Effectiveness of Phosphate Retention in Constructed Wetlands

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INTRODUCTION

Wetlands are a valuable ecosystem, not only for the unique plant and animal species that reside there, but also for humans due to the ecological services that they provide. Nutrient retention in wetlands is a function highly desired by human society (Weisner et al, 2010). This is especially true in the Macatawa Watershed, where high-phosphorous runoff from agricultural land has caused eutrophication of Lake Macatawa. Levels of phosphates in the lake have regularly reached 200 ppb, compared to other eutrophic lakes where 30 ppb of phosphate is a concern (Soukhome, 2009). Project Clarity has undertaken a number of wetland restoration projects in recent years, in part to counteract this nutrient cycling problem. However, little data has been collected to quantify the effects of wetland reconstruction on phosphorus in the Macatawa Watershed.

Many other wetland restoration projects have had difficulty restoring highly-functioning nutrient retention services of wetlands. A meta-analysis of 621 wetland sites shows that even a century after restoration efforts, the biogeochemical functioning of the wetlands remained 23% lower than in reference sites (Yockteng, 2012). Also, restoration ecologists tend to focus on plant diversity in wetlands; however, multiple studies give evidence that these land management techniques may decrease the ability of the wetland to retain nitrogen (Weisner et al 2010, Zedler 2000). Biodiversity and the human-desired ecosystem function cannot both be maximized in the same wetland. According to Zedler, "maximum nutrient removal requires abundant nutrient supplies (eutrophic conditions), where dominance is often by single plant species." Clearly, the management of wetlands and the design of reconstruction projects have important implications for their effectiveness in nutrient retention.

Our research seeks to provide insight on how well the constructed wetlands in the Macatawa Watershed are performing their desired functions. We also hope to contribute to an understanding of how land management techniques and restoration history at wetlands may affect nutrient removal. Another component of this research is to compare wetlands' effectiveness during time periods of high and low stream flow. This would be a helpful indicator of the wetlands' capacity for phosphate removal, because these times are when the most phosphates flow downstream (Smil 2000).

METHODS

Figure 1: Map of Wetland Locations

Figure 1 A map of the five wetlands that were sampled at various times throughout a two-month period. Included are Haworth, Paw Paw, Stu Visser, Upper Macatawa, and Middle Macatawa

For this study, we went out to five different constructed wetlands in the Lake Macatawa Watershed (see Fig. 1) and gathered water samples from pre-determined inflow and outflow regions. These regions were determined using prior knowledge of the area and by analyzing what rivers flow into and out of the wetlands. Three wetlands were sampled twice, once during a low-discharge rate, and once during a high-discharge rate. This is monitored by a USGS gauge station in one of the rivers, and a flow above 150 ft^3/s is generally considered high-discharge.

The samples were collected in either 250 ml or 500 ml bottles that were pre-washed with nitric acid and RO water to ensure that there was no contamination beforehand. The bottles were rinsed three times with the river water before a sample was taken. Within a few hours of gathering the samples, sulfuric acid was added to the bottles to get rid of any other organisms that would use the phosphorus and give lower phosphorus readings. After the addition of sulfuric acid, a quantitative analysis using Ultraviolet-visible spectroscopy (UV-Vis) was used to determine the concentration of phosphorus at the different sampling sites. To do this, a linear regression line of absorbance vs concentration was created by analyzing a set of known phosphorus standards. The equation of this best fit line is used to calculate the concentrations of the unknown samples, since the absorbances are measured by UV-Vis spectroscopy.

RESULTS

The results of our research project show differences in the amount of Phosphorus in the inflow of a wetland compared to its outflow. The five wetlands which we took samples from, differ in their behavior when it comes to Phosphorus concentration changes. The range in the amount of Phosphorus of the wetlands, during high and low flow, was of 23.7 ppb to 1053.69913 ppb for the inflow and a range of 27.6 ppb to 857.7 ppb for the outflow. We tested three of the sites twice, which is shown in Table 1.

Table 1 Concentrations of phosphorus and their respective standard deviations are shown below for in and outflow measurements. Three of the five wetlands were tested twice for these duplicate measurements.

Wetland	ft^3/s	P Inflow (ppb)	S(P inflow) (ppb)	P Outflow (ppb)	S(P Outflow) (ppb)	Total P Retention (ppb)	S(Toal P Change) (ppb)
Middle Mac (10/15)	13	41.7	7.8	60.2	7.0	-19	11
Middle Mac (11/19)	23	74.5	2.4	71.7	2.4	2.8	3.3
Upper Mac (10/22)	15	147.2	6.6	90.2	6.9	57.0	9.5
Upper Mac (12/3)	130	269.9	2.2	124.4	2.3	145.5	3.2
Paw Paw (10/22)	15	23.7	7.3	92.4	6.9	-69	10
Paw Paw (12/3)	130	106.4	2.3	362.8	2.2	-256.4	3.2

The data here shows that Paw Paw had a decrease in the phosphorus retention, while Upper Mac had showed an increase. Middle Mac showed an increase as well, even if slight, of 21.8 ppb. There were also three wetlands that were tested during a high flow and a low flow event. The high flow was collected right after a rain event and when the rate of flow was 250 ft^3/s, compared to 13 ft^3/s for the low flow. Table 2 and 3 shows the data for low flow and high flow, respectively.

Table 2 The phosphorus concentrations for Paw Paw, Haworth, and Middle Mac during a low flow event along with their respective standard deviations.

Normal Discharge (13 ft^3/s)						
	P Inflow (ppb)	S(P inflow) (ppb)	P Outflow (ppb)	S(P Outflow) (ppb)	Total P Retention (ppb)	S(Toal P Change) (ppb)
Paw Paw	23.7	7.3	92.4	6.9	-69	10
Haworth	34.8	7.2	27.6	9.6	7	12
Middle Mac	41.7	7.8	60.2	7.0	-19	11

Table 3 The phosphorus concentrations for Paw Paw, Haworth, and Middle Mac during a high flow event along with their respective standard deviations.

High Discharge (250 ft^3/s)						
	P Inflow (ppb)	S(P inflow) (ppb)	P Outflow (ppb)	S(P Outflow) (ppb)	Total P Retention (ppb)	S(Toal P Change) (ppb)
Paw Paw	302.5	6.8	705.9	6.5	-403.4	9.4
Haworth	233.7	3.8	262.9	6.1	-29.2	7.2
Middle Mac	1053.7	8.7	857.7	7.3	196	11

For this set of data, Paw Paw shows a decrease in Phosphorus retention, along with Haworth showing a decrease of 334.4 ppb and 36.2 ppb, respectively. Middle Mac shows an increase in the phosphorus retention by 215 ppb. Figure 2 below shows the total change between the low and high flows periods.

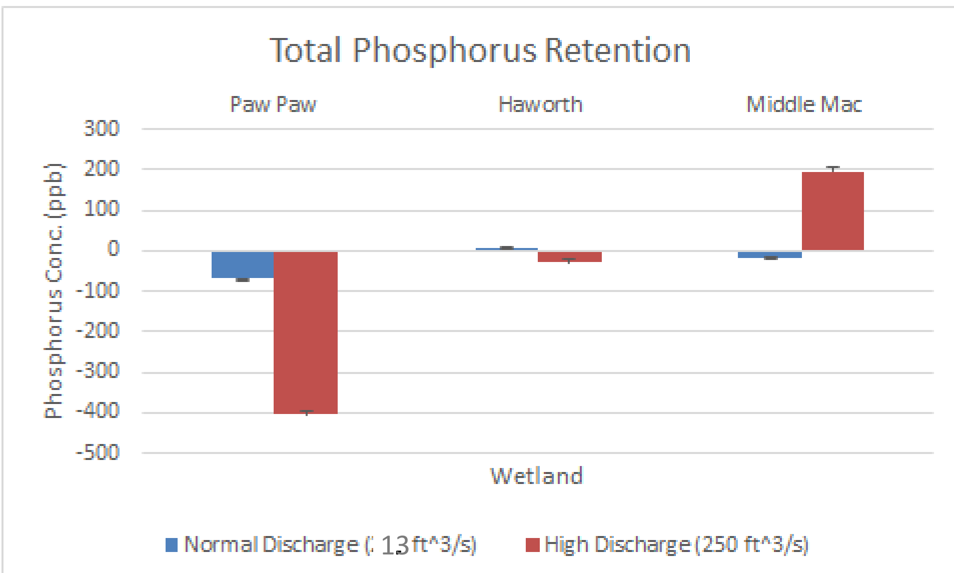

Figure 2 The total concentration of phosphorus changes between low flow and high flow periods with associated error bars.

As seen in Figure 2, the error bars are all relatively the same size and fairly low. Also, form Figure 2, we can see that the average amount of phosphorus in wetlands is higher after a heavy rain event as opposed to before a heavy rain event. Haworth did start off with a positive phosphorus retention, and changed to negative during a high flow, while the opposite happened with Middle Mac.

For the stagnant water/leaf litter data, it is shown in Table 4.

Table 4 The concentration of phosphorus for 2 wetlands where a stagnant water sample was taken, along with their respective standard deviations.

	P Inflow (ppb)	S(P inflow) (ppb)	P Outflow (ppb)	S(P Outflow) (ppb)	Total P Change (ppb)	S(Toal P Change) (ppb)	Total Leaf Liter P Retention (ppb)	S(Leaf Litter)
Stu Visser	32.6	2.4	39.7	2.4	-7.2	3.4	91.9	2.3
Upper Mac	269.9	2.2	124.4	2.3	145.5	3.2	35.4	2.4

In this table, the stagnant water that was collected for Stu Visser showed a higher concentration of phosphorus than in the inflow and outflow with a value of 91.9 ± 2.3 ppb. However, the Upper Mac stagnant water sample had a much lower concentration compared to the inflow and outflow of the wetland, with a value of 35.4 ± 2.4 ppb.

DISCUSSION

To analyze this data, multiple perspectives must be used to see correlations. First, we looked for a connection between the wetlands and the land use prior to the start of the constructed wetland. We were able to find that the wetland with the highest concentration of phosphorus had previous heavy land use. The wetland with the highest total concentration of phosphorus was found in Middle Mac, which used to be an Agricultural field left fallow. Due to the former agricultural use of the Middle Mac area, the environment was contaminated by fertilization, which would explain why there was a high concentration of phosphates. On the other hand, Upper Mac, which used to be an extensively farmed, animal waste disposal and therefore full of organic material, shows high values of phosphorus as well, as seen in Table 1. However, the results of phosphorus retention were opposite for the two wetlands. We believe this is due to the fact that Upper Mac was made with the purpose to sequester the phosphorus, and middle mac was not. We are not entirely sure what this entails, but it is obvious when looking at the data.

Stu Visser and Haworth, the wetlands with the least amount of phosphorus have never have been stressed with pollutants in such a way, which is evident from their low phosphorus concentrations in Tables 4 and 3, respectively. Stu Visser used to be a natural area before it became a constructed wetland and Haworth used to be an old farm field wet meadow before becoming a constructed wetland.

The last wetland, Paw Paw shows relatively high concentrations of phosphorus, as shown in Tables 1 and 3. This area used to be a golf course, where fertilization is likely, but not much of organic material is to be found. Since there is little organic material, this may be the reason why the phosphorus retention is negative.

To see how rainfall affected the wetlands, Tables 2 and 3 and Figure 2 were used. We can see that the average amount of phosphorus in wetlands is higher during a high discharge, because of all the organic material that enters the in- and outflow areas during heavy rain events. The wetlands that show a increase in retention of phosphorus in the outflow during a normal discharge, is presumably due to the longer time that the water spends transiting in the wetland, because there is no flood "pushing" it through. However, Middle Mac seems to be an exception. In one of two trials it shows a more effective retention of Phosphorus during a high discharge, which is not consistent with our other samples. In order to find out why Middle Mac shows this particular behavior in removing Phosphorus, we would have to get more samples over a longer period of time and observe the exact patterns of this precise area. This would also be helpful to discover why Middle Mac, Upper Mac and Haworth occasionally remove Phosphorus at all, since it was found that it is not typical for wetlands to remove Phosphorus in during the fall and winter seasons. This is due to the life cycle and decomposition of plants and subsequently oversaturated wetlands. Once the wetland soils become saturated, the phosphorus may be released from the system. This is supposedly a seasonal dependence and occurs in the late summer, fall, and winter when organic material decomposes and releases phosphorus back into the wetland ecosystem.[1] This addition of Phosphorus becomes clear by looking at the outflow Phosphorus concentration of all the left wetlands in all of the tables and figures where the outflow is higher than the inflow. The trend, however, for wetlands when rainfall occurs, is to model and amplify the data that was collected during a low flow period.

After finding the results of our original questions, we wanted to see if stagnant water with decomposing plant matter would have higher concentrations of phosphorus or not. The leaf litter samples, which we took in Stu Visser as well as in Upper Mac, show opposite results of each other. As seen in Table 4, the phosphorus concentration of the leaf litter sample for Stu Visser was higher than the inflow and outflow concentrations. However, Upper Mac had a lower concentration of phosphorus than what was found in the inflow and the outflow. We believe this to be due to the area where the samples were collected. The Stu Visser sample was collected from a backwater area, that was connected to the wetland and has been sitting there for awhile. This would allow time for the plants to decompose and release phosphorus into the system. For

Upper Mac, the sample was collected from an Oxbow that was most likely created from a recent rain event. This means that there was not a ton of time that the plant matter was sitting in the water and did not decompose as much as the sample from Stu Visser.

Another analysis that was performed was looking at the area around the wetland that drained into it. This is given by Figure 3

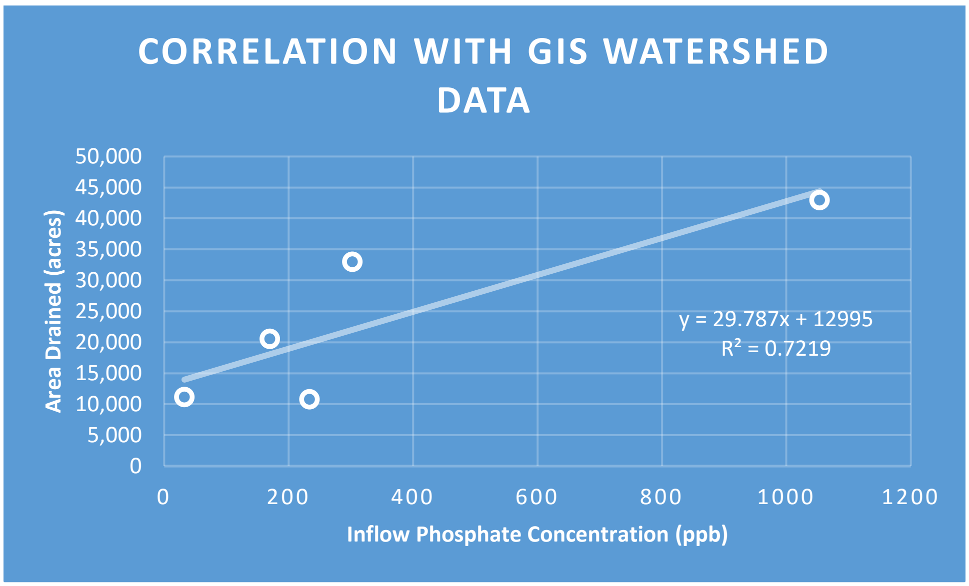

Figure 3 Data of the acres plotted against the inflow concentraion of phosphorus showing a link between the size of the area and how much phosphorus is drained in from that area.

Figure 3 shows that there is a correlation in the size of the area around the wetland, and the phosphorus concentration. This is most likely due to a larger amount of phosphorus being drained into the wetlands from the surrounding land due to all of the plant matter that is decaying and decomposing.

CONCLUSION

For high flow, we saw an increase of what the normal flow showed in the high flow measurements. The leaf litter/stagnant water samples were leaning towards a difference of where the sample was collected and the amount of organic matter that is draining into the system from the surrounding ecosystem. For the duplicate data, we were expecting to see a sequestering of the phosphorus, however, we found that it varied between different wetlands due to a seasonal dependence and what the wetland was constructed for. In order to develop more firm conclusions, we would like to take samples over a year long period of time, since the effectiveness of phosphorus retention depends on the season. We would also like to see the effectiveness of wetland development over the course of five or ten years to see if the the retention of phosphorus increases or decreases. This would make it easier to make comparisons between the different wetlands, too.

In conclusion, we our research proves that phosphorus removal by wetlands does not regularly happen in the fall and winter seasons. We can also see that usually phosphorus is removed more effectively during a low or normal discharge than during a high discharge. By looking at the land use history of each wetland we can discover the tremendous influence of former usage of the surroundings of the area and of the area itself.

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