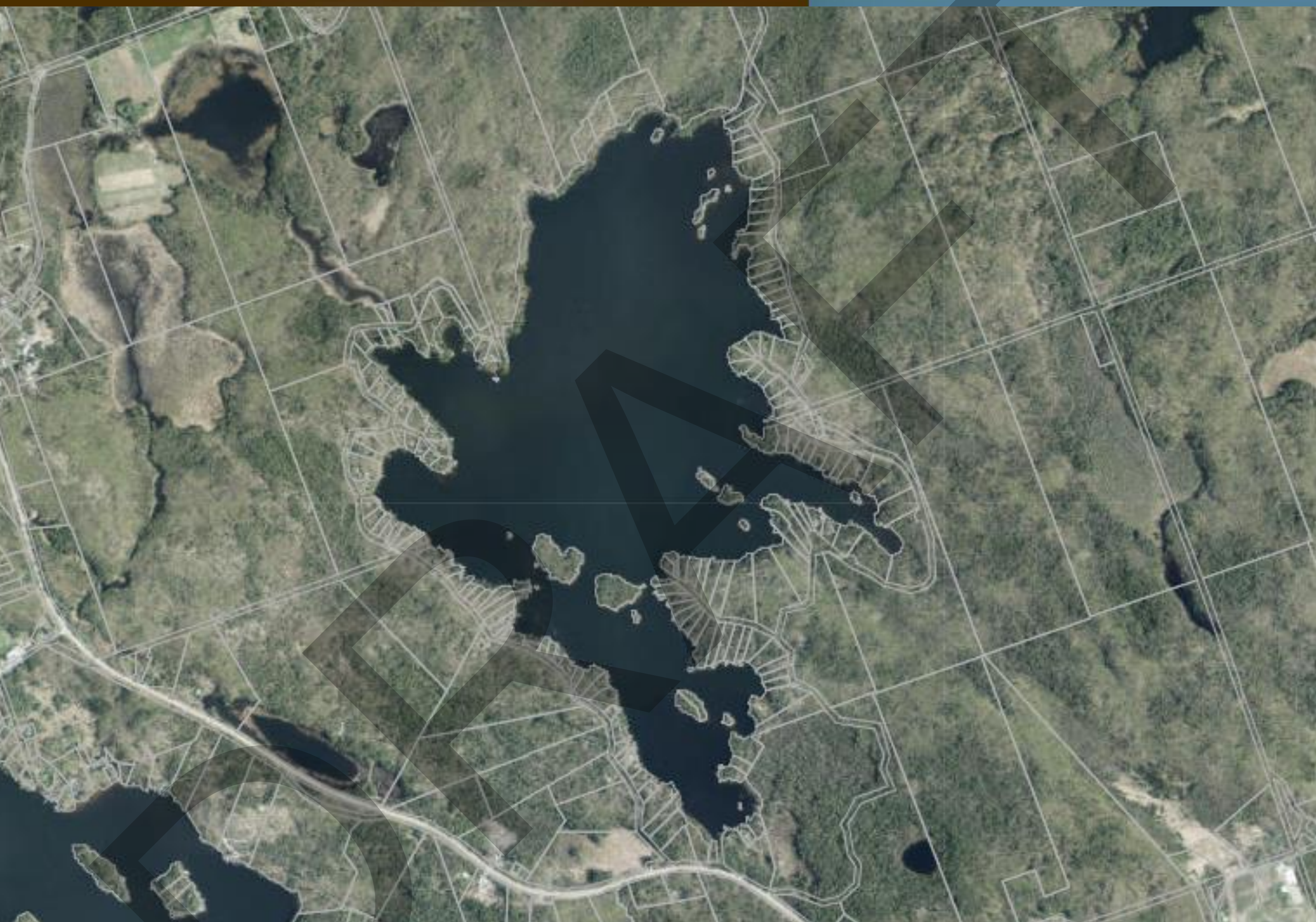
RIVERSTONE
ENVIRONMENTAL SOLUTIONS INC.

Causation Study
Leonard Lake
District Municipality of Muskoka

November 2022



RIVERSTONE
ENVIRONMENTAL SOLUTIONS INC.

December 8, 2022
RS# 2020-208

The District Municipality of Muskoka
70 Pine Street
Bracebridge, ON

SUBJECT: Causation Study, Leonard Lake

RiverStone Environmental Solutions Inc. is pleased to submit our Causation Study Report summarizing our investigations into the potential cause(s) of historical cyanobacterial blooms on Leonard Lake in the District Municipality of Muskoka (DMM).

RiverStone conducted a detailed examination of the potential factors which may be contributing to the occurrence of algal blooms on Leonard Lake, including data collection in the field, analyses of the results, and an assessment of potential causative factors through historical data. As previously stated by Hutchinson Environmental Sciences Ltd. in their pilot Causation Study on Peninsula Lake, it is difficult to determine causation based on occasional bloom events in nutrient poor lakes, particularly without extensive baseline monitoring data which can be used as a control in statistical analyses to identify changes in the environment which may be correlated with or contributing to an increase in observed algal blooms. Although there has been historical monitoring of several potential contributing factors by a variety of agencies and organizations, our investigations of the potential causes or contributing factors to algal blooms on Leonard Lake where hindered by variability in the collection methods and laboratory analysis that have occurred both across time and between organizations. As part of the discussion, RiverStone has included recommendations for a sampling program moving forward that will work to focus on key variables, consistent sampling sites (and times) and consistency in laboratory analysis that will facilitate the analysis of future studies of this nature and will help to equip the DMM and members of the Leonard Lake Stakeholders Association (LLSA) to make informed decisions regarding the contributing factors of algal blooms on the lake.

Leonard Lake is an oligotrophic lake with no evidence of change in nutrients or dissolved oxygen prior to the onset of the frequent bloom events which, based on LLSA observations, began to occur in 2017. There are seasonal fluctuations in phosphorus and brief periods of high phosphorus concentrations in the water column, particularly during the summer months of 2017, in the southern basin, but water chemistry data suggests that consistent water quality has been documented in Leonard Lake for several decades prior to the onset of bloom events that have occurred in recent years. Nutrient levels therefore provide little insight into the shift in frequency and severity of bloom formation on Leonard

Lake. Without credible statistical links to changes in water quality, wind, or other physio-chemical data, the evidence collected during the completion of this report suggest that the blooms reported by the LLSA between 2017- 2022, and those observed by RiverStone during the study period, were likely triggered by climatic conditions that created a warm period with little mixing of the water column which created favourable conditions for the proliferation of harmful algal bloom forming species. Additionally, shifts in food web structure and interactions and the competitive advantage of *Dolichospermum* species, which is a primary species of concern in Leonard Lake, over other less harmful species existing in the water column, suggest that biotic factors may also be an important component in the causation of algal blooms in Leonard Lake. Finally, the physical characteristics of Leonard Lake in the southern portion contributes to the susceptibility of this area to bloom formation.

Given our review of data pertaining to Leonard Lake and the results of our analyses, we have included recommendations for ongoing monitoring of Leonard Lake as well as for future studies that may offer refined resolution of the conclusions outlined in this report.

Please contact us if there are any questions regarding the report, or if further information is required.

Best regards,

RiverStone Environmental Solutions Inc.

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NON-TECHNICAL SUMMARY

Type of Study	**Date**
Causation Study – Leonard Lake	December 13, 2022

Report Summary

The purpose of this study was to complete a Causation Study to collect data pertaining to the documented algae blooms on Leonard Lake. As part of completing this assignment, RiverStone conducted a literature review exercise focused on causes of algal bloom and analyses of contributed data from The District Municipality of Muskoka, the Leonard Lake Stakeholders Association (LLSA), the Ministry of Environment, Conservation and Parks (MECP), the Lake Partner Program (LPP) in addition to data which RiverStone collected during 3 site visits conducted during September, October and November of 2021 following a MECP confirmed bloom in the southwest bay of Leonard Lake.

The findings of this report suggest that climate is likely a primary contributing factor to the onset of algal blooms in Leonard Lake. Climatic changes and conditions are broader than simply changes in water and air temperature. Changes reported by members of the LLSA such as changes in zooplankton and fish abundance can also be attributed to changes in abiotic factors that are driven by climate. Based on an extensive literature review, RiverStone additionally suggests that ecosystem interactions including interspecific competition between algal species, changes in available nutrients in the water column associated with changes in species assemblages, and the introduction of invasive species shifting plankton dynamics may also have contributed to the observed changes in water quality reported by LLSA members. Finally, the physical structure of the southern areas of Leonard Lake make those areas more susceptible to bloom events due to past “priming of the water column” by bloom causing species, shallow waters that are easily stratified and higher levels of stagnation in these areas due to reduced fetch and consequently wind and wave action which is not able to mix the water to disperse or restore nutrients.

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1 PROJECT BACKGROUND

RiverStone Environmental Solutions Inc. (hereafter RiverStone) was retained by The District Municipality of Muskoka (hereafter DMM) to undertake a Causation Study for Leonard Lake in response to recent cyanobacteria blooms and in response to the updated water quality policies in the Muskoka Official Plan (June 2019). The Leonard Lake Causation Study is one of several studies being conducted on behalf of the DMM following the completion of the "Peninsula Lake Pilot Causation Study" by Hutchinson Environmental Sciences Ltd. (hereafter HESL) in 2020. The Leonard Lake Stakeholders Association (hereafter LLSA) has contributed their considerable data and recorded observations, as well as the expert reports that they have commissioned for Leonard Lake. RiverStone has incorporated these data into the report wherever possible. The Peninsula Lake Pilot Study (Pilot Study) attempted to determine if clear causation of algal blooms could be confirmed using long-term data on water quality, climate, and algal history, using statistical relationships. This study has used the Pilot Study as a guide to inform the work completed on Leonard Lake. Understanding the causes of cyanobacterial blooms in freshwater lakes is essential due to their ability to dominate summer phytoplankton assemblages, possible toxicity, negative impacts on aquatic food webs (Paerl et al. 1998) and recreational enjoyment of the lake waterfront.

Leonard Lake is a relatively small oligotrophic lake, with low nutrient levels, clear water, and a moderately steep shoreline. Leonard Lake has a surface area of 1.95 km^2, a maximum depth of 18.3m and a mean depth of 6.8m (Ministry of Natural Resources and Forestry (MNRF) 2015). It is also considered a headwater lake that drains a watershed approximately 4.29 km^2 in area, flowing downstream directly into Lake Muskoka. The Ontario Water Resources Commission (OWRC) describes the lake as "moderately enriched" dating back to 1971 and the MNRF has classified shoreline development as moderately dense, shoreline residential.

Ongoing sampling efforts by the Ministry of Environment, Conservation and Parks (MECP) between 1979 and 2016 did not detect any change in overall Total Phosphorus (TP) concentrations, however a gradual decline in water clarity and an increase in dissolved organic carbon were noted (Ingram and Patterson 2015, Watson and Kling 2017). Previous work by HESL (2016) suggested that Leonard Lake should be classified as a lake requiring normal protection from further lot development.

The MECP has confirmed a blue-green algal bloom (cyanobacteria) most recently in October 2022 on the western shore of Leonard Lake. The recent algal bloom is consistent with observations of lake residents who reported thick algal mats in the southwest area of the lake (Watson and Kling 2017) during previous bloom events. Previous blooms were also identified along the southeast shoreline in November of 2020. Samples collected and submitted to the MECP for analysis were identified as containing *Anabaena* (aka *Dolischospermum sp.*) as well as cryptophytes (*Cryptomonas sp.*) and diatoms (*Asterionella sp.*) in levels too low to contribute to a bloom. The

LLSA suggests that at least one bloom event has been occurring annually since 2017, some years with multiple blooms occurring (**Table 1**).

Table 1. Algae Bloom History, Leonard Lake

Date	Location	MECP Confirmed	Health Advisory	Primary Species
Sept 2017	Northwest Shore	Report not available		*Dolichospermum sp.* (few with akinetes)
Sept 2017	South Bay	Report not available		*Dolichospermum sp.*
Sept 2017	North End, West Bay	Report not available		*Dolichospermum sp.*
Aug 2018	Southern Bay	Remnants of bloom	No	Blue Green Algae, *Dolichospermum sp.*
Sept/Oct. 2018	Southwest Bay	**Yes**	**Yes**	*Dolichospermum sp.*
Aug 2019	South Bay	No	No	Test + coliform and E. coli, *Dolichosperm sp*
May 2020	Multiple locations	No	No	Diatoms, *Dinobryon*, *Dolichospermum* sp
Nov 2020	Southeast side	**Yes**	**Yes**	*Dolichospermum sp.*
Sept 2021	Southwest Bay	**Yes**		*Dolichospermum sp.*
Oct 2022	Western Shore	**Yes**	**Yes**	*Dolichospermum sp.*

2 FIELD COLLECTIONS

2.1 Overview and Methods

As part of the Causation Study and because of an observed algae bloom, RiverStone conducted a monitoring program throughout the summer/fall of 2021. Sampling began in September and consisted of three sampling events occurring on September 9th, October 6th and November 26th. During each sampling event, water samples were collected at two sites (Station 1 and Station 2 – **Figure 1**), representing the main portion of the lake and the southern bay. Duplicate water samples were collected using a Van Dorn sampler at the surface and immediately above the lake bottom. Water samples were submitted to the Dorset Environmental Science Centre (MECP) laboratory for analysis of low-level total phosphorus (TP). A multi-meter (YSI) was used to collect temperature and dissolved oxygen measurements in one meter intervals from the lake surface to the bottom of the water column. Field collections were completed by A. Shaw (Senior Ecologist/ Principal), T. Robinson (Aquatic Ecologist), and J. Gauthier (Environmental Technician).

3 LITERATURE REVIEW

3.1 Ecology of Algal Blooms

Cyanobacteria (Blue-green algae) are widespread in aquatic environments globally. To date, toxic cyanobacteria have been reported in at least twenty-seven countries and have been documented on all continents globally, including Antarctica (Newcombe et al. 2010). Cyanobacteria species are varied in their size, shape and life history and can occur in free floating forms within the water column, as groups or colonies, can be found attached to rocks or within the substrate often in a dormant form that can survive for years in a variety of conditions (Whitton and Potts 2000). When conditions become favorable, cyanobacteria can accumulate causing floating surface scums and coloring of the water column (Newcombe et al. 2010). Cyanobacteria are also known to produce toxins which have been shown to be hazardous for humans, animals and aquatic ecosystems (Gunn et al. 1992; Mez et al. 1997, 1998; Baker et al. 2001; Izaguirre et al. 2007). The term harmful algal bloom (HAB) is used to describe any ecosystem-disrupting bloom (Mitra and Flynn 2006) although there can be some debate as to at what level a bloom can be considered ecosystem-disrupting.

The mechanisms through which algae blooms occur are variable and depend on a variety of factors related to lake specific biotic and abiotic factors. For many lakes, phosphorus has been reported as the primary limiting nutrient, particularly in oligotrophic lakes, where in some regions light can penetrate, and therefore algae can photosynthesize in depths up to 13 m (El-Serehy et al. 2018a), suggesting that blooms can occur throughout the water column in nutrient poor lakes as opposed to being more limited by light penetration in more nutrient rich lakes. The growth of cyanobacteria is thought to be favored by high nutrient levels, particularly phosphorus, in combination with other physical conditions which include high temperature, elevated levels of light and thermal stratification. The interactions of these factors however are not well documented (Newcombe et al. 2010). Generally, algal blooms tend to occur when the accumulation of biomass exceeds the capacity for dispersal through biological and/or physical processes (Mitra and Flynn 2006). Nuisance algal blooms are frequently reported in eutrophic and hypereutropic systems but have been considered relatively rare in oligotrophic systems which typically exhibit clear water, low productivity and no (or infrequent) algal blooms (Carey et al. 2008; El-Serehy et al. 2018b). In addition to specific nutrient and physiochemical parameters, recent paleolimnological analyses have linked climate change with the increase of harmful blue-green algal (cyanobacterial) blooms (HABs) even with no known addition of limiting nutrients (Smol 2019), which is consistent with increasing reports of cyanobacteria blooms occurring in oligotrophic lakes within Ontario, the northeastern region of the United States (Carey et al. 2008) and globally (Favot et al. 2019; Cocquyt et al. 2021).

Generally, population increases in cyanobacteria species occur either through recruitment from sediment resting stages or division in the water column (Wetzel 2001). Recruitment may encourage bloom formation and understanding recruitment dynamics may therefore be useful in predicting and managing cyanobacterial blooms (Carey et al. 2008). Research on the process of oligotrophic algal blooms suggest that, similar to eutrophic lakes, there is a seasonal peak in recruitment and surface abundance of cyanobacteria species in oligotrophic lakes with recruitment generally occurring from shallow (less than 5m) sediments (Carey et al. 2008). An important mechanism of algae blooms in both low and high nutrient lakes appears to be recruitment from sediments, which over time may allow for the important transfer of nutrients in oligotrophic lakes (Carey et al. 2008). As lakes recover from historical periods of acidification the pH will rise, which in turn will allow for increases in the amount of dissolved organic carbon (DOC). Elevated DOC will cause reductions in water clarity and contribute to more persistent lake thermoclines providing larger areas of refuge for cold-water species (Warren et al. 2017).

In many instances, algal bloom formation seems to occur as a result of the interaction(s) between several contributing factors. For example, a positive association between *Microcystis* blooms and cyanobacteria blooms has been documented in some areas, one making conditions more suitable for the other. Further research into potential causes of *Microcystis* blooms suggests that the abundance of plankton species varied with wet and dry conditions, suggesting that climate is a significant driver of trophic structure during blooms (Lehman et al. 2021). *Microcystis* abundance has been shown to vary with several cyanobacteria and phytoplankton genera including several potentially toxic species such as *Pseudoanabaena, Dolichospermum, Planktothri, Sphaerospermpsis*, and *Aphanizomenon* (Lehman et al. 2021). It is important to note that only certain algal species form blooms, and to date there is not a definitive explanation of the physiology for bloom success; however, it does appear that bloom forming species are intrinsically more capable of producing secondary metabolites such as toxins or other structural defenses that render them less attractive to grazers (Mitra and Flynn 2006) that would normally keep populations in check. In some instances, bloom forming algal species are thought to adversely affect the growth of competitor (non-bloom forming) species, furthering their dominance in the water column (Newcombe et al. 2010).

3.1.1 *Dolichospermum sp*. (formerly *Anabaena*)

Dolichospermum species are among the most toxic cyanobacterial genera and often succeed each other during a harmful bloom event. This genus has been identified in every potential algal bloom identified by either the MECP or the LLSA on Leonard Lake. The life cycle of this species includes a planktonic stage (free floating in the water column through the formation of gas vesicles) and a benthic or bottom dwelling stage in the form of akinetes which are the algal equivalent of seeds or spores (Baker 1999). When the environmental conditions are appropriate, the akinetes germinate allowing populations to persist throughout the seasons (Baker 1999). The filaments of this species grow through cell division, followed by akinete production and release, which is generally thought to be an overwintering mechanism of this species. This is followed by growth from the akinete which is triggered by abiotic factors such as temperature and/or light. Buoyancy within the water column is achieved by using gas chambers within the cells (Walsby 1978). Colonies located closer to the surface are exposed to higher levels of light and tend to have a higher rate of photosynthesis which results in the buildup of carbohydrates (sugars) within the cells. The carbohydrates make the cells heavy which causes them to sink out of the euphotic zone, where light penetrates, therefore the colonies stop producing carbohydrates and begin to consume them through respiration (Reynolds et al. 1987). This allows colonies to become buoyant again and return to the surface to begin photosynthesis. The daily migration cycle of *Dolichospermum* species positions colonies at the optimal depth for light penetration for photosynthesis limiting the impact of water clarity on bloom formation and may also provide a mechanism through which colonies are able to scavenge available nutrients from the water column (Newcombe et al. 2010). The vertical migration observed in several *Dolichospermum* species likely provides an adaptive advantage over other planktonic algal species, particularly in stratified lakes where turbulence is low. The characteristic scums observed on the surface of the lake when the water is calm can likely be attributed to the vertical migration of this species when they become buoyant at night and rise to the surface (Newcombe et al. 2010).

3.1.2 Gloetrichia echinulata

Gloeotrichia echinulata is a nitrogen-fixing cyanobacteria that has been associated with blooms in eutrophic lakes across a broad geographic range. Some species of cyanobacteria such as *G. echinulata* use recruitment from substates to subsidize its bloom formation. This species is a nitrogen-fixer that typically produces large (~2mm) colonies (Carey et al. 2008). This species is not thought to be primarily responsible for the blooms observed in Leonard Lake (**see Table 1** for the primary list of species associated with each bloom event) but it does likely exist in the environment and may interact with other bloom-causing species, contributing to harmful bloom events in the future.

3.2 <u>Light</u>

The euphotic zone, by definition, “extends from the surface to the depth at which 1% of the surface light intensity is measured”. The euphotic zone can be estimated by multiplying the Secchi depth values by a factor of approximately 2-3. Cyanobacteria such as *Dolichospermum* sp. have the capacity for buoyancy regulation and can overcome the limitation of the euphotic zone by floating to depths with optimal light conditions. The depth of light penetration is important for the growth of benthic cyanobacteria species, with greater light penetration increasing the depths at which the benthic species can grow (as reviewed in Newcombe et al. 2010).

Cyanobacteria contain chlorophyll a as well as other light harvesting pigments called phycobiliproteins which can capture light in the yellow, orange, and green part of the spectrum, enabling cyanobacteria species to efficiently use light energy from across the spectrum. In conditions where light is limiting, growth rates of Cyanobacteria tend to be higher than that of other green algae species, which in combination with the buoyancy regulation capacity of *Dolichospermum* sp. allows them to outcompete less harmful algal species such as green algae (Newcombe et al. 2010).

3.3 <u>Water Temperature</u>

The growth rates of Cyanobacteria and algal species are temperature dependent. While some growth can occur at lower temperatures, there is significant potential for growth when water temperatures are above 15ºC with optimal growth temperatures for most species occurring about 25ºC (Robarts and Zohary 1987). Temperature is also an important contributing factor to the other physical characteristics of the lake such as stratification, which is based on temperature associated differences in water densities creating stable, non-mixing layers in the water column during particular times of the year (Heinze et al. 2013; Verschoor et al. 2017; Dadi et al. 2020). It has been well documented that increased stratification is a contributing factor to the increased onset of reported algal blooms (Newcombe et al. 2010).

3.4 <u>Nutrients</u>

Elevated nutrient concentrations, including phosphorus, have typically been associated with algal blooms. A well accepted relationship between spring (total) phosphorus loading and summer biomass of all algal phytoplankton has been established in the literature (Paerl et al. 1998; Carey et al. 2008; Newcombe et al. 2010) for some time. The conventional understanding is that HABs are, at least initially, driven by catchment processes that contribute excess nutrients to the waterbody (Newcombe et al. 2010). Since, historically, many of the blooms recorded have occurred in eutrophic lakes, it was thought that high phosphorus and nitrogen concentrations were required. Generally, it is thought that phosphorus levels below 10ug/L are associated with a low risk of algal blooms, 10-25ug/L present a moderate risk and over 25ug/L present high algal growth potential and risk of bloom formation (Newcombe et al. 2010). Cyanobacterial blooms, however, have been documented in aquatic environments with relatively low phosphorus levels, such as a few micrograms per liter. Experimental data have demonstrated that the affinity of many cyanobacteria species for phosphorus or nitrogen are higher than other photosynthetic microalgae, suggesting that if phosphorus or nitrogen is limiting, that cyanobacteria species can out compete other algal species (as reviewed in Newcombe et al. 2010) suggesting that if the physical conditions are ideal, algal blooms can occur even with low levels of phosphorus and/or nitrogen (Weyhenmeyer and Broberg 2014). Additionally, some cyanobacterial species have been shown to have the capacity to store enough phosphorus to complete between two and four (2-4) cell divisions which represents a four to thirty-two (4-32) fold increase in biomass with no additional phosphorus input (Newcombe et al. 2010).

The ratio of Total Nitrogen to Total Phosphorus (TN:TP) may also be a contributing factor to the tendency of cyanobacteria to dominate over other plankton species in a lake (Smith 1983), although this relationship is not as well established as the role of spring phosphorus loading and algal blooms. Other publications suggest that it is not the relationship between TN and TP, but rather whether either nutrient is limiting, which may be limiting for either cyanobacterial growth or the growth of other algal species (Smith 1983, Newcombe et al. 2010).

3.5 Stratification

The thermal stratification of a waterbody influences many physical conditions such as depth of light penetration, concentrations of nutrients within the waterbody and the depth at which cyanobacteria species are likely to be located (Newcombe et al. 2010). The latitude, shape, structure and characteristics of the waterbody and the climatic conditions all influence thermal stratification. Generally, if stratification occurs, the water is separated into two non-mixing layers known as the epilimnion and the hypolimnion with a transition layer known as the thermocline. The upper epilimnion layer tends to be warmer and can be mixed by wind and wave action resulting in an exchange of dissolved gases such as oxygen with the atmosphere. The lower hypolimnion is isolated from the upper layer by the thermocline and is not able to mix or exchange gases with the upper layers. Stratification, and associated anoxia can result in a sizeable release of phosphorus from the sediments resulting in an increase in internal nutrient loading in the lake (Newcombe et al. 2010) which may promote bloom formation.

3.6 Trophic Structure and Food Web Interactions

Many algal blooms invariably disrupt the flow of energy and elements through the trophic levels of aquatic ecosystems (Mitra and Flynn 2006). Aquatic ecosystems are likely to experience multi-trophic effects of changing resource quality associated with warming temperatures due to climate change, because macroalgae and phytoplankton quality are highly sensitive to temperature (Tseng et al. 2021). Additionally, algal nutrient status affects the likelihood of top-down control of these species through grazing, with any negative impact on predator growth decreasing nutrient regeneration which will further stress algal species, increasing their unpalatability to grazing species (Mitra and Flynn 2006). For example, during algae blooms, a decrease in large zooplankton and an increase in small zooplankton species has been reported (Lehman et al. 2021). These shifts, both in organism quality and quantity, can have cascading effects on higher trophic levels (Tseng et al. 2021) leading some to predict that warmer water temperatures will result in decreased secondary productivity in aquatic systems (Hixson and Arts 2016).

The MNRF (2015) has identified a fish community in Leonard Lake consisting of stocked Rainbow Trout (Oncorhynchus mykiss), Lake Whitefish (Coregonus clupeaformis), Burbot (Lota lota), Smallmouth Bass (Micropterus dolomieu), Walleye (Sander vitreous), Golden Shiner (Notemigonus crysoleucas), Pearl Dace (Margariscus margarita), Brown Bullhead (Ameiurus nebulosus), Pumpkinseed (Lepomis gibbosus) and Yellow Perch (Perca flavescens). Anglers on Leonard Lake reported a decrease in Rainbow Trout caught and are concerned about the diversity of the invertebrate community which is considered an indicator of ecosystem health. The MNRF reported that the invasive Spiny Water Flea (Bythotrephes longimanus) was introduced in 2001 and is a voracious predator of crustacean zooplankton species such as Daphnia and can alter the tropic structure of lakes. The invasion of the Spiny Water Flea is thought to be associated with reductions in species richness and abundance of cladoceran species although the full impacts of the Spiny Water Flea on ecosystems have not been established (Kelly et al. 2013). The Spiny Water Flea has been introduced to other lakes in the Muskoka region, including Peninsula Lake in 1991 according to the NDMNRF fact sheet. Further research is needed to fully understand the interactions of plankton dynamics and invasive species on ecosystem health and bloom formation, particularly in oligotrophic lakes that have begun to experience bloom events.

It is interesting to note that the features of Leonard Lake that contributed to historically poor habitat quality for fish species such as Walleye include small size, moderately high depth, lack of extensive shallow areas, and high water clarity. In recent years, residents of Leonard Lake have indicated that they have observed a decrease in lake clarity, which was initially thought to be associated with the increased occurrence of algal blooms. More recently, communication with a resident of Leonard Lake suggested that perhaps some of the change in clarity has occurred due to a recovery in Leonard Lake from the impacts of acid rain (Warren et al. 2017) and a reduction in water clarity that is associated with higher productivity and a higher pH.

3.7 Ecological Consequences of Algae Blooms

The formation of algal blooms requires the decoupling of grazing from phytoplankton growth which alters the dynamics of nutrient regeneration in the ecosystem. The dynamics between limiting nutrients as opposed to nutrient consumption by algal species is a mechanism through which trophic interactions and ecosystem composition can impact harmful algal bloom (HAB) formation in lakes. HAB events often follow blooms of non HAB species and over time can alter species diversity and abundance (Mitra and Flynn 2006) resulting in shifts in species assemblages throughout the ecosystem.

3.8 General Conclusions from Literature Review

Algal blooms tend to occur when a grouping of environmental conditions favoring blooms, including nutrient concentrations, temperature, light and thermal stratification, occur concurrently. Generally, high levels of phosphorus alone are not sufficient to trigger the formation of algae blooms including HABs, and in some cases phosphorus can be relatively low and a bloom can still occur if the other biotic and abiotic factors are present and HAB forming species are successfully able to out compete non HAB forming species in the water column. The development of algal blooms tends to occur in a series of phases including an initial seeding phase, a rapid growth phase, a plateau and a die off. Under calm water conditions, colonies which are excessively buoyant may accumulate together at the surface. While the term "algal bloom" does not have an agreed upon definition, in the scientific literature it is generally considered to be a cyanobacterial concentration that is significantly above the average for the waterbody (as reviewed in Newcombe et al. 2010).

4 CAUSATION STUDY LINES OF EVIDENCE

4.1 Algal Bloom History

The first recorded and recognized algal bloom in Leonard Lake, for which RiverStone was able to access data and records, occurred in 2017, with the LLSA sampling three blooms, two of which were issued incident numbers by the MECP. Subsequent blooms have occurred in 2019, 2020, 2021 and 2022. The LLSA has identified additional blooms occurring in 2018 (**Table 1**). Generally, the description recorded by the LLSA reports that the potential algal blooms consisted of surface blooms along the shoreline. Analyses conducted either by the MECP lab or by the algal expert contracted by the LLSA generally found that *Dolichospermum* species were the primary species identified in both the MECP and LLSA samples. In some instances, the LLSA reported multiple bloom events (e.g. Rpt 26 LL 2017, Rpt. 27 LL 2017, Rpt. 2017 28, Rpt 29 LL 2017, Rpt. 30 LL 2017, Rpt 31 LL 2018) during a season in which the MECP identified a single bloom suggesting that there is a discrepancy in the assessment of the onset and the resolution of a bloom event or that Leonard Lake has frequent and brief "bloom like events" where algal mats begin to form but are not stable enough in the water column for long enough to be documented by the MECP or identified by the Simcoe Muskoka District Health Unit as a cause for concern before the algal assemblages are broken up and dispersed throughout the waterbody.

4.2 Water Quality Analysis

4.2.1.1 Total Phosphorus Concentrations

Data collected by the LPP on Leonard Lake between 2002 to 2019 suggest that the total phosphorus concentrations are generally decreasing at sampling Station 1. Sampling was conducted annually from 2002 to 2006 and then resumed in 2019. Initially total phosphorus samples were 7.1 µg/L and 11.4 µg/L in May of 2002 and had decreased to 5 µg/L and 4.8 µg/L in May of 2019 (**Figures 2-4**). While six years of data is not enough to perform any meaningful statistical analyses to determine if the decrease in TP is significant across time, the general downward trend (with a slight increase in 2005 and 2006 before dropping to lowest values recorded) suggest that TP sampling values at this location do not suggest a link with the increasing occurrence of algal blooms and that TP concentrations in the water column alone are not responsible for the increased frequency of blooms on Leonard Lake. This is supported by an MECP report (Ingram and Patterson 2015) using data from 1979 – 2015 which demonstrates high variability in the yearly spring phosphorus values ranging from over 7 µg/L in 1979 and 2001 to TP spring values of 5 in µg/L 1987 and 2013. This suggests that there is not a distinct upward trend in phosphorus in Leonard Lake across time, and that phosphorus alone is not responsible for the change in bloom frequency and intensity that has been reported for Leonard Lake.

4.2.1.2 <u>Other Water Quality Parameters</u>

Nitrogen

Sources of nitrogen input into lakes can vary and include a variety of forms such as ammonia, nitrates, and nitrites which can be deposited into the lake via inflows, groundwater, precipitation and through nitrogen fixation of planktonic organisms such as cyanobacteria (blue-green algae). There are no long-term trends reported for nitrogen concentrations on Leonard Lake (1980- 2014, Ingram and Paterson 2015) and there appears to be large interannual variation. The DMM collected total nitrogen samples in spring/early summer in Leonard Lake between 2017 and 2019. Concentrations showed very little variation, ranging between 0.21 and 0.26 mg/L indicating that change in frequency and intensity of algae blooms documented in Leonard Lake cannot be attributed to changes in nitrogen concentrations.

Calcium

Water chemistry data provided to RiverStone from the DMM span sampling periods between 2007 and 2021. Concentrations of total calcium ranged between 2.0 mg/L and 2.6 mg/L, with an average value of 2.32 mg/L (**Figure 5**). These data suggest that the calcium concentrations in Leonard Lake have remained relatively stable since 2007 (**Appendix 2**). The MECP (Ingram and Patterson 2015) calcium data in Leonard Lake from 1980-2014 is consistent with the data that RiverStone reviewed from the DMM, with variable levels of calcium documented across time. Generally, the calcium concentrations in Leonard Lake were consistently between 2.1 mg/L and 2.5 mg/L. Data referenced in communication from Leonard Lake residents suggest that calcium values from the LPP program have indicated a decline in calcium with concentrations reported as low as 1.7 mg/L raising concerns among some residents that the decline in calcium may have resulted in a decline of algae grazers such as *Daphnia* sp. It is unclear whether the differences in calcium trends reported are attributed to different sampling locations or methodologies or differences in the interpretation of the results. Regardless, changes in zooplankton species cannot be attributed to calcium concentrations alone and are more likely the result of the complex interaction of a variety of factors including calcium concentrations in addition to the introduction of invasive species such as the Spiny Water Flea (*Bythotrephes longimanus*), shifts in the abundance and diversity of the fish community and the predation pressure they exert. Additionally, changes to the abiotic environment that can be associated with climate change have been reported as a global trend resulting in changes in distribution, range, and density for many species from a variety of freshwater taxa.

Alkalinity and pH

The DMM has conducted water chemistry sampling which has included alkalinity (**Figure 6**) and pH (**Figure 7**) measurements. Alkalinity data has been collected since 2007 with the addition of the total fixed endpoint method measurements starting in 2009. The alkalinity data suggests an upward trend with a low value of 2 mg/L in 2007 and an upper value of close to 5 mg/L in 2021. The alkalinity level in Leonard Lake is related to carbonates and bicarbonates in the water and is decreased by sewage outflow and aerobic respiration. The alkalinity of a lake represents the buffering capacity of the lake to acidification and changes in pH can impact alkalinity levels, as pH values decrease, this can also reduce alkalinity. The upward trend in the alkalinity data suggests that sewage outflows are likely not an issue contributing to water quality in Leonard Lake.

Past work by Ingram and Patterson (2015) from MECP suggested that between 1979 and 2015 the pH level (annual spring whole lake) increased from approximately 5.5 in 1979 to roughly 6.5 in 2015. Additionally, this report suggests that the overall increase in pH is associated with a recorded decrease in sulphate. The DMM has also taken pH measurements between the years of 2007 and 2021 in Leonard Lake. The pH values fluctuate yearly ranging from a low of 6 with a high of 7 with a gradual upward trend observed, consistent with the findings reported by the MECP (2015).

Within a 24-hour period, pH values can vary naturally. The process of photosynthesis uses hydrogen which increases pH levels, while respiration and decomposition can both decrease pH levels, while photosynthesis of algae and other aquatic vegetation can raise the pH resulting in fluctuations throughout the day (Sutherland et al. 2021).

Dissolved Organic Carbon and Water Clarity

The Secchi disk depth has been collected by the DMM from 1987-2021(**Appendix 2**). There is no clear trend in the data that indicates an increase or decrease in Secchi depth, suggesting that there has not been a meaningful change in water clarity as blooms have increased. The depth of visibility of Leonard Lake demonstrates interannual variability with the bulk of the values falling between three and five meters (3-5) with a high of 8 metres in 1987 and a low of 2 metres in 1993. There is no marked change in Secchi depth that coincides with the onset of algal blooms in Leonard Lake.

Another measure of lake clarity that is often used is the measure of dissolved organic carbon (DOC), which is a measure to assess the level of dissolved organic compounds which can occur as a result of decomposing plant matter. In Leonard Lake, a slight increase in DOC between 1979 and 2015 has been recorded (Ingram and Paterson 2015). There is no clear trend in DMM DOC data, although, 2019-2021 DOC values of 4.8 mg/L suggest that there is a slight increase from 4.1 mg/L in 2007, although the ranges varied interannually with a high of 5.3mg/L occurring in 2015. The lack of trend observed in both data sets suggest that while there has been a slight increase in DOC across times, the high levels of interannual variation do not align with the onset of algal blooms Leonard Lake. This suggests that while there may be an increase in the amount of decomposing plant matter in the water column the increase in frequency and intensity of algal blooms in Leonard Lake are not linked to changes in DOC concentrations or the associated biological processes.

4.2.1.3 Dissolved Oxygen Profiles and Deep-Water Sampling

The depth profiles of temperature and oxygen (**Figure 7**) showed evidence of stratification until mixing of the water column occurred. Historical depth profiles of temperature and oxygen are available in **Appendix 2**.

4.3 Climate History

4.3.1 Temperature

Globally, documented air temperatures have been increasing, resulting in an increase in water temperatures. The DMM has consistently collected water temperature at depths throughout the water column during multiple sampling events throughout the year starting in 1987. There is a general trend towards increasing water temperatures with surface temperatures consistently reaching over 25 degrees Celsius starting in May of 2015 (**Appendix 2**).

4.3.2 Wind Speed

Changes in wind speed, which is largely responsible for wave action and ultimately mixing of the water column, can result in changes in the exchange of water between the surface and depth, changes to stratification and conditions which may favour HAB formation. Local wind data specific to the region surrounding Leonard Lake was not available at the time of this report. These data were particularly difficult to access through the MECP. Data that is publicly available from the Harp Lake Meteorological station does show a marked decrease in wind speed in September of 2017, which coincides with the onset of a bloom reported by the LLSA in September of that year. Additional wind data was obtained from the North American Regional Reanalysis (NARR) which is a long term atmospheric and land surface hydrology data set (Mesinger et al. 2006) was reviewed and while there are some fluctuations in windspeed within and between years, it does not clearly explain the change in onset of bloom formation in Leonard Lake. Most of the algal blooms reported by the LLSA occur in the southern region of the lake and health advisories have been issued in both the southeast and southwest areas of the lake. Based on the physical structure of the lake, it is likely that the southern area of the lake does not experience the same wind and wave action, and therefore mixing, as other areas of Leonard Lake, suggesting the potential for increased stratification in this area favouring bloom formation. The differences in wind speeds in different areas of the lake are consistent with observations made by RiverStone staff. Stations 1 and 2 were sampled consecutively on the same day by Riverstone Staff, and station 1 had considerably more wave action than station 2, which is more sheltered by physical structures from wind and therefore experiences less wave action. Wind measurements from the surrounding area that do not address intralake differences in wind and, consequently, wave action, are therefore not the best measurement to use in assessing the importance of wind speed and wave activity in the formation of algae blooms on Leonard Lake.

5 WEIGHT OF EVIDENCE ANALYSIS

5.1 Climate

It is predicted that the risks associated with cyanotoxins and blooms will continue to increase globally due to clear changes in thermal regimes associated with climate change coupled with the increasing eutrophication of aquatic ecosystems (Chia et al. 2018). It is reasonable to conclude that climate, likely in interaction with several other factors, is a major factor contributing the occurrence of both algal blooms and HABs on Leaonard Lake.

5.2 Discussion and Summary of Findings

Defining what constitutes an algae bloom is not as straight forward as one would expect. This is particularly clear given the discrepancy between the number, date of onset and resolution, and severity of algae blooms confirmed by the MECP in comparison to those proposed by the LLSA over the past number of years (**Table 1**). Currently, there is not an agreed upon scientific threshold of what constitutes an algal bloom. The broad definition generally used is the rapid increase in the population of algae in an aquatic system. The Ontario Drinking Water Quality Standards and Guidelines outlines the acceptable concentration for microcystin-LR, a common algal toxin, as a maximum of 1.5 parts per billion or 15 micrograms per liter. The American Environmental Protection Agency (EPA) defines a harmful agal bloom as an overgrowth of algae in the water, some of which produce dangerous toxins, while acknowledging that even non-toxic blooms can cause damage to both the environment and the local economy (United States Environmental Protection Agency 2022).

Several theories as to possible causes of the recently observed algae blooms in Leonard Lake have been presented by members of the LLSA. Based on the historical data collected by the LLSA alongside data acquired from the DMM, LLP, MECP, and our own sampling efforts, RiverStone considered each theory that may be contributing to the occurrence of blooms on Leonard Lake. Based on a comprehensive literature review assessing changes in frequency and timing of blooms globally, specific information and history provided about Leonard Lake, alongside our own observations and analysis, it is our opinion that the documented blooms on Leonard Lake can be attributed to a few potential factors. These factors include changes in climatic factors (temperature primarily) associated with climate change, among others such as changes in patterns of precipitation and weather patterns, climate influenced changes in species range and abundance and interactions among and within species assemblages.

The blooms on Leonard Lake are recorded to have primarily occurred in the south and southwest portions of the lake. Site specific conditions in this area of the lake may also be contributing to the occurrence and/or persistence of bloom events. During our field sampling site visits, it was noted by RiverStone ecologists that the southwest region of Leonard Lake experienced considerably less wave action when compared with the other sampling sites in the deeper and more open portion of the lake. This indicates that the water column in the south and southwest areas of Leonard Lake is likely more stratified due to a lack of wind/wave action and the associated mixing of the water column which would occur as a result of the agitation caused by the wind and/or waves. Additionally, the past occurrence of algal blooms can, with some species, increase the probability of the occurrence of future blooms by "priming the water column" though changing the type and concentration of nutrients available. A lack of mixing in the areas of the lake that have been identified as prone to bloom occurrences is problematic in that it does not allow accumulated concentrations of minerals to be dissipated into the larger environment or for minerals in low concentrations in this region of Leonard Lake to be replenished from other areas of the lake.

This can impact trophic interactions and alter the composition of food webs that would otherwise help to keep the conditions in the water column less hospitable to bloom prone species. In Leonard Lake the MNRF reported that the Spiny Water Flea, an aggressive invasive invertebrate, was recorded as early as 2001. The introduction of this species is often associated with changes in the pelagic community, and in zooplankton diversity and abundance. The reported changes in the invertebrate and fish communities observed by some residents of Leonard Lake, while potentially associated with changes in water chemistry parameters or lake health, could also be indicative of interspecific interactions and a response to changes in global climatic conditions associated with climate change.

Climatic change and conditions are broader than simply changes in water and air temperature. Many changes reported by members of the LLSA such as changes in zooplankton and fish abundance can also be attributed to changes in abiotic factors that are driven by climate. Based on an extensive literature review, RiverStone additionally suggests that ecosystem interactions, including interspecific competition between algal species, changes in nutrients available in the water column associated with changes in species assemblages, and the introduction of invasive species shifting plankton dynamics, may also have contributed to the observed changes in water quality reported by LLSA members.

Finally, the physical characteristics of the southern basin of Leonard Lake makes it more susceptible to bloom events due to past "priming of the water column" by bloom causing species, shallow waters that are easily stratified, and higher levels of stagnation in these areas due to reduced fetch and consequently wind and wave action which is not able to mix the water in these areas as efficiently as other areas in Leonard Lake.

6 GAP ANALYSIS AND RECOMMENDATIONS FOR LEONARD LAKE

6.1 Gap Analysis

One of the most challenging aspects for scientists, policy makers and program managers is to select an appropriate environmental time scale over which to conduct an assessment. For many, if not most lakes, consistent long-term monitoring data is not available. Where lake monitoring programs do exist, data have rarely been collected consistently for longer than a few years. Determining the nature and timing and magnitude of ecosystem changes based on the short-term data sets available is often difficult, if not impossible (Smol 2019), as the application of statistical tests to provide conclusive results cannot be completed. Additionally, it is often after a problem has been identified that studies are designed, or monitoring programs are implemented and critical baseline or pre-disturbance data is not available, limiting the understanding of the causes and contributing factors of a problem (Smol 2019).

In the case of Leonard Lake, multiple sampling programs have been conducted by various agencies and volunteers which have recorded data on a wide variety of parameters. A lack of consistency across time in sampling locations, methods and information gathered greatly limits the usefulness of this data in performing even basic statistical analysis upon which conclusions can be drawn. For example, in some instances, different sites within the lake are sampled on different days within the same season, which added increased variability to the data. Increased background variability in the data set results in a decreased ability of statistical analysis to differentiate legitimate trends from background noise making it difficult to identify variables, and in many cases the interactions between variables, which may be just as important as considering factors individually. The information does provide insight into trends; however, a more robust analysis would have been useful in weighing relative importance of both individual variables and interactions between factors. All future sampling efforts should focus on reducing the number of sites (a combination of nearshore and deep water would be ideal) and maintaining consistency across time in terms of sampling methods, locations and measures collected. If possible, and as mentioned in the Lake-Specific Recommendations section of this report, all sites selected for future monitoring by the LLSA or volunteers as part of the LLP should be sampled on each sampling trip to eliminate variability in date/time and changes in abiotic factors as potentially confounding factors in the analysis.

Paleolimnological studies are useful in establishing baseline information regarding the presence of algal species in oligotrophic lakes (Smol 2019). Similar studies in other regions have indicated that although cyanobacteria were present in the lake system since the 1950s and 1960s, it was not until the late 1990s that changes in the population(s) associated with the formation of HAB began to occur (Smol 2019). This type of study allows for valuable baseline data to be collected that can help identify critical factors and can be used as a tool to help streamline the design of sampling programs to identify the parameters that should be prioritized for ongoing monitoring. (Smol 2019).

The MNRF conducted extensive zooplankton surveys from 1981 to 1987 which characterized the plankton community in Leonard Lake. RiverStone did not obtain any data suggesting that this study had been updated since the introduction of the Spiny Water Flea to quantify potential shifts in the pelagic community or since the onset of algal blooms in Leonard Lake in 2017. This existing data could be used as baseline data for purposes of comparison in future studies that may help better characterize the role of plankton abundance, food web dynamics and top-down versus bottom-up impacts and how these are either contributing to or responding to bloom events.

6.2 Lake-Specific Recommendations

Generally, in order to effectively manage lake ecosystems and for ongoing monitoring of incremental environmental stressors, temporal sampling windows (which are often lacking with standard monitoring regimes) are required and can be achieved by supplementing ongoing monitoring effort with high-resolution lake sediment analyses (Smol 2019). In the case of Leonard Lake, both historical data and ongoing monitoring efforts through the Lake Partner Program could be used alongside paleolimnological methods to expand the timeline and scale at which the trends in Leonard Lake can be evaluated. This would allow for more meaningful analysis with greater statistical power and would provide a more robust assessment of the importance of the many contributing factors to the occurrence of algal blooms in Leonard Lake that have been outlined in this report. Lake sediment analyses or paleolimnology methods have been used in a variety of studies to perform retrospective assessments of ecosystem changes that have been occurring slowly and "under the radar". Using environmental proxies in dated sediment cores the relative contributions of natural and industrial sources of pollutants can be identified alongside the trajectory of the ecosystem (Smol 2019).

In order to increase the capacity for analysis, where the data is available, it may be beneficial for the DMM to consider a comparison across lakes in the immediate watershed of Leonard Lake using existing data to identify the key factors in multiple lakes that may, where possible, require policy or legislation at the municipal, regional, or provincial planning level to address.

Additionally, to better understand the role of trophic interactions and food web dynamics on the formation of algal blooms in Leonard Lake, RiverStone recommends that the zooplankton sampling conducted by the NDMNRF in the 1980s is repeated following the same methods and using the same sampling locations every three to five years to observe changes in ecosystem composition as they relate to the frequency, intensity, and toxicity of algal blooms in Leonard Lake. If this is something that the LLSA decides to implement, it could be accomplished relatively inexpensively with water samples collected by LPP volunteers and analyzed by a contracted expert, similarly to how the water/algae samples have been processed to date.

The ongoing program by the DMM and the LPP of water sampling and analysis should continue. Continued monitoring of oxygen depth profiles, water temperature, and air temperature can be easily and inexpensively completed by volunteers using a YSI meter. Additionally, pH, alkalinity, total phosphorus, nitrogen, calcium, and iron oxide should continue to be monitored. Methods should be kept consistent across time as should sampling sites to reduce any unnecessary variability in the data set that may reduce the efficacy of statistical tests.

Site specific wind measurements that will allow differences in wind speed to be documented and quantified should be collected. Shoreline measurements in the areas of the previous sampling locations, particularly in sampling areas adjacent to areas where algal blooms are known to occur, would allow the differences in wind speed to be quantified and would provide more relevant information than generalized wind data for the Muskoka area to be used in the event of future algal blooms on Leonard Lake.

Finally, while additional phosphorus deposition from overland flow and sewage is not identified as a primary cause of an increase in bloom events in Leonard Lake, RiverStone recommends that the LLSA seek to implement practices known to improve water quality wherever possible. It is well established that a vegetative buffer is important for fish habitat and water quality. RiverStone therefore recommends that the existing policies outlined in the official plan of the Township of Muskoka Lakes (Adopted 2022) and the Official Plan of the Muskoka District Area (Consolidated 2019) regarding the naturalization of the vegetative buffer along the shores of

Leonard Lake is implemented for all properties on the lake, and particularly those in the south and southwest areas of the lake.

Similarly, although septic runoff was not identified as a likely cause of the Leonard Lake bloom events, proper use and maintenance is a priority for each septic system and the general health of the lake ecosystem. RiverStone therefore recommends that the residents of Leonard Lake adhere to the following recommendations:

- Ensure the effluent filter on the septic tank is serviced regularly.
- Have the system pumped out every two to three years, depending on use.
- Never dump grease, oil, or fats into the drain.
- Do not use a garbage disposal system.
- Be conscious regarding the amount of water and waste dumped at one time.
- Never do more than two loads of laundry in one day.
- Practice water conservation (use low flow toilets and showerheads).

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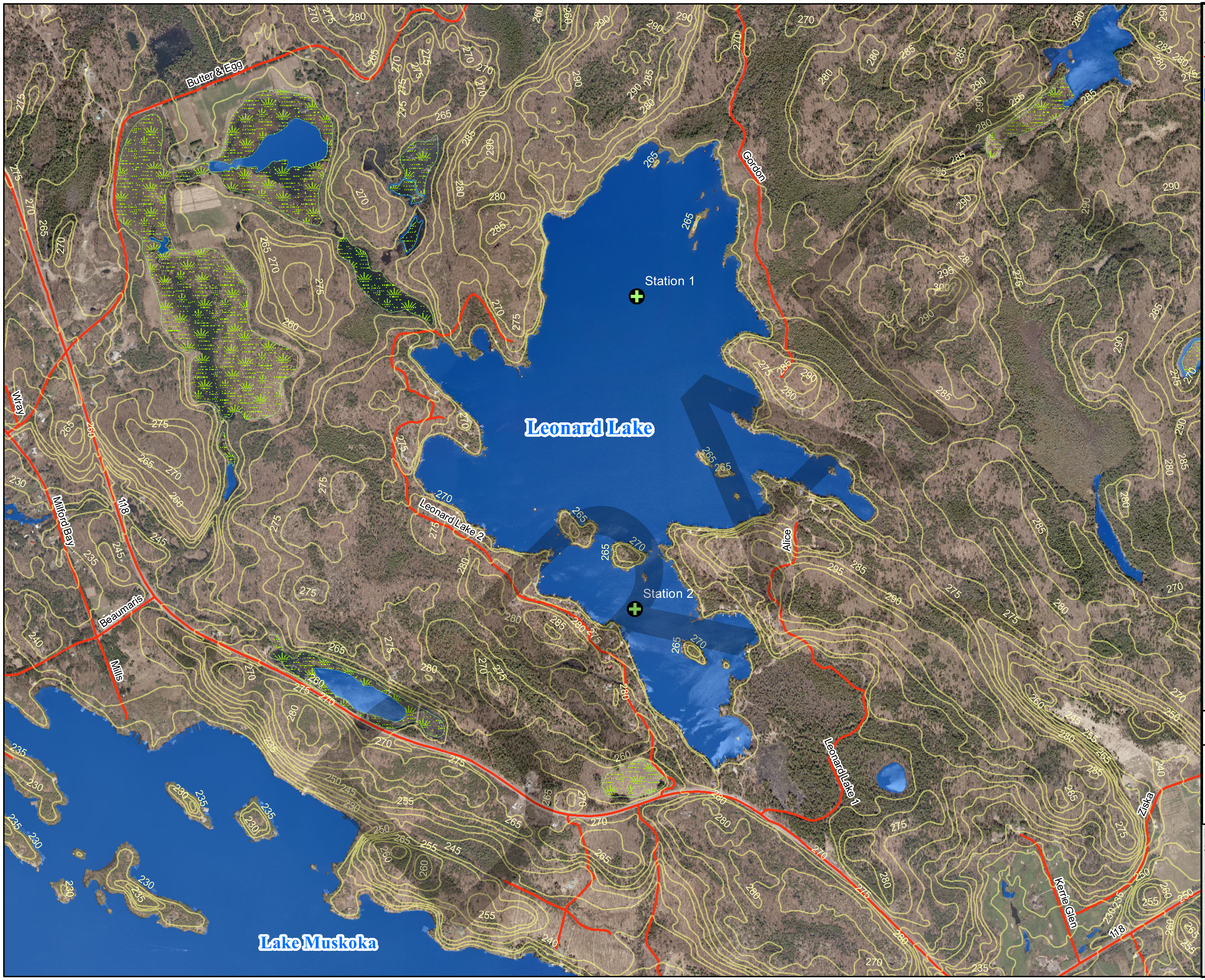


Legend

Ontario Base Mapping (OBM)

- Roads
- 5 m Contours
- Lake Area
- Wetlands

RiverStone Monitoring Locations

- 2021 Sampling

Scale	RS Project No.	Date Last Updated	By
1:15,000	2020-208	Sep 5, 2022	AS

0 225 450 Metres

RiverStone

Figure 1. Loation of Leonard Lake and Monitoring Stations. Township of Muskoka Lakes.

Prepared for District Municipality of Muskoka

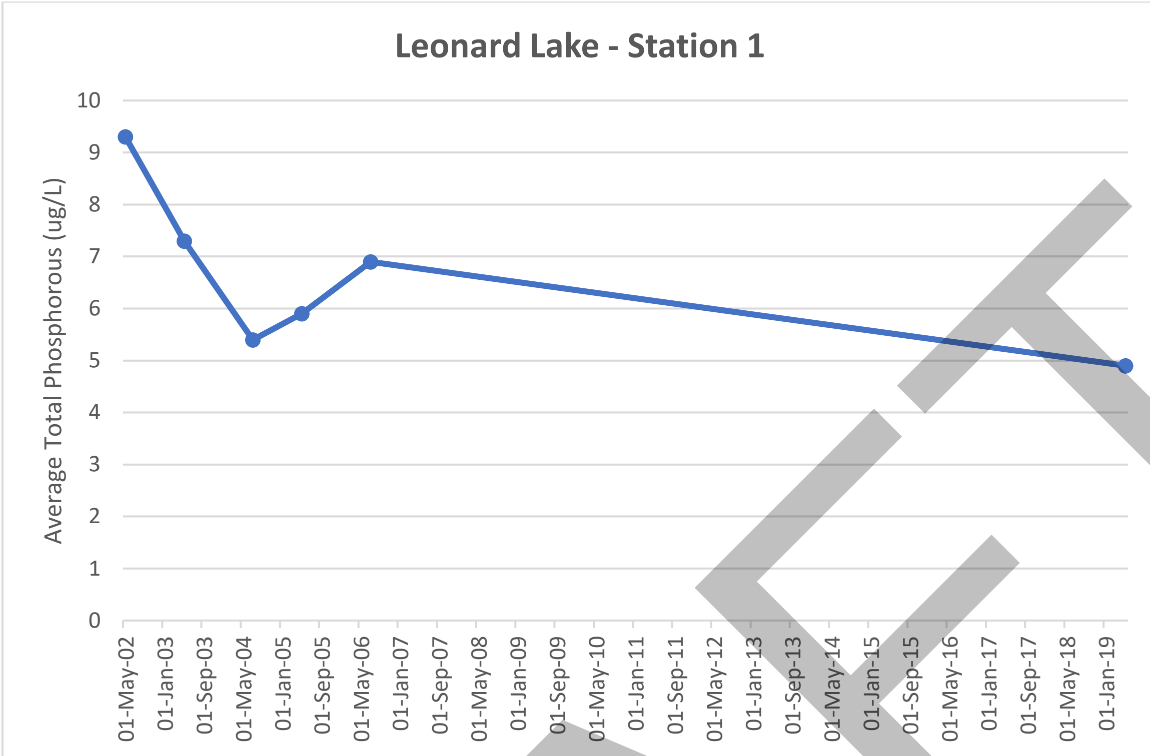


Figure 2 . Average Total Phosphorous data collected by volunteers as part of the lake partner program. The data was accessed July 2021.

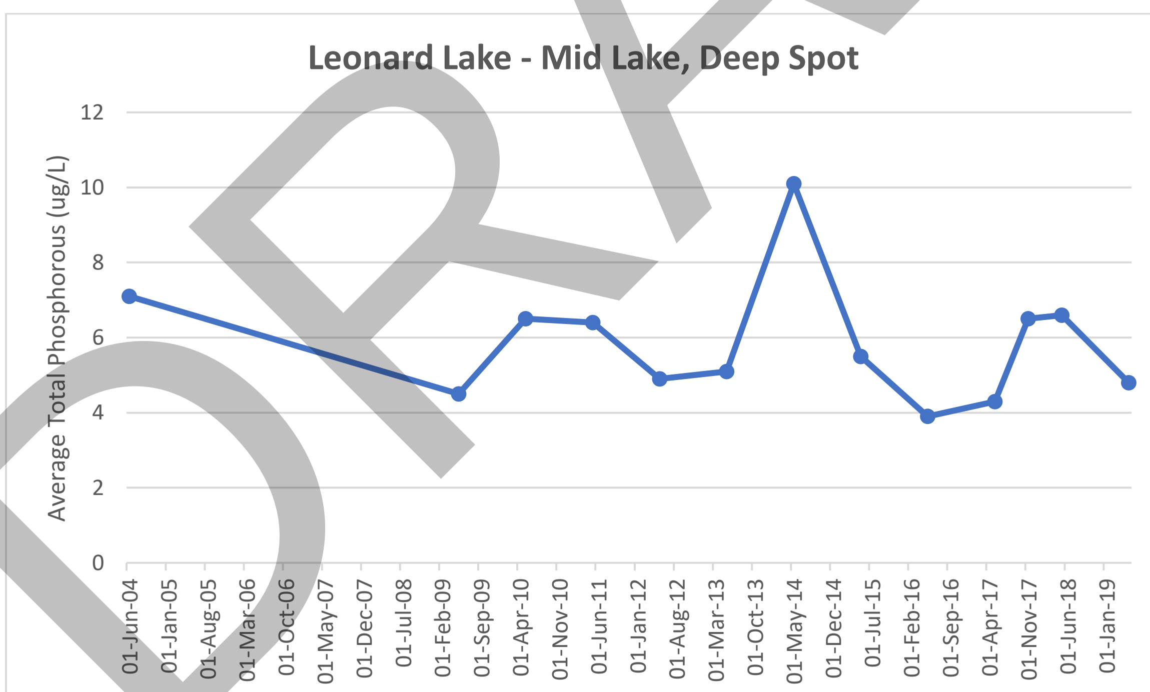


Figure 3 . Average Total Phosphorous data collected by volunteers as part of the lake partner program. The data was accessed July 2021.

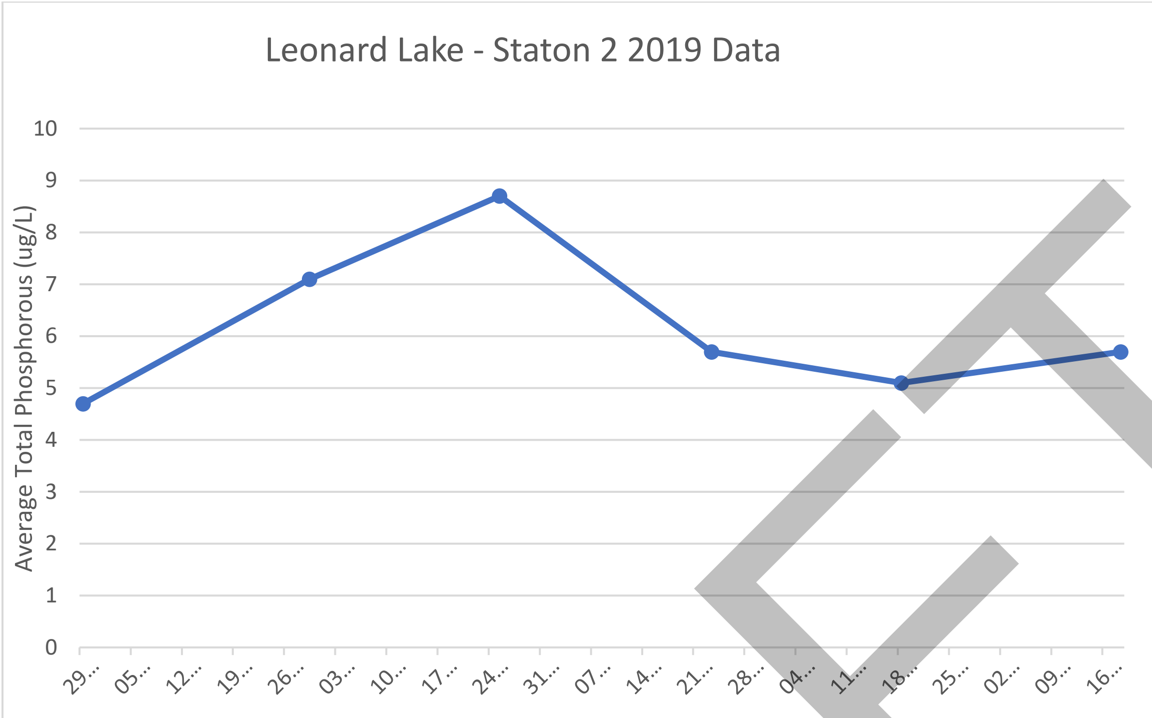


Figure 4 . Average Total Phosphorus data collected by volunteers as part of the lake partner program. The data was accessed July 2021.

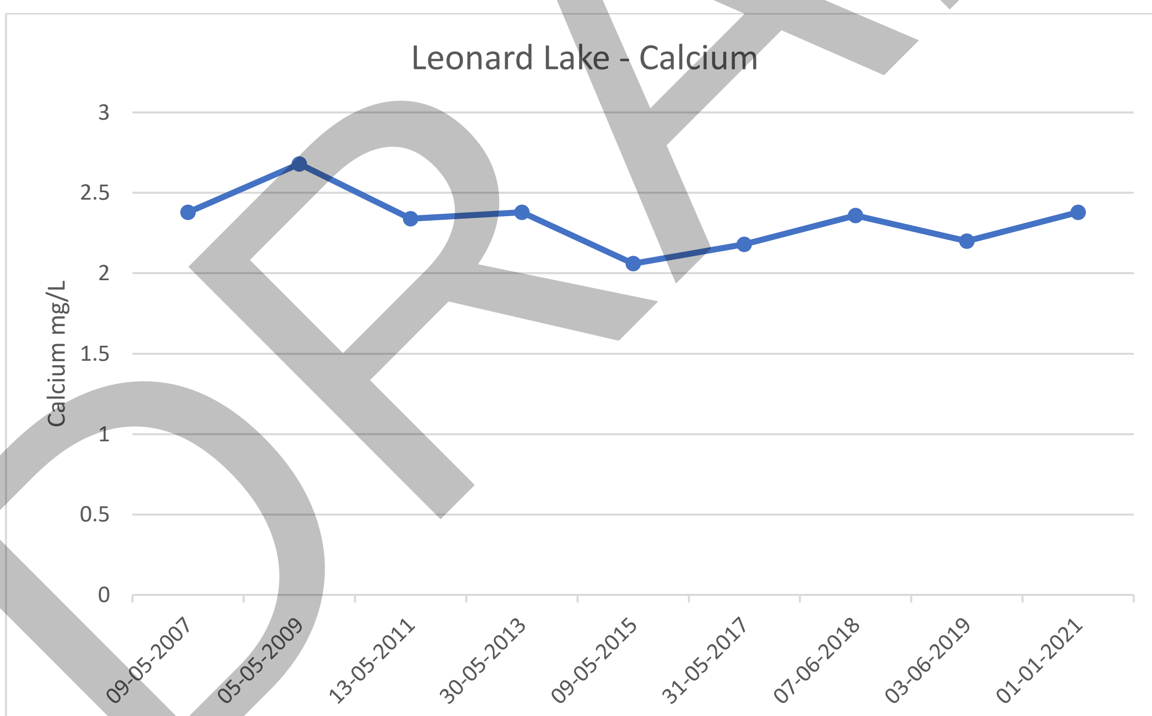


Figure 5. Calcium measurements in water samples collected form Leonard Lake from 2007-2021, data provided by the District Municipality of Muskoka

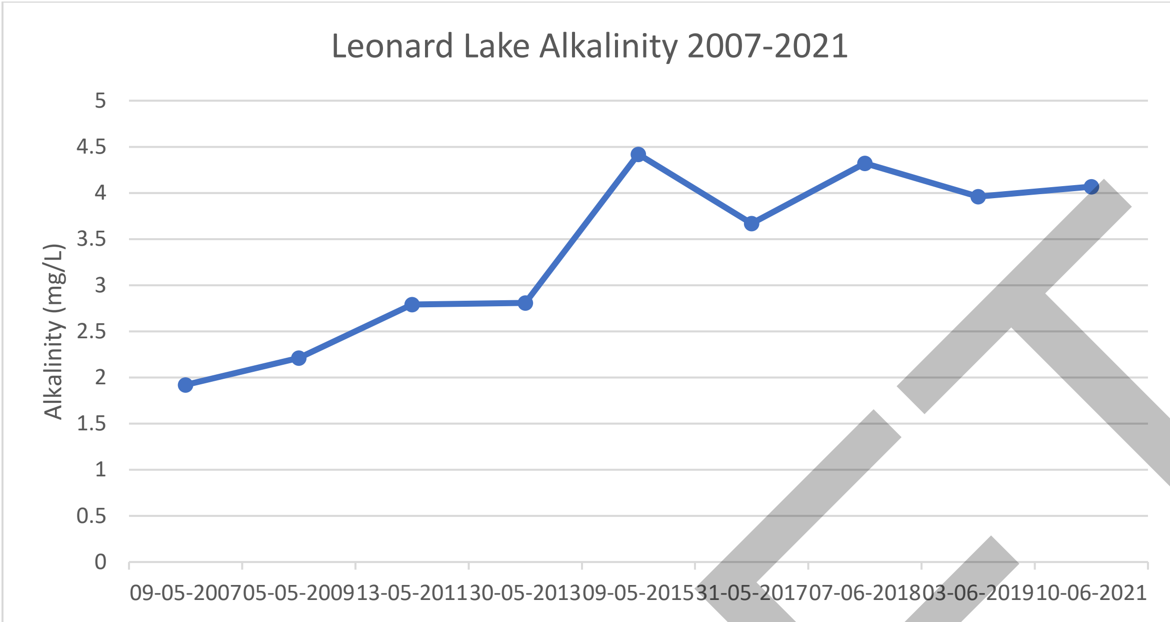


Figure 6. Alkalinity data from 2007 – 2021 provided by the District Municipality of Muskoka.

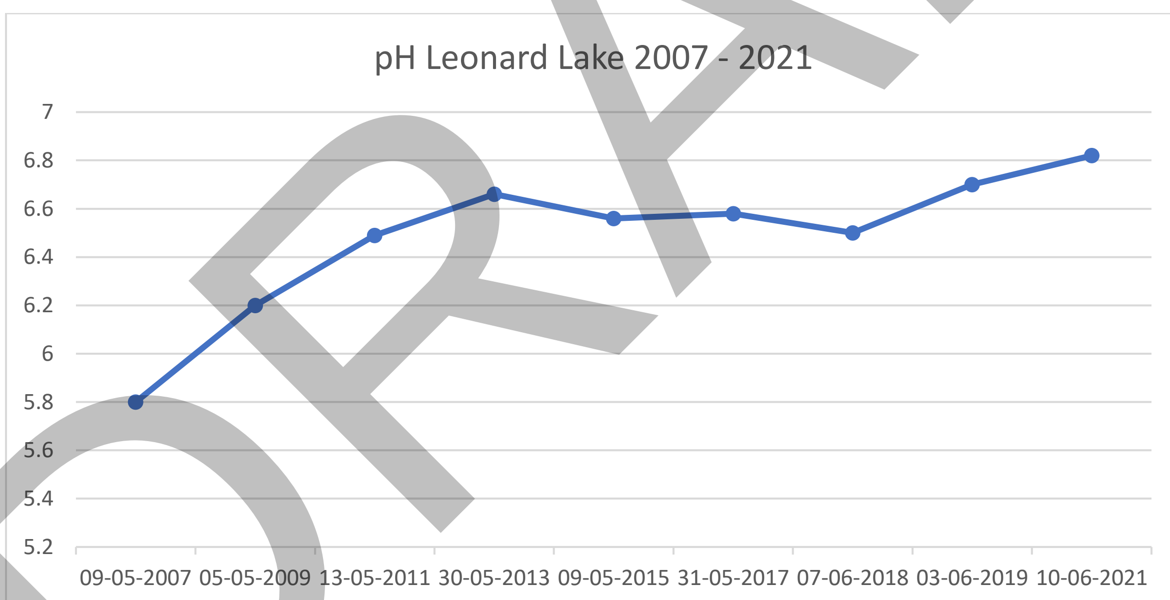
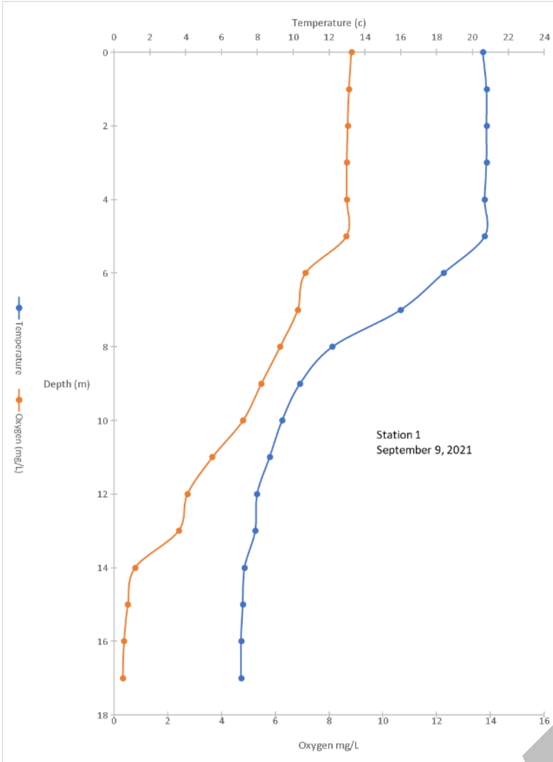
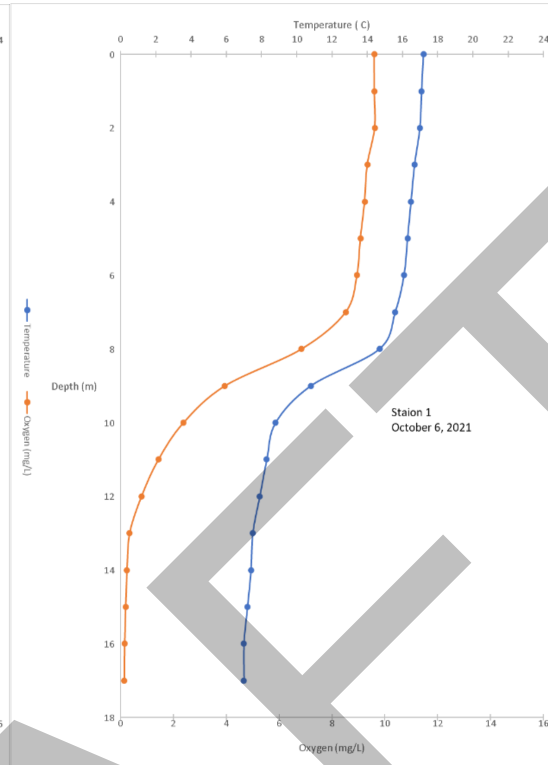
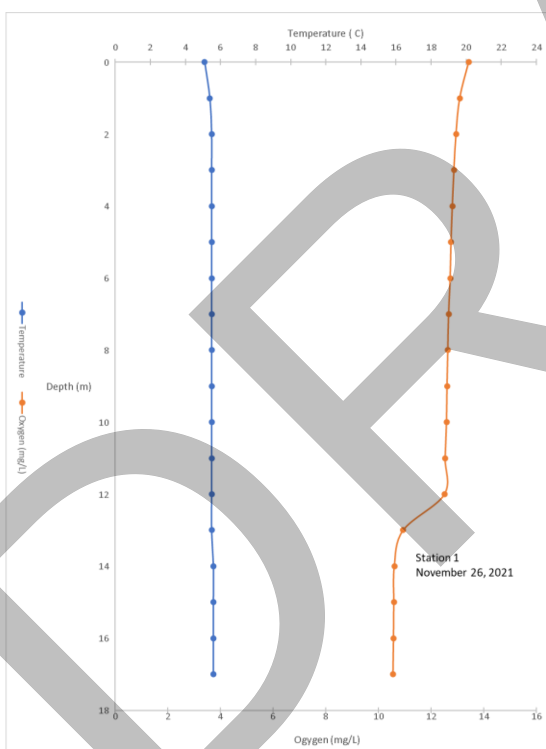
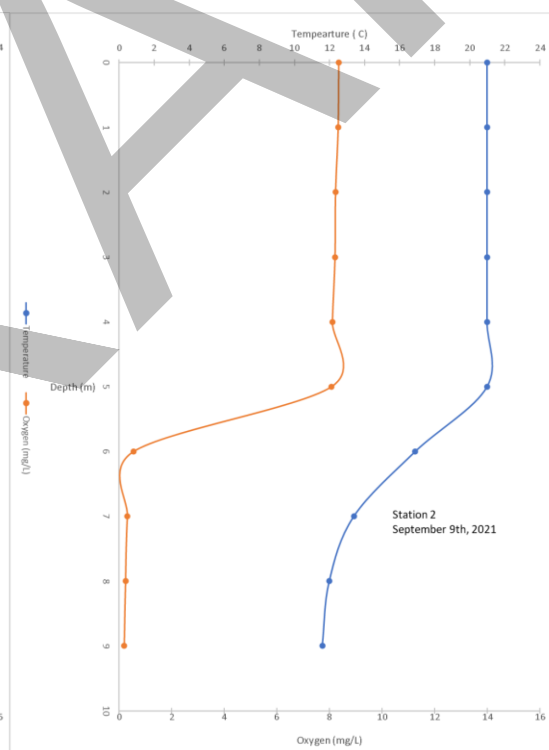


Figure 7. PH data provided by the District Municipality of Muskoka. Data was collected from 2007 to 2021.


Temperature (c)
Depth (m)
Temperature
Oxygen (mg/L)
Station 1
September 9, 2021
Oxygen mg/L


Temperature (C)
Depth (m)
Temperature
Oxygen (mg/L)
Staion 1
October 6, 2021
Oxygen (mg/L)


Temperature (C)
Depth (m)
Temperature
Oxygen (mg/L)
Station 1
November 26, 2021
Ogygen (mg/L)


Tempearture (C)
Depth (m)
Temperature
Oxygen (mg/L)
Station 2
September 9th, 2021
Oxygen (mg/L)

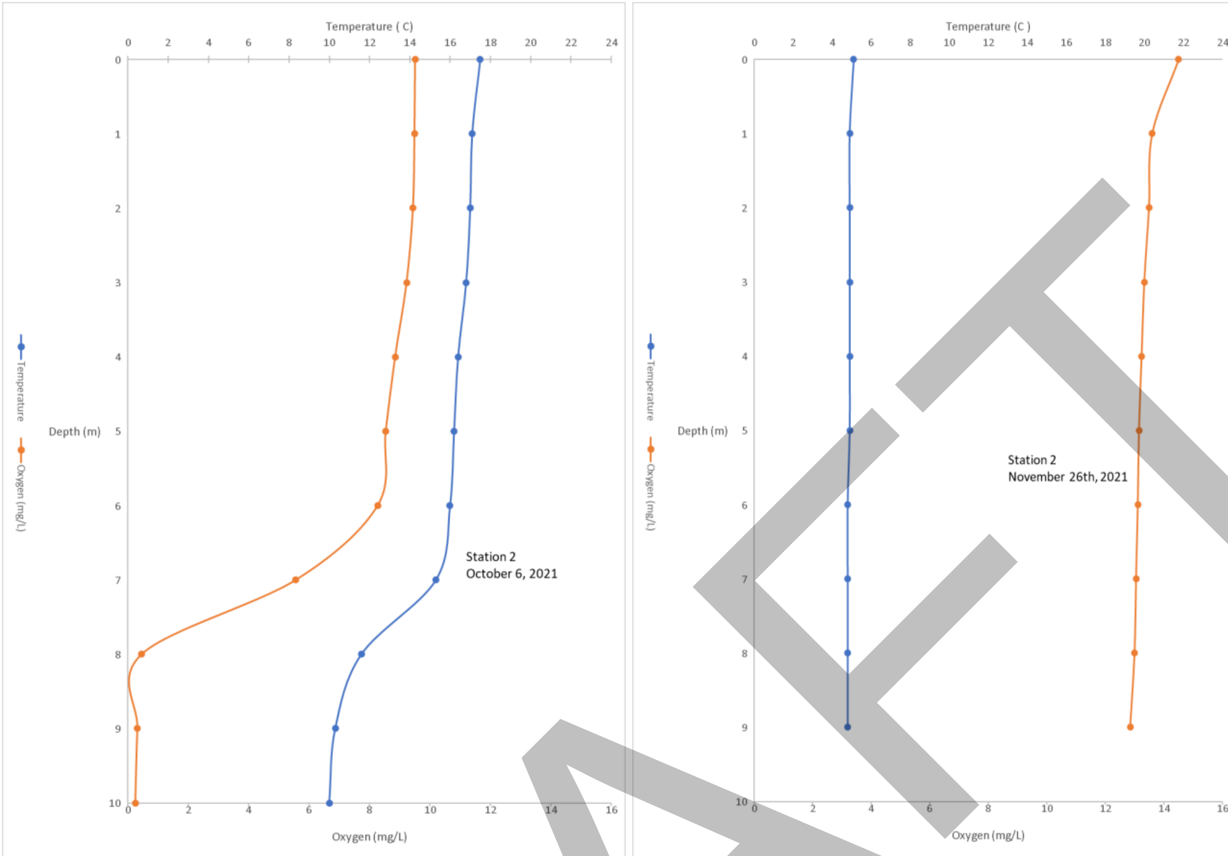


Figure 8. Temperature and oxygen data collected at Stations 1 and 2 from September to November 2021.

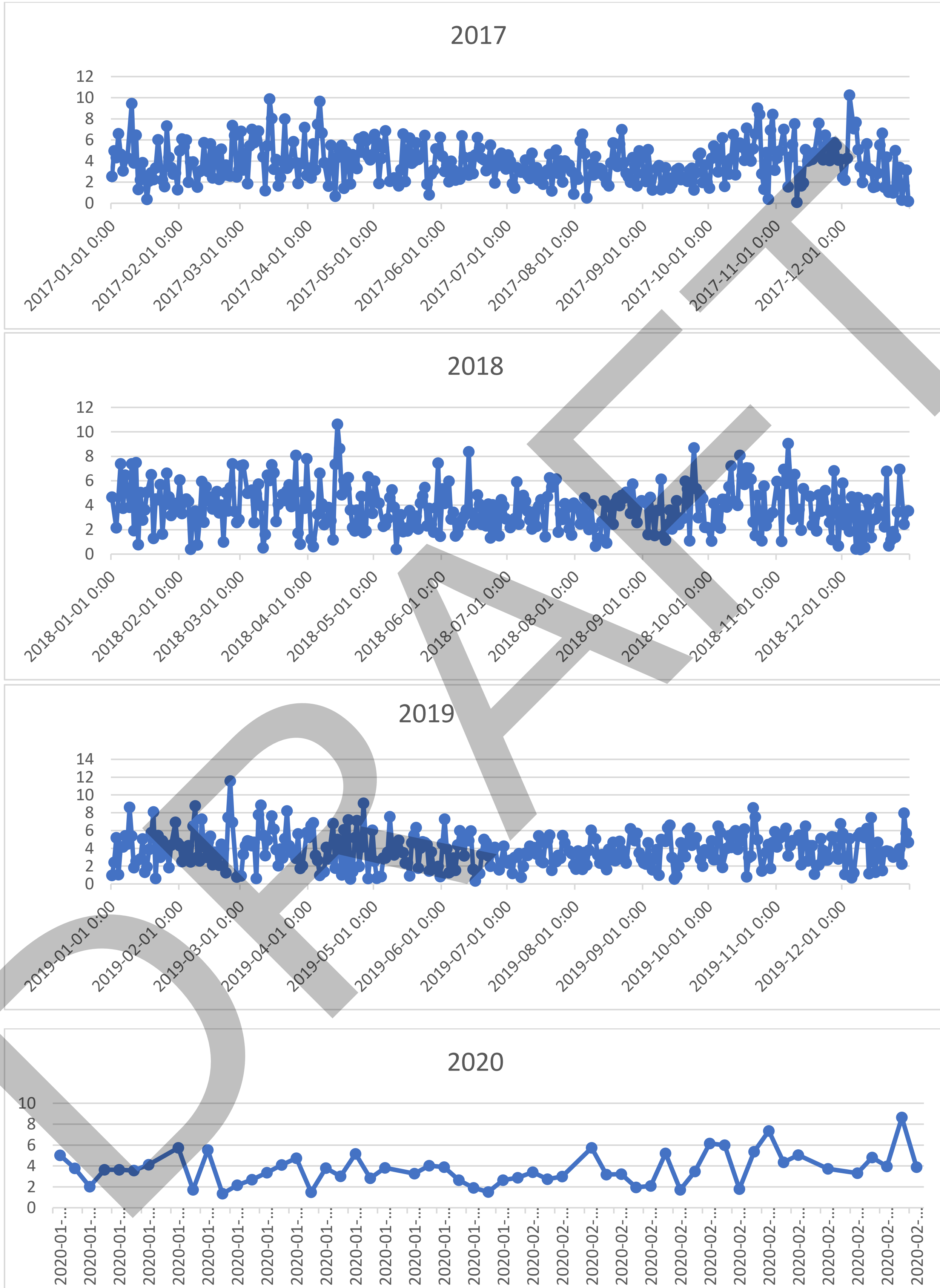


Figure 9. Wind data from North American Regional Reanalysis (NARR). Data was collected from 2017 to 2020.