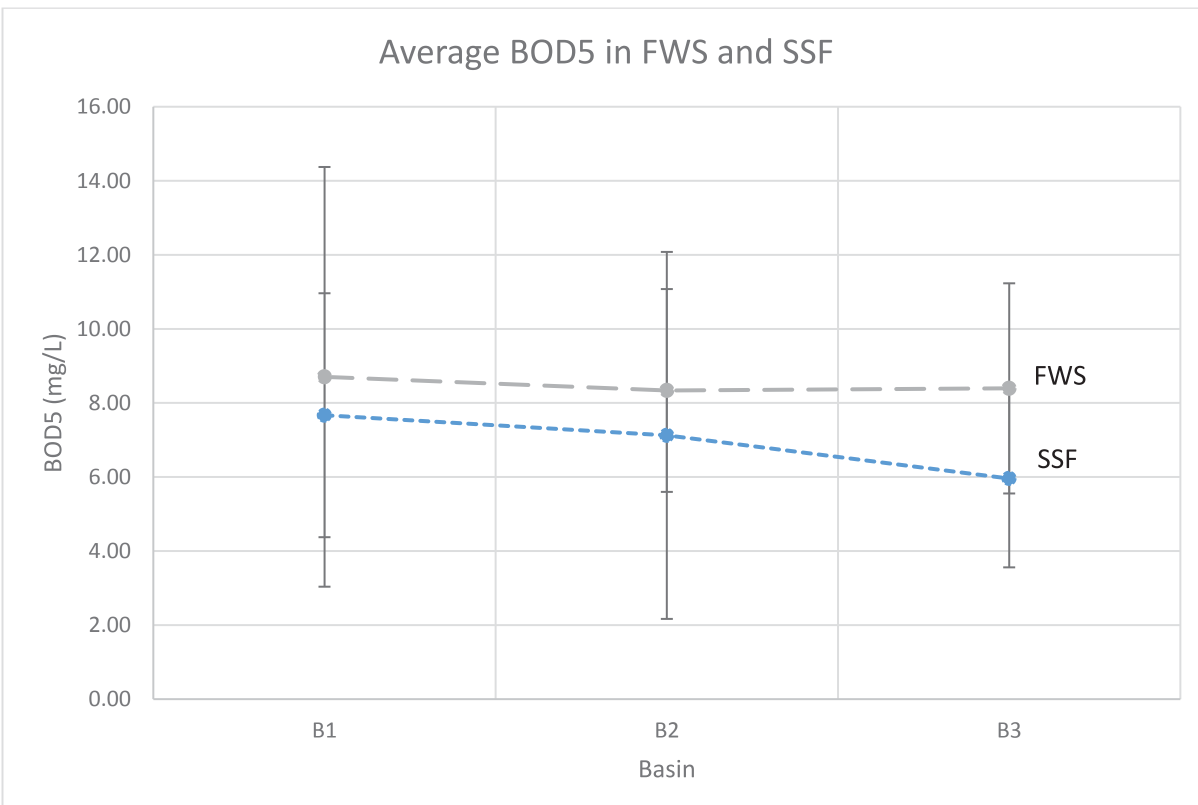

Figure 10. Average BOD5 measurements for each basin in both FWS and SSF wetland systems

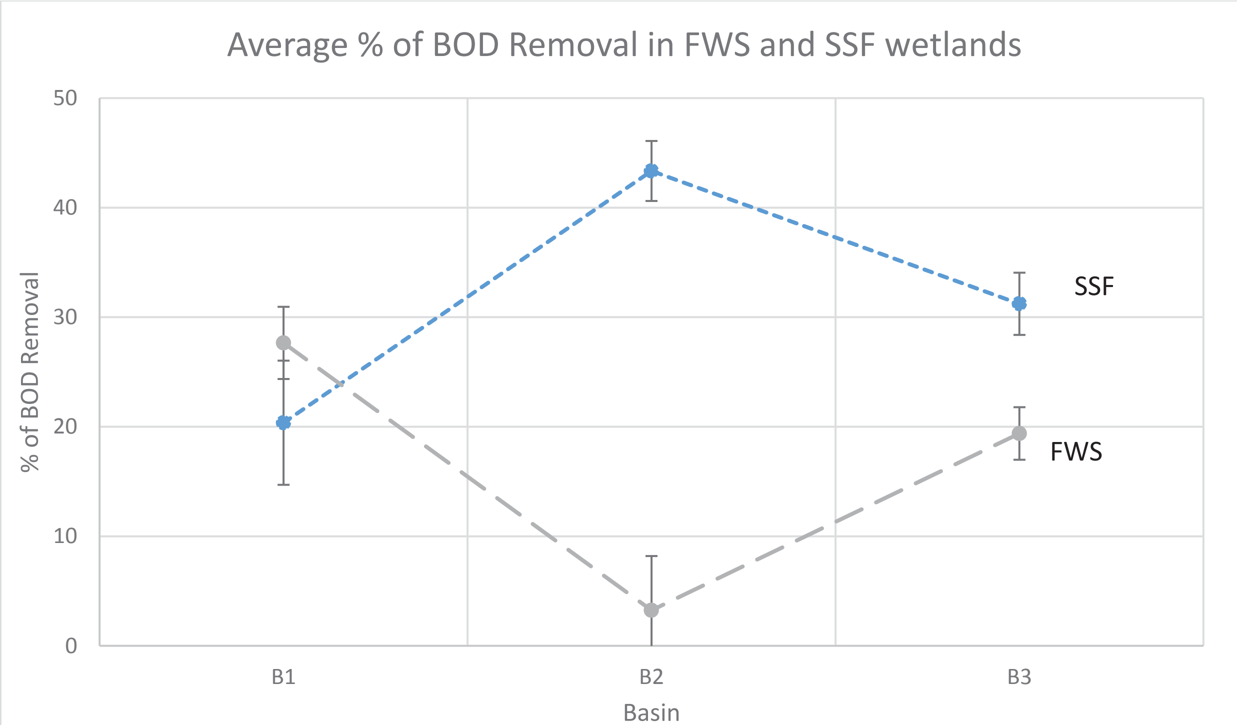

Figure 11. Percentage of BOD5 removal for each basin in both systems

Phosphate:

The phosphate concentrations increased throughout the wetlands. The third basin was designed for phosphate removal with high clay content soils (the second basin in subsurface flow also had high clay content for this purpose). In some cases, the phosphate concentrations increased in these basins and overall throughout the wetland. This may be due to phosphate existing in the soil or being released by plant activity. Additionally, the phosphate removal rates worsened over the course of the testing of the wetland. This may indicate the creation of a phosphate source. Phosphate removal in wetlands is often a collection of the phosphates in the soil, rather than the absorption of the phosphates into plant matter (22). The soil has a finite collection capability for the phosphates. Once this collection capacity is reached, the soil can release phosphates that had previously been "removed." Previous research shows it may take years to reach this carrying capacity in a full size wetland; in the small scale wetland, however, there is the possibility that the worsened phosphate removal may be a result of the soil's carrying capacity (23).

Nitrate:

There was a decrease in the nitrate concentrations through both trains in the wetland in all cases, except the water sample from the J.I. Case Wetland. Overall, inlet nitrate concentrations were low, so changes were difficult to measure. A High Nitrate water (~4.0 mg/L KNO_3), was tested and revealed a nitrate consumption of 73 ± 9.9%. There was an outlier point in the third basin (see Figure 12 below) of the subsurface flow that displayed incredibly high concentrations. This outlier point could be caused by a number of factors and should not be included in trend analysis. Overall, the basins showed significant decrease in nitrate levels throughout the basins.

The first figure below shows the data with the outlier point to demonstrate the decreasing nitrate concentrations. The second figure is the same graph if the outlier point is excluded.

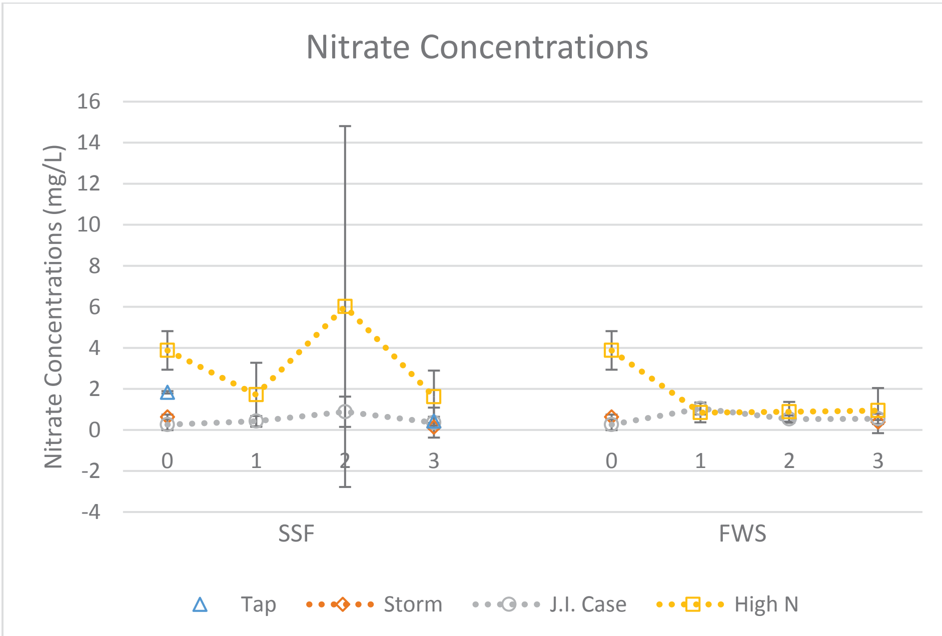

Figure 12: Nitrate concentrations

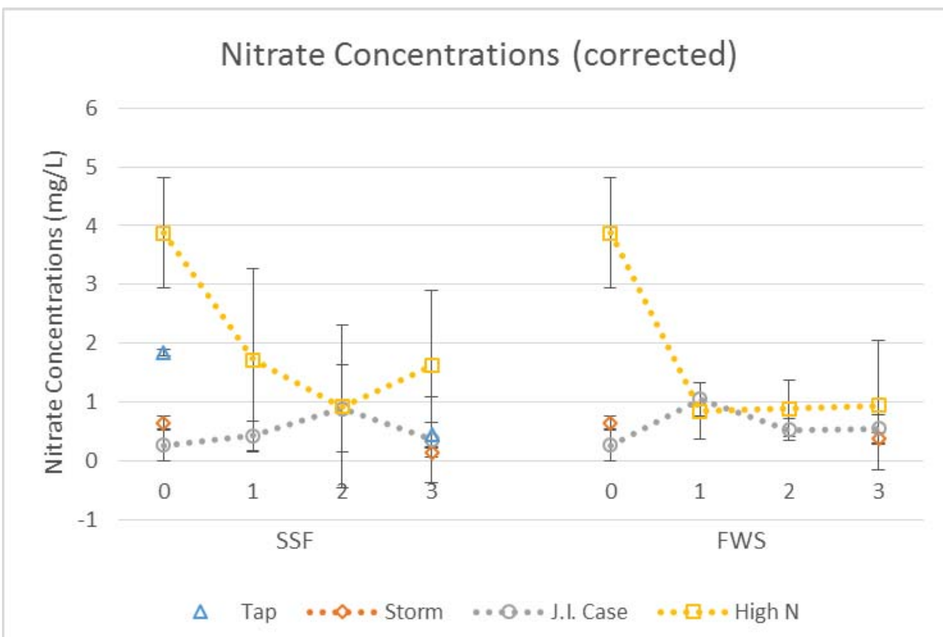

Figure 13: Corrected Nitrate concentrations

Nitrite and Ammonia:

The nitrite and ammonia levels were tested in order to indicate the transformation of nitrogen and indicate nitrate removal through the wetland. Nitrite and ammonia were only tested in the samples from the J. I. Case Wetland and the High Nitrate samples (Figure 14 and 15). For the High Nitrate sample, there was an increase in both nitrite and ammonia concentrations in both trains. For the sample from the J.I. Case Wetland, there was an increase in nitrite concentrations in the subsurface train, but a decrease in the free water train. The increases in the nitrite concentrations indicate the transformation of nitrogen throughout the basins. These transformations point to movement through the nitrogen cycle, although the pathway therein is unclear and cannot be determined from these tests alone.

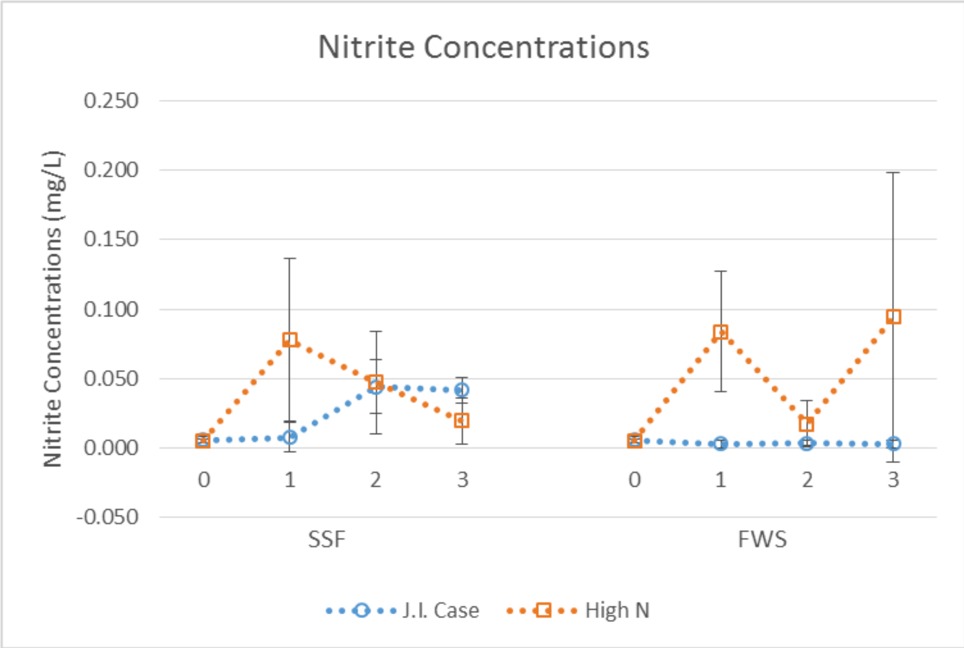

Figure 14: Nitrite Concentrations

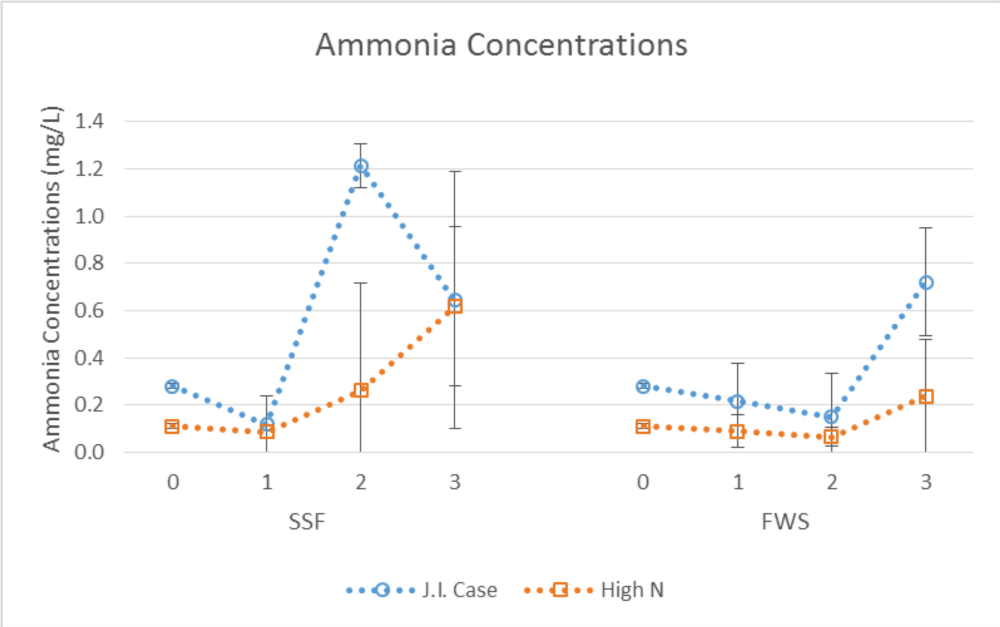

Figure 15: Ammonia Concentration

5.0 Discussion and Conclusions:

Overall, the wetland performed as expected. Turbidity decreased throughout the basins (up to 82%), pH remained at a level (6-8) for healthy plant growth, and temperature fluctuated with the natural weather patterns. Phosphorous was not effectively removed, but this is consistent with previous research. Nitrate removal and nitrite and ammonia increases demonstrate an effective wetland. The only parameter that did not adhere to expectations based on previous research was dissolved oxygen.

Dissolved Oxygen decreased (49.3 ± 9.84%), which could be anticipated. As plants grow, they release oxygen into the water. Healthy plant growth should result in increased oxygen levels in the water, but all basins indicated decreased DO levels. This could be due to a number of factors affecting our small scale wetland. One likely factor is organic pollution. Bacteria and microbes consume the oxygen in the water for biologic processes and can decrease the DO concentration. This process is aided by the laminar flow of the water through our wetland, allowing the oxygen to settle and have more exposure to these organisms (24). Another factor to be considered is the establishment of the plants. Our plants were not fully established when the first tests were run, and thus may not have been producing the levels of oxygen to be predicted (25).

During the stormwater test, FWS wetland provided 57.10±7.34% with 5 hr detention time and 57.45+22.01% with 18 hrs while SSF wetland provided 24.11±22.57% with 5 hr detention time and 45.26±12.54% with 18 incubation time. For the J.I.Case wetland water test, in the FWS weltand, 12.15±0.88% of BOD been removed in 5 hr detention time and 44.32±44.66%. In the SSF wetland, the average BOD removal is 31.31±15.70% in 5 hr and 61.01±49.72% for 18 hr. based on the test results, the FWS had higher BOD removal for stormwater test and SSF wetlands provided better BOD removal in J.I. Case wetland water test.

It is possible that a FWS constructed treatment wetland could remove more BOD if it were larger in size with more complete plant coverage. Based on both test results, the FWS system can provide decent amount of BOD removal even in a small wetland with a short detention time. During the tests, the plants had trouble growing in FWS basins 2 and 3. There were also insects, fish, and algae growing inside of FWS basin 2. Most of the algal and aquatic life were introduced from the J.I. Case wetland water, and may have consumed or produced some DO which might impact the DO BOD_5 measurements.

The SSF wetland provided greater BOD removal compared to the FWS system. According to Table 6, the additional incubation time allowed for additional BOD removal. The tests showed that even a small-scale SSF wetland is capable of removing BOD from various inlet water samples within a relatively short time period. Insect and algae growth are not an issue with SSF wetlands as long as the wetland is properly operated and the water level is maintained below the soil surface.

According to individual basin test, we found that higher rates of BOD removal were observed in basins that contained the greatest amounts of soil and plant coverage. Naturally-occuring microorganisms in the soil and on plant roots participated in removing BOD from water, and higher rates of BOD removal were observed in basins that contained the greatest amounts of soil and plant matter. During the entire summer research period, the SSF basin 2 contained the most soil and had the highest plant coverage, and the most BOD removals were provided.

The wetland failed in both trains to effectively remove phosphorous. In previous research, wetlands have been able to remove a small amount of phosphorous, but not to the level required for CSO treatment. Existing wetlands have shown that high clay content soils do better than others in phosphorous removal, but that over time even these wetlands fail maintain adequate phosphorous removal. The clay content in the soil in our wetland had the potential to remove phosphorous, but its failure is consistent with previous research (25). Further phosphorous could have been added to samples by decaying plant matter in the third basin.

Nitrate levels in the wetland decreased (73 ± 9.9%), while both nitrite and ammonia concentrations increased. This indicated a removal and/or transformation of the nitrogen in the water passing through the wetland. Ammonia can be formed through multiple processes in the nitrogen cycle, so this rise in ammonia concentration is not an adequate indicator for what reactions the nitrogen is undergoing as it travels through the wetland. Further testing would be required to accomplish this. Regardless of the path the nitrogen transformations take, the removal of nitrate indicates biologic activity and denitrifiers in the soil interacting with the water and thus an overall active wetland (23).

6.0 Recommendations for Future Investigation:

Future work on this wetland can include a reconfiguration of the basins. Placing the initial basin as the last in a train will maximize turbidity removal, for example. This reconfiguration can be done to maximize and prioritize nutrient removal. Additional testing should be done on the dissolved oxygen levels with more established plant matter in the soil. The better establishment may affect the data. Likewise, testing can be done to examine the effectiveness of plant activity on phosphorous removal. Altering the detention time and flowrate of the water through the basin may also optimize contaminant removal.

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