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THE EFFECTS OF MOTOR BOATS ON WATER QUALITY IN SHALLOW LAKES

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A case study was performed to determine if motor boats could accelerate the rate at which eutrophication occurs in shallow lakes. Two lakes were examined and tested for pH, turbidity, and phosphorous concentrations: one with motor boat activity and one without. Results indicate that motor boat activity creates enough disturbance on the bottom sediment to release the stored phosphorous into the overlying water.

Keywords: Phosphorus; natural eutrophication; cultural eutrophication; storage pool; limiting nutrient; pH; turbidity

INTRODUCTION

Lakes provide hours of recreation to swimmers, fishermen, water skiers as well as many others. However, over the years, a lake may be observed to go through unpleasant changes in its physical characteristics. Searching for an explanation as to why this has occurred, it is natural to look towards the increased activity on the lake, focusing mainly on motor boats. However, even without any human influence a lake will naturally go through these changes if given enough time. The process of increased algae growth, which leads to a decrease in water clarity, unattractive odor, poor taste, and depletion in dissolved oxygen is a result of *eutrophication*. It is well known that eutrophication may have several adverse ecological and economical effects.[1] The question is whether the increased use of motor boats on the lake is acting as a catalyst.

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TABLE I Effective Mixing Depth by Engine Size

HORSEPOWER	*MIXING DEPTH (m)*
10	1.8
28	3.0
50	4.6

In a lake ecosystem that is generally rich in nutrients, particularly phosphorus, the excess phosphorus which has not yet been assimilated is stored in the form of polyphosphates which have been found to comprise of up to 20% of the dry cell weight.[2,3] About 90–95% of the phosphorus entering the lake is accumulated in the top layer of the sediment.[4] A significant portion of this is not readily available for uptake by algae, but the mixing of the sediment would release a considerable amount which would be available for assimilation and utilization in the eutrophication process. Man-made mixing processes include swimming, motor boat activity, and other artificial mixing. The majority of the mixing can be related to motor boat activity under the following conditions: the lake has considerably high motor boat activity; it is considered shallow (less than 10 m); and it has considerable resistance to wind and pressure changes. Table I illustrates the maximum depth at which mixing occurs for varied horsepower motor boat engines.[5] Todays' engine sizes are generally much larger for water ski and speed boats than shown in Table I. They can reach up to 300 horsepower in which their mixing depth would increase accordingly.

The following case study examines two shallow lakes that are similar in physical characteristics, except that one has motor boat activity while the other does not, to determine the effects that motor boats have on water quality and ultimately the rate at which eutrophication is occurring. The parameters measured and compared include pH, turbidity, and phosphorous concentrations.

EXPERIMENTAL METHODS AND ANALYTICAL PROCEDURES

To obtain meaningful results it was important to select lakes that have little or no interference from any outside sources of pollution. Both lakes selected are located in the Whiteshell Provincial Park in Manitoba, Canada. There are no known point sources of pollution entering either lake. These lakes are also similar in surrounding geology, vegetation, lake depths and temperatures. This ensures that all influencing factors on the lakes are consistent with each other, including non-point sources of pollution, except for the boat traffic.

Brereton Lake was selected as the lake with motor boat activity. It is approximately 5.5 kilometers long and 2.6 kilometers wide with an average depth of 3.5 meters.[6] It is very active in the summer months with a water-ski club, campground, and two resorts that commonly attract large numbers of fishermen.

Lyons Lake does not allow any motor boats on it. It is approximately 1.1 kilometers long and 1.0 kilometers wide with an average depth of 4.2 meters. The only activities on it include some shoreline fisherman as well as those who travel by canoe or row boat.

For the case study four sites were chosen from each lake where samples were retrieved from approximately 0.5 meters below the surface to avoid floating debris or surface contamination. A detailed description of all sites is available elsewhere.[7] The first set of samples (*spring samples*) were taken on May 28, 1995 between the hours of 11:00 am and 1:00 pm. The second set (*fall samples*) were retrieved on September 4, 1995 between 11:00 am and 2:00 pm. The spring samples were obtained from each lake before much motor boat activity had occurred on Brereton. The fall samples were retrieved after an entire summer of motor boat traffic on Brereton had gone by. These samples were taken from the same locations as the spring samples and tested in a similar manner.

The tests performed for turbidity (Hach Turbidimeter 16800), pH (Fisher Accumet pH Meter 825 MP), orthophosphorus (PO_4^{-3}), and total phosphorus (TP), followed procedures outlined in Reference.[8] The Automated Stannous Chloride Method was used for the phosphorus concentrations.

RESULTS AND DISCUSSION

The differences in water quality that occurred over the summer were determined by comparing the two sets of results for each lake. Using the changes that occurred in Lyons Lake as a base for comparison, it was possible to determine what extent of the changes had occurred naturally in Brereton Lake and which may have been a direct result of motor boat activity.

a. Visual Examination

A visual examination revealed that some distinct differences existed between the spring and fall in the two lakes. The most noticeable difference in Lyons Lake was approximately 2 feet of growth of the submerged weeds. There was very little surface algae or increase in odor in this lake along with a predictable increase in water temperature. Brereton Lake had noticeably larger changes in the appearance. The primary difference was that there was significant amounts of surface algae during the period of the fall sample as compared to the spring. There was minor detectable difference in the odor and a predictable increase in water temperature.

b. pH Levels

The main purpose of the pH testing was to solidify the similarities between the two lakes. The results for the pH tests are illustrated in Table II. The pH levels rise approximately by the same amount in each lake throughout the summer which re-enforces the similarities between them. An increase in pH is perceived as an indicator that there has been an increase in algae growth due to the decrease in carbon dioxide in the water. This phenomenon will be further discussed in the following subsections.

c. Turbidity

The turbidity results are listed in Table II. It is clear that the values for turbidity are generally higher in Brereton Lake in both the spring and fall. The more important observation however, is that the values in Brereton Lake increased throughout the summer months. An explanation for this is that the motor boat activity disturbed the bottom sediment causing small particles to become suspended, thereby reducing the clarity of the water. Also, an increase in algae growth, which corresponds to the eutrophication process, adds to the turbidity in the lake. Finally, it was observed that the turbidity in Lyons Lake actually

TABLE II pH and Turbidity of Water in Sample Lakes in Spring and Fall

SAMPLE STATION (SPRING)	*pH LEVELS*	*TURBIDITY (NTU)*	*SAMPLE STATION (FALL)*	*pH LEVELS*	*TURBIDITY (NTU)*
BRERETON			BRERETON		
1	6.90	2.5	1	7.25	3.6
2	6.69	2.9	2	6.02	2.5
3	7.00	2.6	3	7.13	2.7
4	6.71	3.0	4	7.00	3.2
LYONS			LYONS		
5	7.76	1.9	5	8.24	0.52
6	8.03	1.8	6	8.18	0.85
7	7.51	2.1	7	8.28	1.9
8	7.49	1.6	8	8.72	1.7

decreased throughout the summer months. It is probable that the spring melt runoff was the cause of some of the small suspended particles in the lake that require time to settle.

d. Phosphorus

Phosphorus concentrations can be directly used to determine the rate at which eutrophication is occurring over a given time period. The two types of phosphorus analyzed include orthophosphorus and total phosphorus. However, due to the almost identical patterns established between these two parameters as well as the fact that orthophosphorus accounted for 70% to 90% of the total phosphorus measured,[7] the word *phosphorus* will refer to *orthophosphorus* from this point forward. Figures 1 and 2 illustrate the results of the phosphorus testing on the two lakes in the spring and fall.

The first notable observation is that, with a few exceptions, the phosphorus concentrations increased significantly throughout the summer in Brereton Lake. However, values for Lyons Lake actually decreased.

These trends are not totally unexpected. If higher concentrations are directly related to eutrophication, one might initially expect the phosphorus values to increase throughout the summer in both lakes. However, the lower fall values in Lyons Lake may be due to stratification. This is possible because there are no motor boats or other human activities as well as very little wind disturbance due to its size and tree cover to endorse mixing. During the early

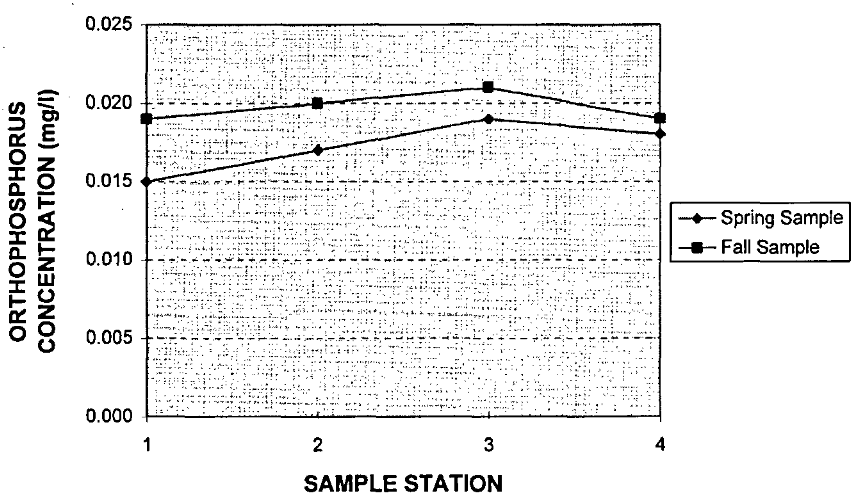

FIGURE 1 Orthophosphorus Concentrations in Brereton Lake for Spring and Fall.

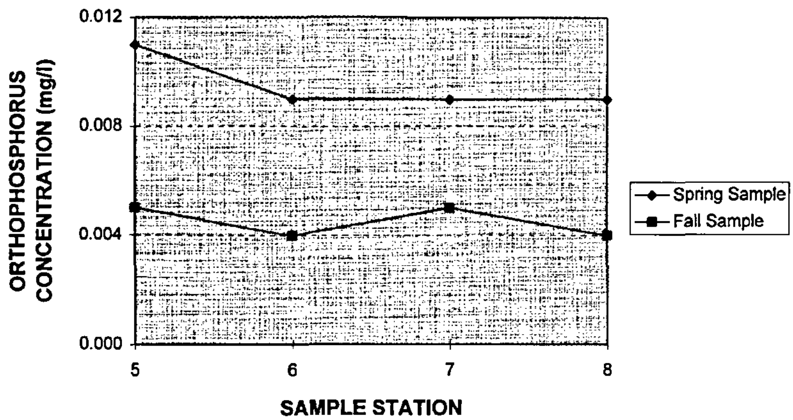

FIGURE 2 Orthophosphorus Concentrations in Lyons Lake for Spring and Fall.

summer months in a stratified lake, an increase in temperature and sunlight leads to an increase in biomass growth and depletion in dissolved nutrients in the upper layer (epilimnion) of the lake. Later in the summer, plant growth and reproduction slow down and as plants and other aquatic life begin to die they release nutrients which eventually sink to the bottom of the lake (sediment). With limited mixing, stratification prevents these nutrients from re-entering the water column through resuspension. However, in the fall and spring months differential temperature changes in the epilimnion and the hypolimnion cause them to rotate positions. This, in turn, mixes the water and disturbs the bottom sediment releasing the nutrients to the overlying water and creating suitable conditions for the start of the next annual cycle. This can explain the relatively high concentration levels in the spring and their decrease throughout the summer.

Alternately, the same behavior should not be expected in Brereton Lake for several reasons. Even though Brereton is also well protected, it is larger than Lyons Lake and therefore more susceptible to wind disturbances which may result in some minimal mixing. However, the major cause of mixing is the direct result of motor boat activity.

When levels of inorganic phosphorus (orthophosphorus) exceed 0.01 mg/l, nuisance conditions can be expected. Concentrations between 0.02 mg/l and 0.09 mg/l in the lake can be considered to create optimal conditions for algae and biomass growth.[9] Based on these concentration values, it is clear that Brereton Lake contains high enough soluble phosphorus to cause a nuisance with algae growth. Furthermore, with heavy boat traffic throughout the summer, phosphorus concentrations exceed the minimum level for optimal biomass and algae growth.

CONCLUSION

It was determined that motor boat activity had sufficient impacts on Brereton Lake to disrupt the bottom sediment and release phosphorus and other nutrients into the overlying water. In a lake without motor boat activity, such as Lyons Lake, the phosphorus remains in the upper layers of the bottom sediment, but is not released in significant amounts consistently throughout the summer to have measurable effects, due to stratification.

The release of phosphorus is an important water quality issue since phosphorus is often the limiting nutrient in the process of eutrophication. With motor boat activity, Brereton Lake may have prematurely reached the early stages of eutrophication as the current concentrations of phosphorus are within the range of optimal algae and biomass growth.

Acknowledgments

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References

[1] H. Klapper (1991). *Control of Eutrophication in Inland Waters*, Ellis Harwood Ltd. Chichester, West Sussex, England.
[2] B. H. Sellers and H. R. Markland (1987). *Decaying Lakes: The Origins and Controls of Cultural Eutrophication*, John Wiley & Sons Ltd., Chichester, West Sussex England.
[3] Y. A. Yousef, W. M. McLellon and H. H. Zebuth (1979). Changes in Phosphorus Concentrations Due to Mixing by Motor Boats in Shallow Lakes, *Water Research*, **14**, 841-852.
[4] Modelling and Managing Shallow Lake Eutrophication: With Aplications to Lake Balaton, International Institute For Applied Systems Analysis, Laxenburg, Austria, (1986).
[5] D. O. Wright and K. J. Wagner (1991). Power Boats in Shallow Lakes: A Brief Summary of Literature and Experience on Lake Mohegan (NY), *Lake Line*, **TT(4)**, December, 8-12.
[6] Water Quality in the Whiteshell Provincial Park: Brereton Lake, Manitoba Environment, Lakes and Rivers Water Quality Management, Winnipeg, Manitoba, Canada, (1995).
[7] D. N. Nedohin (1996). The Effects of Motor Boats on Water Quality in Shallow Lakes, B.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada.
[8] American Public Health Association (APHA), Standard Methods for the Examination of Water and Wastewater, 18^{th} ed., Washington, D.C. (1992).
[9] R. Pick (1967). Shoal Lake Survey, The Metropolitan Corporation of Greater Winnipeg, Waterworks and Waste Disposal Division.