Phytoremediation of Phosphates and Nitrates in the Lake Macatawa Watershed Using Wetland Plants

Nathan D. Ide, Aaron D. Petersen, Steve J. Rypma
Department of Geological and Environmental Sciences
Hope College, Holland MI 49423

Abstract:

The Lake Macatawa Watershed, like many other watersheds surrounded by agricultural areas, has hypereutrophic characteristics. These characteristics include; high turbidity, high sediment deposition, and high levels of aqueous nutrients, such as phosphate and nitrate. Non-point source agricultural run-off is believed to be the leading cause of these high phosphate and nitrate levels. Phytoremediation is an area of interest in the development of strategies for the prevention and removal of these nutrients from the Lake Macatawa watershed, among others. In this study, hydroponic growth systems were constructed to facilitate the growth of plant samples collected from their natural environment in the Lake Macatawa Watershed. The plants used in this study included the Purple Loosestrife (*Lythrum salicaria*), the common cattail (*Typha sp.*), and a common wetland grass (*Panicum sp.*). The three plant-containing systems, along with a control system containing no plants, were filled with a mixture of vermiculite and perlite growing media, to which a hydroponic nutrient solution was added. The total phosphate and nitrate concentrations were periodically measured using area counts provided by analysis with an Ion Chromatograph. The experiment has shown that naturally occurring wetland plants can be transplanted into a hydroponic growth system, after which the change in phosphate and nitrates can be measured and plotted as a function of time.

Introduction and Background:

The Lake Macatawa Watershed is a 115,000 acre coastal system covering several counties and townships in Western Michigan. In 1971, Lake Macatawa was listed in the publication "Problem Lakes in the United States" (Kettelle and Uttermark, 1971). Today, Lake Macatawa continues to struggle with the problems of nutrient enrichment and hypereutrophicity. Some of the characteristics that define a hypereutrophic lake include high nutrient levels (phosphates and nitrates), visibility of less than one foot due to high turbidity, and a high sediment deposition rate (MDEQ, 1999). High phosphate concentrations in this watershed are believed to be the leading cause for the hypereutrophicity (Stepenuck, personal communication). In a 1997 study, the MDEQ (Michigan Department of Environmental Quality) estimated that every year, approximately 138,500 pounds of phosphates are released into the watershed through point and non-point sources. It was also found that only nine percent of the phosphate discharge came from point sources, leaving the source of the problem mainly attributed to agricultural runoff in regions upstream of the Lake. Phosphate acts as the natural limiting nutrient in plant growth and energy production (Walterhouse, 1998).

Due to the role that aqueous phosphates play in plant physiology, it can be determined that many of the plant species native to this ecosystem are effective as natural removers of aqueous phosphates through their nutrient uptake mechanisms. An experiment was designed to compare phosphate uptake rates between those plants. A comparison of phosphate uptake rates between plants specific to this watershed has never been performed. Data that was collected from this experiment could prove to be useful in natural phosphate removal plans for troubled non-point runoff areas around the watershed, where conventional runoff prevention might not be effective, but phytoremediation remains a possible solution. Although phosphates are considered to be the limiting nutrient for plant and algal growth in Lake Macatawa, nitrate concentrations were also studied because nitrates are a nutrient that is necessary for growth and are actually the limiting reagent for growth in watersheds of other geographical areas. Therefore, the phytoremediation of nitrates from Lake Macatawa may not be necessary, but data on the uptake of nitrates may prove useful for other problem lakes.

Methods:

The first step in the experiment was to do a rough qualitative survey of a site in the Lake Macatawa watershed that has a known high concentration of phosphates. The goal of the survey was to determine the dominant semi-aquatic species in this region of high phosphate concentration. This site chosen was the region where the Black River combines with Lake Macatawa, just East of the River Ave. bridge in Holland, MI. This river delta has significant numbers of semi-aquatic plants and known concentrations of high phosphates (MDEQ 1999). This river delta is also advantageous, because it offers a prime location for the type of phytoremediation that might be shown possible by this experiment. This phytoremediation would consist of finding a plant species that consumes large amounts of phosphates, encouraging it to grow in the region, and periodically harvesting it to permanently remove the phosphates from the river system. This plant matter could then be spread across farmer's fields to further minimize the use of phosphorous.

The second step consisted of removing samples of Purple Loosestrife, *Panicum*, and Cattail from the Black River Delta, which were the three species of plants determined to be the most abundant by visual survey. The plants were rinsed free of residual soil and transplanted into a set of hydroponic growth tubs, after one week of adjustment to the Hope College greenhouse environment (75°C, 45% humidity, and 16 hour light cycle). The plants were weighed upon rinsing, so that the initial weight of the plants would be known.

The hydroponic tubs consisted of large Sterilite® plastic tubs with a sampling tube and air line inserted into them. The sampling tube had a screened-in container on the internal side of the tub, which prevented solids from entering the samples. The air line was inserted and connected to an aquarium pump to ensure that proper aeration was maintained, and that oxygen levels did not drop dangerously low. The tubs were then filled with a dry mixture of vermiculite and perlite hydroponic media in a 1:1 ratio. Liquid growth solutions were prepared using a 3:2:1 mixture of FloraGro®, FloraMicro® and FloraBloom® solutions, which were purchased from General Hydroponics®. The mixture was consistent with that recommended by General Hydroponics® for promoting vegetative growth.

A fourth tub, the control system, was set up identically and measured in the same way as the experimental systems. This acted as a background to account for concentration changes due to evapotranspiration, adsorption onto the growth material, and algal contamination.

The hydroponic systems were all refilled to their original fluid levels, with distilled water, ten hours prior to sampling. This was done to account for evapotranspiration water losses and thereby ensure a consistent volume at all sampling times. The first measurement was taken seven days after the plants were transplanted into the hydroponic systems. All samples were filtered prior to analysis for phosphates and nitrates. This analysis was carried out in duplicate on a Dionex 500 Series Ion Chromatograph [30 mM NaOH @ 1.5 mL/min on a Dionex IonPac AS11-HC 4mm (10-32)]. Concentrations (ppm) were calculated from integrated area count measurements using a Beer's law type calibration plot made with standard phosphate and nitrate solutions.

At the conclusion of the experiment, the final wet weight of the plants was measured, in order to determine how much growth had occurred during the experimental period.

Data and Results:

The Ion Chromatograph provided area counts for nitrates and phosphates in the samples. The two area count values obtained by running each sample in duplicate were averaged and converted to parts per million concentrations using a Beer's law plot produced by plotting area counts measured for various known phosphate and nitrate solutions. Using the changes in concentration of the control system, a correction factor was produced to adjust the other concentrations back up and account for the drop in concentration caused by the algal growth in the tubs. The corrected phosphate and nitrate concentrations are shown below in Table 1.

Day	***Panicum* Phosphate (ppm)**	**Purple Loosestrife Phosphate (ppm)**	**Cattail Phosphate (ppm)**	***Panicum* Nitrate (ppm)**	**Purple Loosestrife Nitrate (ppm)**	**Cattail Nitrate (ppm)**
0	149	79	236	1496	1748	1637
3	109	59	133	1512	1651	1506
10	124	53	122	1644	1774	1768
12	302	302	302	2049	2104	2157
15	232	188	228	1992	1776	2300
18	147	115	166	1900	1945	2145

Table 1. Phosphate and nitrate concentrations in each system during the experiment.

The concentration had dropped to a low enough level that it was not changing very rapidly at the ten day mark, so the systems were drained and refilled as described before, effectively restarting the experiment.

There was no discernible trend in the concentration change of the nitrates over time, so the nitrate data was not analyzed any further. The phosphate data, however, showed a definite decreasing trend, and over the last three data points (days 12-18), the drop appeared to be linear. A linear fit was done to the data, providing correlation coefficients of greater than 0.98, which confirms that it was a linear relationship. Using the slope of the linear fits, a rate of phosphate consumption was calculated. This value was then divided by the final mass of the plants, in order to determine a rate per unit mass per day. The values determined for each plant are shown below in Table 2, along with the correlation coefficient of the linear fit for each plant.

Phosphate Consumption Rate for *Panicum*	**Phosphate Consumption Rate for Cattail**	**Phosphate Consumption Rate for Purple Loosestrife**
7 ppm/lb-day	11 ppm/lb-day	3 ppm/lb-day
$R^2 = 0.09969$	$R^2 = 0.9974$	$R^2 = 0.9842$

Table 2. Phosphate uptake rates for each plant species.

Discussion and Interpretation:

The results indicate that Cattail consumes more phosphate in a day than either *Panicum* or Purple Loosestrife, per pound of plant matter. *Panicum* consumes phosphates twice as fast as the Purple Loosestrife and the Cattail consumes phosphate at about three times the rate of Purple Loosestrife. The rates also appear to be first order with respect to phosphate concentration in the range of 100-300 ppm. The fact that phosphate concentration change became minimal at low concentration seems to hint toward a higher order relationship between concentration and rate, but only further experimentation with more data points could confirm this suspicion.

While these rates can be considered good approximate rates for phosphate uptake, they are still only approximate values. The values are approximate for all of the following reasons. First, there was a large amount of algae that accumulated on the top of each hydroponic system. While the correction factor used during data analysis should have corrected for this problem, the accuracy of the data is negatively affected by the use of such a correction factor, because the algae was probably not present in each system to the same extent. Second, the weight of the plants was measured as a wet weight and without a precision scale, and therefore the weights are not entirely accurate or reproducible. Third and finally, the *Panicum* and Cattail plants both experienced dormancy problems. Due to the collection of the plants during October, the plants had already started to enter their natural dormant stage, thus leading to death of the originally transplanted individuals. The phosphate consumption that did occur in these two plants was due to new growth. Both the Cattails and *Panicum* experienced significant new growth. The presence of residual dead plant matter led to a weight measurement problem, which was remedied by measuring only living weight of the plants.

Conclusions:

The data from this experiment seems to show that the uptake rate for nitrates is not easily measured using a hydroponic system. This could be due to the high concentration of nitrates, production of nitrates by some living species, the slow decrease in nitrate concentration, or some sort of uncontrolled nitrate source affecting the systems. One example of an uncontrolled nitrate source could be the atmosphere. It is understood that lightning can cause oxidation of nitrogen molecules, and thus storm events could alter the concentration of nitrates in the experimental systems, simply due to a change in related atmospheric chemical species. If the atmosphere, by some sort of nitrogen oxidation mechanism, influences the nitrate concentration in the experimental systems, then a controlled atmosphere system might allow for a better study of nitrate uptake by plants.

This inability to measure nitrates is not a significant problem for experiments dealing with lakes of this region. This is because the phosphate concentration has the most significant impact on the rate of growth of undesired algae and plants in the lakes of this area. Nitrate concentration has a minimal effect on this algal growth, because it is not the limiting nutrient.

This experiment has successfully shown that phosphate concentration changes in hydroponic systems can be measured by ion chromatography and that phosphate uptake rates for wetlands plants can be determined from the data. There were some problems with the experiment, mainly with algal infestation and weight measurements, but the experiment shows significant promise for future work. The plant dormancy problem could be eliminated by collecting the plants earlier in the year or by growing them from seeds. Growing the plants from seeds might also eliminate the algae problem, which was probably due to algae that was present on the plants during transplanting. A further improvement could be made by using some type of online measurement technique, which would allow for constant monitoring of the phosphate concentration, production of many more data points, and a better understanding of the phosphate uptake rates for these wetland plants.

This experiment also seems to indicate that phytoremediation of phosphates with wetland plants could be a feasible way to remove phosphates from the watershed, so long as the plants were harvested to keep the phosphates from leaching back out of the dead plant matter. A further study, utilizing the uptake rates of these plants per acre of wetland, would be extremely useful for determining which plants would actually consume the most phosphate in a natural setting.

Based on the data of this experiment, it seems theoretically possible that a multiple-acre plot of Cattails, or other plant species, could be planted in a wetland area and harvested regularly to permanently remove the phosphates from the watershed. The harvested plant matter could then be recycled onto farmland and re-used as fertilizer. This type of technique, if used in the delta of a river, could potentially decrease the amount of phosphate that ever reaches the lake. With rivers like the Black River, which contributes a significant amount of phosphate into Lake Macatawa, this type of technique could prove extremely valuable.

This sort of technique, unlike attempts to limit the phosphates emitted by point and non-point sources, is actually a cure for the problem as opposed to a purely preventative measure. While it would be unwise to curtail efforts aimed at lowering phosphate loading, it would appear that such attempts, in combination with techniques used to actually remove existing phosphates, could provide an extremely effective combination.

Phytoremediation, as a natural way to remove pollutants from the environment, is especially promising in lakes like Lake Macatawa, which have one main source of water flowing into them. Another factor that makes the Lake Macatawa watershed ideal for phytoremediation techniques is that the Black River delta is in a fairly natural state, with minimal development around it. This would cause a limited disturbance to any existing homes and businesses, while also limiting human disturbance to the natural phosphate cleanup effort. Phytoremediation is also cost effective, relatively self-sustaining, non-invasive to the natural system and aesthetically pleasing.

Based on the data from this experiment and all of the reasons stated above, it is the conclusion of this project that phytoremediation of phosphates from the Lake Macatawa watershed is worthy of additional research to determine its potential benefits for the watershed.

References

Bodenbender B., Evans T., Hansen E., Murray K., Netzly D., Peterson J., Stepenuck K. September, 00. Personal Communication.

Breeze, V.G. The Uptake of Phosphate by Plants from Flowing Nutrient Solution. *The Journal of Experimental Botany.* April 1987. Pp. 618-630.

DeKorne, James B. The Hydroponic Hot House : Low-Cost, High-Yield Greenhouse Gardening. New York. 1992.

Foehse, D. Phosphorus Efficiency of Plants. External and Internal P. Requirement and P. Uptake Efficiency of Different Plant Species. *Plant and Soil.* V. 110 no.1 1988. Pp. 101-109

Gardiner, D.T. A Comparison of Methods for Estimating Phosphorus Uptake Kinetics Under Steady-State Conditions. *Journal of Plant Nutrition.* V. 13 no. 9 1990. Pp. 1079-93.

General Hydroponics. Home page. 7 Dec. 2000 <www.genhydro.com>

Granite Hydroponics. Home page. 7 Dec. 2000 <www.granitehydro.com>

Kettelle, M. and P. Uttermark. 1971. Problem Lakes in the United States, University of Wisconsin for U.S. EPA, Project #06010.

Nicholls, Richard. Beginning Hydroponics : Soil-less Gardening : A Beginner's Guide to Growing Vegetables, House Plants, Flowers, and Herbs without Soil. New York. 1990.

Walterhouse, M. 1998. Phosphorus Loading Assessment for Lake Macatawa, 1995-1997. MDEQ, SWQD Report no. MI/DEQ/SWQ-98/015.

Yerokun, Olusegun A. Relating High Soil Test Phosphorus Concentrations to Plant Phosphate Uptake. *Soil Science Society of America Journal.* V. 54 May/June 90. Pp. 796-9