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Optimizing the Removal of Stormwater Pollutants in Small-Scale, Constructed Treatment Wetlands

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Executive Summary

Natural wetlands use plants to absorb and break down harmful pathogens and water pollutants. This process improves water quality in a natural and efficient way. By mimicking natural wetlands with constructed wetlands, we are able to perform the same functions. We used the two small-scale treatment wetlands in the Cook Laboratory for Bioscience Research to perform experiments to optimize the removal of stormwater pollutants. These two treatment wetlands consist of three connected basins each with the goal of removing harmful pollutants in each basin. These stormwater pollutants include total suspended solids, biochemical oxygen demand (organic carbon), and nitrate.

Past studies led us to expect greater pollutant removal with a greater hydraulic retention time. In our project, to lengthen the retention time and test its effect, we recycled water that had gone through the wetland once already. We placed a pump at each end of the constructed wetlands to circulate water through the system, and a basin with the proper tubing to capture this water before it was cycled through again. We performed several experiments by pumping stormwater through the wetlands while measuring the turbidity, nitrate concentration, temperature, and pH of the water. We measured these parameters with instruments available in the Environmental Engineering lab.

Our findings indicated that the updated wetland setup was successful in removing turbidity. Further work should be conducted now that the recycle line is in place. This project provides insight on how to improve the efficiency and effectiveness of the two constructed wetlands. This information can be used to for the design of wetlands stormwater treatment.

Background

Treatment wetlands are studied for their great affects at removing pollutants from stormwater runoff. One large aspect of our study is the detention time and how it affects pollutant removal. Adding a recycle line to the wetland increases the retention time therefore increasing the BOD (biochemical oxygen demand) and nitrate removal (Barten 1987, Carleton et al. 2001, García et al. 2005, Kadlec and Wallace 2009). In our research, we expanded on studies to fit the needs of our treatment wetlands for Lost Creek.

The hydraulic loading rate (HLR) and hydraulic retention time (HRT) affect removing pollutants in treatment wetlands (García et al. 2005). The studied was performed in a pilot scale subsurface wetland over a period of three years. The study found that as the HLR increased the concentration of BOD_5 and chemical oxygen demand increased (García et al. 2005). However, the effect on the average effluent ammonia concentration with HLR varied each year. The studied also includes research on water depth and its effect on pollutant removal. The study found that depth had less of an impact compared to HLR. The finding presented in this article leads us to believe that by creating a recycle line to our treatment wetland, we will have a great impact on pollutant removal than increasing the depth.

Thirty-five studies from four stormwater runoff treatment wetland systems were analyzed to find patterns in optimizing removal of pollutants (Carleton et al. 2001). They found that pollutant removal highly depends on the long-term mean hydraulic loading rate and nominal detention time (Carleton et al. 2001). Using a first-order steady flow design equation (Equation 1), the authors were able to relate hydraulic loading rate (*q*) to inlet concentration (*C*).

$\frac{C}{C_i} = e^{-\frac{k_a}{q}}$ k_a = “areal” rate constant [units of length over time]   Equation 1

This model could be used to estimate a retention time needed for a certain percentage removal of the concentration of a pollutant. The paper gives several k_a values from other researches. By modeling our treatment wetland with this equation, we could compare them to wetlands used in this study.

Other research papers explored an optimum detention time deeded to remove a percentage of particulate phosphorus during six years (Barten 1987). The authors found that in order to remove 54 percent of influent total phosphorus it required a minimum three-day detention. This research shows that for a higher percentage of removal, a greater detention time is required. Our treatment wetland will imitate a longer detention time by creating a recycle line in order to remove a greater percentage of pollutants.

Methods

Wetland Setup

The two wetland trains consisted of three basins each. Each wetland train had a reservoir at the beginning of the train where stormwater was pumped into the system. Nozzles in between each wetland controlled the water flow rate. Tick marks were painted at the opening location on the valve for the ideal water retention time of three to six hours for one run-through. At the end of the train, the stormwater flowed from the final basin into collection basins below the table that the wetlands sat on. The water in those collection basins was subsequently pumped back up into the basins at the beginning of the train in order to double the retention time.

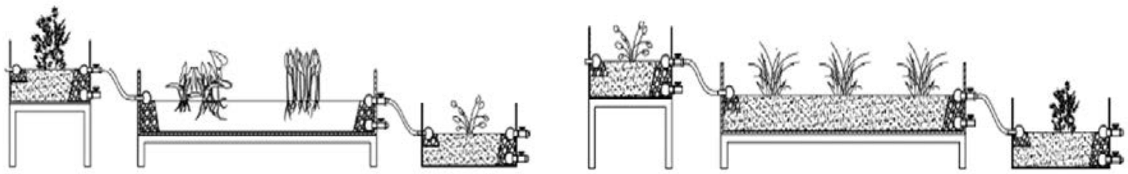

Figure 1: Subsurface (SSF) wetland system (left) and free water surface (FWS) wetland system (right) (Mueller Price, 2015)

Figure 2: Subsurface (SSF) wetland system (left) and free water surface (FWS) wetland system (Mueller Price, 2015)

Since the setup in 2015, the plants in the wetland have changed as some plants have died and new ones were planted. Figure 3 shows the current plant growth. Currently, there are no plants in Basin 3 of both trains, and Basin 1 of both trains consist of grass. Basin 2 of the SSF wetland consists of new growth and also some decay of old plants. Basin 2 of the FWS wetland contains new growth of some of the water plants.

Figure 3. Updated Treatment Wetland plants and setup

Artificial Stormwater Runoff

Capturing and using stormwater runoff was an effective way to replicate an actual wetland in the field, however planning around a rainfall event proved to be challenging. By creating artificial stormwater runoff, controlled tests could be performed independent of the weather. Natural stormwater was mimicked by adding crushed ZIPP soil to tap water for turbidity and potassium nitrate to water for the desired nitrate concentration.

Wetland Hydraulics

To test the hydraulics of the wetlands with the new recycle system, stormwater runoff and artificial stormwater were pumped through the wetlands. Real stormwater was only collected once due to the difficulty of collecting the water.

To effectively operate the wetlands, either real stormwater or the artificial stormwater must be pumped into the wetland shortly after it is either collected or mixed in order to maintain all of its parameters. This is especially true for nitrate because it can change forms. To perform a run-through, first, the two reservoir pumps should be started to pump water into the wetland trains. The valves in between each of the basins should be opened to the indicated tick mark in order to have a retention time of 3.31 hours corresponding to a flow rate of 0.0127 +/- 0.00474 L/s.

Water Quality Testing

The water was collected at three points in each wetland setup: the initial artificial stormwater runoff, after the first run-through (taken from outflow of Basin 3), and after the second run-through (taken from the second outflow of Basin 3). Turbidity, nitrate, temperature, and pH were measured in the Environmental Engineering Laboratory. Samples were taken the day of the run-through and remained in the Cook Laboratory for Bioscience Research overnight. The following day the samples were transferred to the lab and placed in beakers for the tests. A XXXX pH meter was used to measure pH and temperature, three measurements were taken for each sample. A XXX turbidimeter was used to measure turbidity, and three measurements were taken for each sample. Before reading each sample, the sample was gently mixed and the glass vial was cleaned with a cloth. A XXX Hach spectrometer was used with Method 8171 for mid-range nitrate to test nitrate concentrations. Three measurements were again taken for each sample.

Results

Wetland Setup

We changed the wetland hydraulics to increase the retention time in order to optimize the efficiency of the treatment wetlands. We replaced a single reservoir and one pump with two separate reservoirs and two pumps that pump into the individual trains. By making this change, we were able to verify that the same amount of water was flowing into each of the two treatment wetland trains. We added two basins beneath the wetland setups in order to capture the water so that it was easily recycled through the wetlands. This modification required two additional pumps, extra connections, and tubing to make the recycled system work.

Because of the large amount of soils in Basin 2 of the SSF wetland, the SSF wetland retained ¾ of the water pumped through it after one run-through. Conversely, the FWS wetland retained only 1/3 of the water pumped through it after one run-through. This finding demonstrates the importance of wetlands serving as a stormwater reservoir, in addition to improving the quality of the stormwater.

Artificial Stormwater Runoff

Part of this project required developing a recipe for artificial stormwater runoff so that the project would not be dependent on the weather. Using stormwater runoff, I developed a recipe to mimic the turbidity and nitrate concentration of the runoff. The stormwater runoff had a turbidity of 3.09 +/- 0.446 NTU and a nitrate concentration of 0.177 +/- 0.0000333 mg/L. Because the stormwater runoff was taken after several days of rain, we assumed the nitrate concentration to be diluted and used past nitrate concentration data in order to make the artificial stormwater runoff. A higher nitrate concentration also allowed for better measurement of the nitrate by not being near the detection limit.

For a nitrate concentration of 3 mg/L, 1.21 g of KNO_3 was added to 25 gal of tap water (Table 1). We included a multiplier factor to our calculation in order to relate an empirical equation to actual lab tests. A multiplier factor of 10 accounted for some of the KNO_3 not dissolving completely into the tap water and settling at the bottom of the reservoir making it too low for the pump to reach.

Table 1. KNO_3 to add to tap water

Total Nitrate Desired (mg/L)	Amount Tap Water (gal)	Multiplier Factor	KNO_3 to add (g)
3.0	25	10	1.21

To achieve a turbidity of 3.5 NTU, 8.04 g of pulverized ZIPP was added to 25 gal of tap water (Table 2). Again, a multiplier factor was used to account for settling of the ZIPP.

Table 2. ZIPP to add to tap water

Turbidity Desired (NTU)	Amount Tap Water (gal)	Multiplier Factor	ZIPP to add (g)
3.5	25	5	8.04

Run-through Laboratory Testing

To determine the efficiency of the wetlands with the recycle line, artificial stormwater was pumped through the systems. During these tests, turbidity, nitrate, pH and temperature were measured. Temperature and pH remained generally constant with ranges of 25.5 – 26.7 ˚C and 8.03 – 8.27, respectively (Figures 4 and 5).

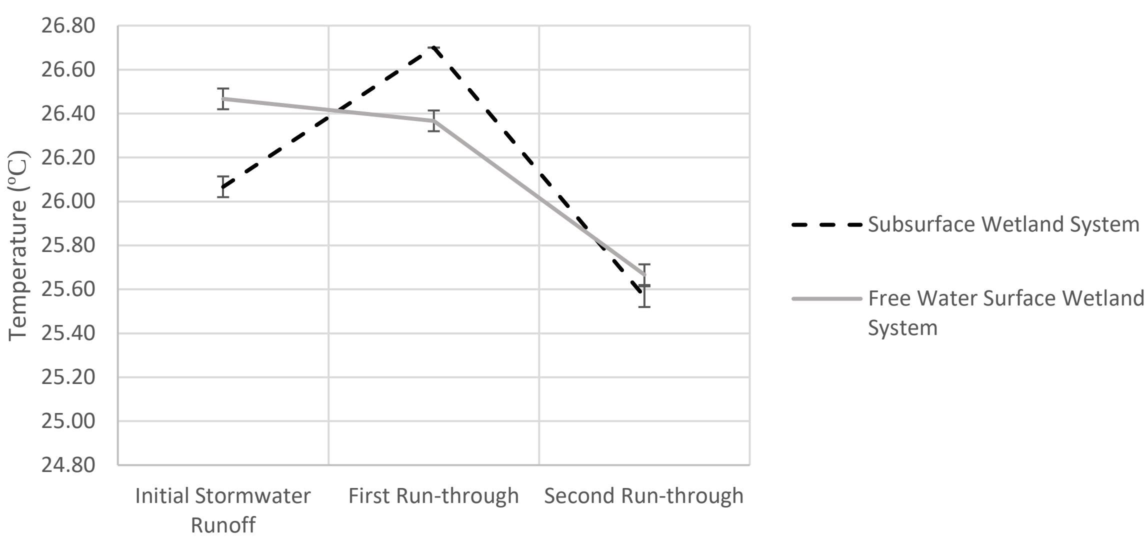

Figure 4. Temperature (error bars represent three measurements from one artificial stormwater test)

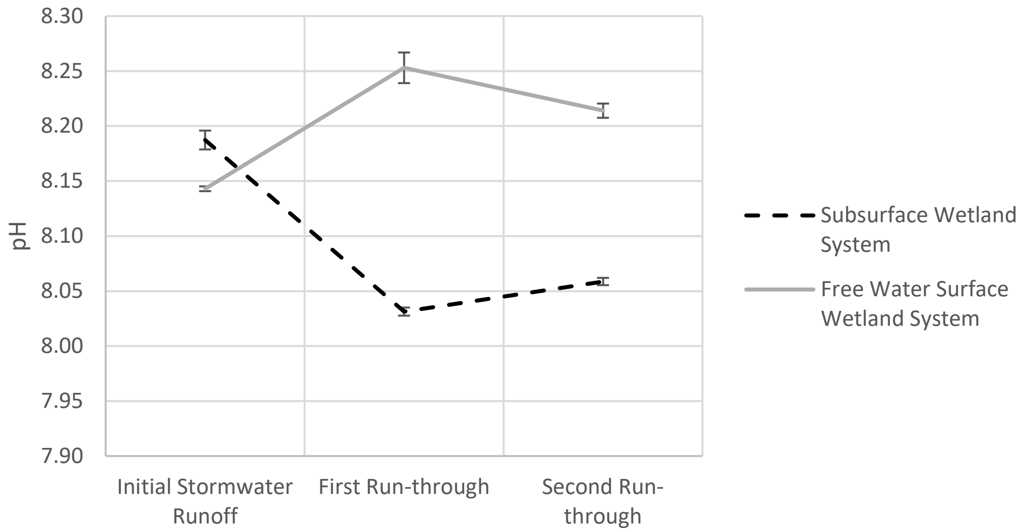

Figure 5. pH (error bars represent three measurements from one artificial stormwater test)

Turbidity generally decreased in both SSF and FWS wetland systems (Figure 6). In the SSF wetland system, turbidity continued to be removed when the water was recycled through the wetland. In the FWS, turbidity was removed well as a result of the first run-through, and slightly increased during the second run-through. It is possible that because of the large volume of water in Basin 2, during the first run-through the water is diluted and as a result, has lower turbidity overall. During the second run-through the water was already diluted as it moves through the soils again the turbidity is then slightly increased. However, for both systems, turbidity was removed at 66.8 +/- 4.84 percent.

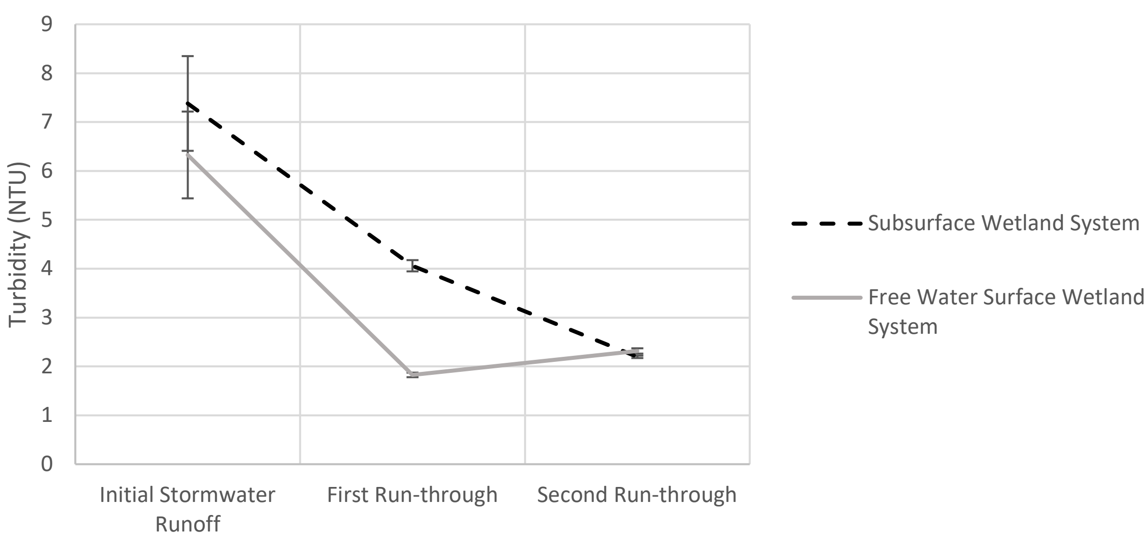

Figure 6. Turbidity (error bars represent three measurements from one artificial stormwater test)

In the FWS wetland, there was net removal of nitrate at 27.8 percent. Nitrate was removed in the first run-through, and nitrate concentration increased slightly as it was pumped through a second time (Figure 7). Because the FWS wetland had a large amount of water initially in the basins, the nitrate removal in the first run-through could be due, in part, to dilution of the artificial stormwater.

In the SSF wetland, there was an increase in nitrate concentration after the first run-through and after the recycle line (Figure 7), resulting in a 265 percent increase. This increase could be from a variety of factors, including from plant material and nitrifying bacteria present in the wetland systems.

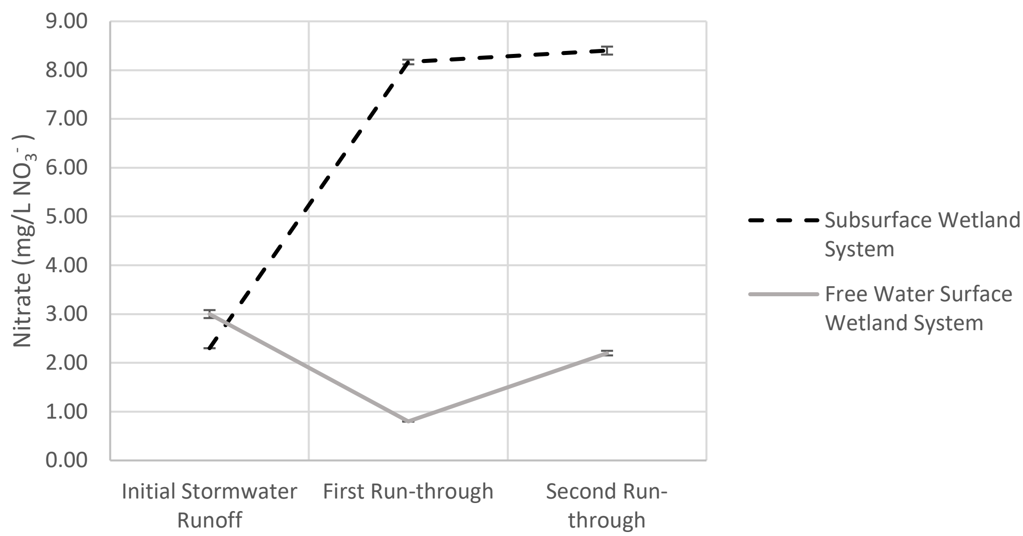

Figure 7. Nitrate Concentration (error bars represent three measurements from one artificial stormwater test)

Results Summary

SSF Wetland:

- retained 3/4 of the water pumped through it after one run-through
- increase of nitrogen when stormwater runoff filtered through
- strong removal of turbidity when stormwater runoff filtered through

FWS Wetland:

- retained 1/3 of the water pumped through it after one run-through
- decrease of nitrogen when stormwater runoff filtered through
- removal of turbidity when stormwater runoff filtered through

Discussion

A first-order steady flow design equation has been previously used to loosely relate hydraulic loading rate (*q*) to inlet concentration (*C*) (Carleton, 2001).

$\frac{C}{C_i} = e^{-\frac{k_a}{q}}$ k_a = "areal" rate constant [units of length over time] Equation 1.

Applying this model to our data (Figure 8), the k_a values are very high. Because the data collected was from a single test, we do not have confidence in using the k_a values to predict the optimized retention time for removal. The values for k_a range from 57.1 to -9.6 +/- 16.6 m/yr in previous studies (Carleton et al. 2001). The studies uses values from both natural and constructed treatment wetlands with both FWS and SSF wetlands. The values shown in Figure 8 differ by greater than a factor of ten from the range presented in previous studies, leading us to believe that more tests must be done to be confident in using Equation 1 to predict pollutant removal.

Subsurface Wetland System Nitrate Removal

$C_i := 2.3$

$C := 8.4$ After second run-through

$q := \frac{104 \cdot 2}{6} \frac{in}{hr}$ $q = (7.719 \cdot 10^3) \frac{m}{yr}$

$\frac{8.4}{2.3} = e^{-\frac{k_a}{7.719 \cdot 10^3}}$ $k_a := -\ln\left(\frac{8.4}{2.3}\right) \cdot 7.719 \cdot 10^3 = -9.999 \cdot 10^3$

Subsurface Wetland System Nitrate Removal

$C_i := 3.0$

$C := 2.2$ After second run-through

$q := \frac{104 \cdot 2}{6} \frac{in}{hr}$ $q = (7.719 \cdot 10^3) \frac{m}{yr}$

$\frac{2.2}{3.0} = e^{-\frac{k_a}{7.719 \cdot 10^3}}$ $k_a := -\ln\left(\frac{2.2}{3.0}\right) \cdot 7.719 \cdot 10^3 = 2.394 \cdot 10^3$

Figure 8. Calculations for "areal" rate constant

Conclusions

Our research has shown that the hydraulics of the treatment wetlands can greatly affect the success of run-throughs. From the new wetland setup, we found that the SSF wetland absorbs over half of the water that is pumped into the system. This is a beneficial quality of SSF wetlands because of their ability to absorb a large quantity of water for stormwater control. The turbidity decrease for the SSF wetland show the strongest correlation with reduced turbidity for each run-through.

Future Work

Because much of our research consisted of the setup of the treatment wetlands, it is important to continue testing in order to build on our data. Additional data would allow for statistical analysis to be performed. Modeling removal rates using the the equation published by Carleton, et al. would be very useful to compare the performance of our wetlands to that of other wetlands.

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