# Characterization of Phosphorus Sources in the Mattatall Lake Watershed

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**Prepared by:**
Centre for Water Resources Studies
Dalhousie University
1360 Barrington St., D514
Halifax, Nova Scotia
B3H 4R2

waterstudies
CENTRE FOR WATER RESOURCES STUDIES | DALHOUSIE UNIVERSITY

**The report *Characterization of Phosphorus Sources in the Mattatall Lake Watershed* was prepared by Rob Jamieson, Richard Scott, Lindsay Johnston, Meggie Letman, and Jenny Hayward at the Centre for Water Resources Studies (CWRS) at Dalhousie University.**

**Further information in regards to this document may be obtained by contacting:**

**Centre for Water Resources Studies**
**Dalhousie University**
**1360 Barrington St. D514**
**Halifax, NS**
**B3H 4R2**
**902.494.6070**
**water@dal.ca**

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# Executive Summary

**Study Objectives**

This study focused on Mattatall Lake (45°41'45"N; 63°28'18"W), which is a 120 hectare (ha) headwater lake located on the boundary of Cumberland and Colchester counties in rural Nova Scotia. Cyanobacteria blooms have been observed in the lake during the summer and early fall of 2014, 2015, and 2016. Phosphorus (P) is widely considered to be the key nutrient which influences trophic state and cyanobacteria bloom risk within freshwater ecosystems. The primary objective of this study was to quantitatively characterize the primary sources of P within the Mattatall Lake Watershed. This information was then used to identify targeted watershed and lake management strategies that could be employed to reduce P concentrations in Mattatall Lake.

**Scope of Work and Methods**

The study involved two main components: (i) a water quality monitoring program, and (ii) a P watershed modeling analysis. The water quality monitoring program was initiated in late November 2016 and continued until late October 2017. During this time period the lake was sampled on a monthly basis during the ice free period, with more intensive bi-weekly sampling conducted between July and October 2017. The lake was also sampled in March 2017 when the lake was ice covered. The monitoring program was designed to: (i) determine the average annual concentration of total P (TP) in the lake, (ii) evaluate the current trophic state of the lake, and (iii) quantify the magnitude of internal loading of P from lake sediments.

A watershed modeling analysis was conducted in conjunction with the monitoring program. The modeling analysis involved the application of an adapted version of the Nova Scotia Phosphorus Loading Model to predict average annual TP concentrations in the lake as a function of land-use and hydrology. The model was validated against the average annual TP concentrations measured during the 2016-2017 monitoring program. Once validated, the model was then used to assess how TP concentrations in the lake have changed since the watershed was relatively undeveloped (*i.e.*, 1985). The modeling results were also used to estimate the relative contribution of different land uses, and internal sources, to TP concentrations in the lake.

**Lake and Watershed Characteristics**

Mattatall Lake consists of three distinct basins that are connected in series. Mean water depths in the three basins range from 3.2 to 4.4 m; however, there are several areas of the lake that are deeper than 5 m. The deepest section of the lake system is located in Basin 1 (Headwater Basin), where a maximum depth of 11 m was observed. Weak thermal stratification during the summer of 2017 was observed at lake stations where depths were greater than 5 m, with stronger, persistent stratification occurring in the 11 m deep station located in Basin 1. During periods of thermal stratification the bottom layers of these sections of the lake were anoxic (dissolved oxygen concentrations <1 mg·L$^{-1}$), which is a prerequisite for P release from lake sediments.

Flushing rate has a large influence on the sensitivity of a lake to disturbances. The flushing rates for the three individual basins in Mattatall Lake ranged from 0.7 yr$^{-1}$ in Basin 1 (Headwater) to 4.6 yr$^{-1}$ in Basin 3. The low flushing rate of Basin 1 would make this area of lake particularly sensitive to changes in P loading. The development of the watershed since 1985 was assessed using current and historical satellite imagery and aerial photography. Significant changes have occurred in the watershed during this 32 year period. In particular, approximately 280 ha of forested land in the watershed has been clear cut at some point in time, and there are now 117 residential dwellings in the watershed, the majority being seasonally-used lake front cottages. Both of these land-uses have the potential to increase P loading to the lake.

**Water Quality Results**

The average annual measured TP concentrations were 9 µg·L$^{-1}$ in all three basins. These concentrations of TP would indicate the lake is just below the boundary between an oligotrophic and mesotrophic ecosystem. Average chlorophyll *a* concentrations ranged were 4.1 µg·L$^{-1}$ in Basin 1, 2.9 µg·L$^{-1}$ in Basin 2, and 3.3 µg·L$^{-1}$ in Basin 3, indicating the lake is mesotrophic. An algae bloom was not observed in 2017. Increases in TP concentrations in Basin 1 were observed to occur after turnover events in the spring and early fall. A focused sampling program was also initiated in July 2017 to investigate internal loading of P in the sections of the lake that are deeper than 5 m. Large releases of soluble reactive P from lake sediments were observed at the 11 m deep station in Basin 1. Mixing of this P throughout Basin 1 during a late-summer turnover event was linked to the increase in average TP concentrations at that time.

**Modeling Results**

Comparison of model results against measured TP concentrations during the 2016-2017 monitoring period demonstrated that the model performance was acceptable, providing predictions that were within 12 – 17% of measured concentrations. The outputs from the modeling analysis indicated that the cumulative land use change in the watershed during the time period 1985-2017 would have increased mean annual TP concentrations in the lake by 1 – 2 µg·L$^{-1}$.

The largest sources of P within the watershed are runoff export from natural landscapes and atmospheric deposition. Anthropogenic sources of P in the watershed include runoff export from roads and residential lots, increased runoff export from areas of the watershed that have been clearcut, and P loading from septic systems. Depending on the basin, roads were estimated to provide between 6 – 10 % of the total TP load, residential lots provided between 1.4 – 5 %, clearcuts provided between 0 – 6.8%, and septic systems provided between 1.6 – 10.6 % for present day conditions.

**Potential Causes of Previous Algae Blooms**

Although an algae bloom did not occur in 2017, the study results have provided information on factors that could have contributed to blooms in previous years. The modeling analysis has indicated that small increases in average annual TP concentrations in the lake have likely occurred in the past 32 years. These concentration increases would probably not be large enough to trigger cyanobacteria blooms, but would generally stimulate increased level of primary productivity (plant and algae growth) in the lake. This additional biomass would settle to the bottom of the lake and increase sediment oxygen demand. Thus, this would increase the extent and duration of anoxia in the bottom layers of the lake. As a result, increased levels of soluble reactive P would be released from lake sediments, and could become available to algae when mixed into the upper layers of the lake. This process would be influenced by inter-annual variability in climate, hydrology and potentially, boating activities on the lake. Basin 1 would be a likely trigger point for algae blooms due to the low flushing rate and presence of an 11 m deep zone that was observed to produce significant internal P loads. Observed increases in air temperatures in the region over the past two decades could also be accelerating internal loading processes. Further monitoring is required to confirm these hypotheses.

**Recommendations for Lake Management**

The report discusses several recommendations for continued management and restoration of the lake. Briefly, key recommendations include:

1. Continuation of the monitoring program into 2017-2018 with a specific focus on tracking internal P loading processes in the lake.

2. A targeted education and awareness program for cottage and homeowners focused on P removal in septic systems, septic system life spans, and potential alternative systems that could provide long-term P removal.

3. Engagement of forestry companies that are active in the watershed to make them aware of the sensitivity of the lake to disturbance, and to identify additional best management practices that could be employed to limit impacts. This should be conducted in collaboration with the Nova Scotia Department of Natural Resources and Nova Scotia Environment. Due to uncertainty associated with the effects of glyphosate on freshwater algae, future spraying of this herbicide should be minimized. If glyphosate is applied in the watershed a monitoring program should be established to assess if the application impacts water quality and algae communities in the lake.

4. Continuation and expansion of efforts to limit the resuspension of sediment and associated P from boating activities.

5. It is premature to consider the application of an in-lake restoration technology. However, if continued monitoring demonstrates that internal P loading from localized areas of the lake is a trigger for cyanobacteria blooms, an in-lake treatment technology may be required. In-lake technologies and methods that could be used to reduce internal P loading should be explored, specifically the use of active capping technologies such as Phoslock.

6. Although the focus of this study was Mattatall Lake, the study has highlighted key factors (*e.g.*, flushing rate, morphological characteristics, *etc.*) that influence the sensitivity of a lake to watershed disturbances. As rural landscapes will only continue to be increasingly developed it is critical that sensitive lakes are identified, and protected through enhanced watershed management. Proactive approaches to lake management will undoubtedly be more cost-effective than reactive measures. Global processes, such as climate change, also have the potential to increase the sensitivity of freshwater ecosystems to changes in nutrient loading, further highlighting the need for enhanced land-use planning to control nutrient sources.