CHAPTER 2 – PHOSPHORUS CONCENTRATIONS IN LAKES

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Water quality is one of the fundamental components of a healthy watershed. As people live, work, and play around lakes, they may impact and change lake ecosystems. One change that may be a result of human influences is an increase of phosphorus concentration in lakes.

WHAT IS PHOSPHORUS AND WHY IS IT IMPORTANT IN MUSKOKA?

Phosphorus occurs naturally in the environment and is an essential nutrient that plants and animals need to grow. However, too much phosphorus can impact the amount and types of algae found in a waterbody and may contribute to the development of algal blooms (Hutchinson Environmental Sciences Ltd., 2016). Algal blooms can detract from the recreational use of water and, in some cases, can result in deoxygenation of deep waters leading to mortality of species such as lake trout.

Phosphorus has many pathways of entry to a waterbody, both from natural processes and human activities. Natural processes include the weathering of rocks, erosion of soil, decay of organic material, and deposition from the atmosphere through pollen and dust (Ontario Ministry of Environment, Conservation and Parks, 2010). Human-driven activities can include erosion due to vegetation removal, runoff from urban stormwater, and/or agricultural lands fertilized with products containing phosphorus or manure, discharge from sewage treatment plants and septic systems, and atmospheric deposition from the burning of fossil fuels (Ontario Ministry of Environment, Conservation and Parks, 2010).

Excessive phosphorus loading can degrade water quality and disrupt the balance in aquatic ecosystems (Ontario Ministry of Environment, Conservation and Parks, 2010). Without clean and safe water, many of our favourite summer recreational activities may be jeopardized and our sense of enjoyment from being in a natural and relatively pristine environment can be lost (Schiefer, 2008).

Phosphorus levels in a lake will naturally vary from year to year due to factors such as amount of precipitation, wind, and levels of sunlight (Hutchinson Environmental Sciences Ltd., 2016). Climate change may also affect phosphorus levels. To understand trends in phosphorus concentrations, scientific investigations that relate all these factors to variables such as development, invasive species, and other human impacts are necessary (Hutchinson Environmental Sciences Ltd., 2016).

TROPHIC STATUS IN AREA LAKES

In any watershed, there is natural variation in phosphorus concentrations among lakes because of differences in lake size, the amount of wetland in the lake catchment area, and characteristics of water flow through the lake. Lakes are generally classified into one of three categories based on their nutrient status. Lakes with less than 10 micrograms per litre (µg/L) or parts per billion of total phosphorus are called *oligotrophic* lakes. These lakes have low primary productivity as a result of low nutrient content and are generally considered desirable for recreational activities and cottage development. 73% of lakes included in the Report Card sampled between 2001-2022 are oligotrophic.

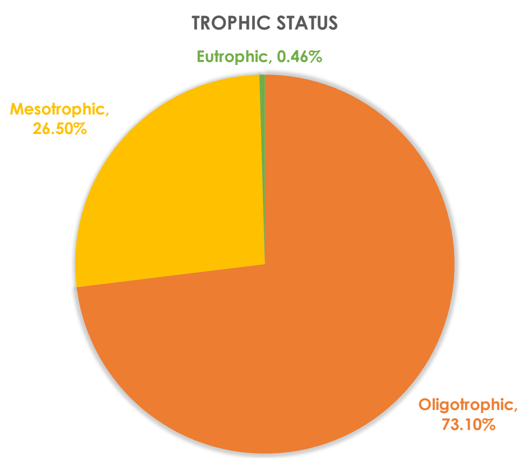

Figure 4. Distribution of sampled lakes by trophic status (2001-2022).

Lakes with moderate total phosphorus concentrations are called *mesotrophic* lakes, which have between 10 and 20 µg/L of total phosphorus. These lakes tend to be smaller and support warm-water fish species and more diverse shoreline habitat. Almost 27% of lakes included in the Report Card sampled between 2001-2022 are mesotrophic. Lakes with greater than 20 µg/L of total phosphorus are called *eutrophic* lakes. These lakes are enriched with phosphorus and are highly productive. They may also show signs of persistent and nuisance algal blooms. Less than 1% of lakes included in the Report Card sampled between 2001-2022 are eutrophic. Figure 4 shows the classifications of trophic status or productivity of lakes in the Muskoka area. Lakes in the Muskoka area, like others on the Canadian shield, are naturally low in total phosphorus concentrations due to geology, vegetation cover, and smaller human influence from sources like agriculture, industry, and large urban centres. Long-term monitoring carried out at the Dorset Environmental Science Centre (DESC) over a 40-year period has shown an overall decline in total phosphorus concentrations in both developed and undeveloped lakes in Muskoka. Eimers (2016) suggested that possible drivers of this decline may include a decrease in atmospheric deposition to lake surfaces and a decrease in phosphorus inputs to lakes from their watershed, potentially as a result of recovering from past disturbances such as cottage development, agriculture, and logging.

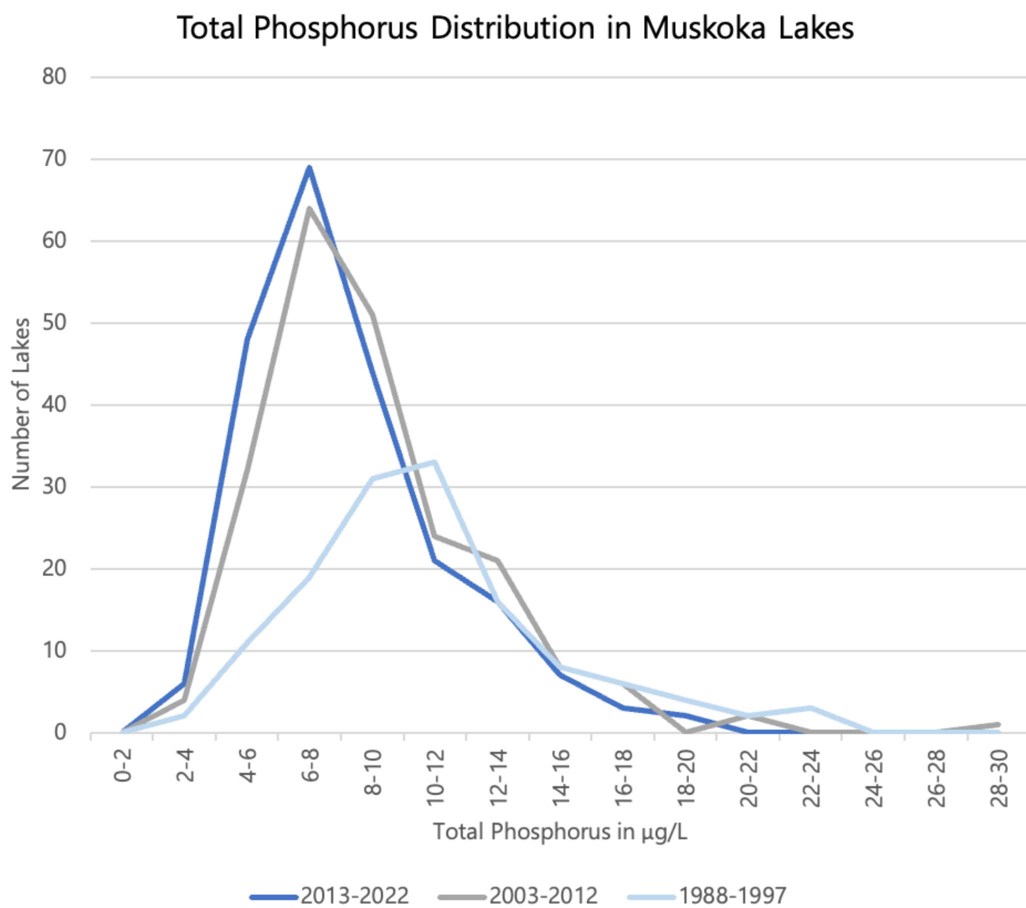

Figure 5. Distribution of sampled lakes in Muskoka's watersheds based on 10-year average phosphorus concentrations for three time periods: 2013 to 2022 (n= 216), 2003 to 2012 (n= 213) and 1988 to 1997 (n= 135).

This trend of decreasing phosphorus concentrations is also seen in the District Municipality of Muskoka's (DMM) and the Lake Partner Program's (LPP) datasets. Figure 5 shows the average spring turnover phosphorus concentrations for a range of lakes in Muskoka's watersheds for three time periods (1988-1997, 2003-2012, and 2013-2022). Lower phosphorus concentrations are seen in the more recent time periods.

HOW IS PHOSPHORUS MEASURED IN MUSKOKA?

Datasets were obtained from DMM Lake System Health Water Quality Monitoring Program and the Ontario Ministry of the Environment, Conservation and Parks (MECP) LPP and analyzed for the phosphorus indicator in the Report Card.

DMM has monitored over 160 lakes across the District for almost 40 years, assessing many water quality parameters including phosphorus. LPP is a volunteer-based initiative established in 1996 and has more than 600 volunteers sampling over 800 sampling locations in 550 inland lakes across Ontario. The DMM dataset was used for lakes within the District and the LPP dataset was used for lakes within the watershed but outside of the District. In total, 218 lakes were assessed for the phosphorus indicator.

The 2023 Muskoka Watershed Report Card assesses long-term trends of total phosphorus concentrations in individual lakes since 2001. Only data since 2001 were included as this is when collection methodology and laboratory and data analysis methods were standardized and remain consistent to this day.

Linear regressions were carried out for each lake that had a minimum of three years of data. The following steps were used to determine the grade of each lake:

1. Individual lake data collected between 2001 to 2022 was plotted on a line graph.
2. A trend line was added to the graph, and
   a. If the trend line was decreasing (i.e., negative slope of the regression), the lake is deemed *not stressed* as total phosphorus concentrations are not increasing
   b. If the trend line was horizontal (i.e., no slope), the lake is deemed *not stressed* as total phosphorus concentrations are not increasing
   c. If the trend line was increasing (i.e., positive slope of the regression), the r^2 value of the trend line was calculated. If the r^2 value was less than 0.1, the lake is deemed *not stressed* because the trend line of the regression does not describe the data well. If the r^2 value was greater than 0.1, the p-value (probability) of the trend line was calculated to determine if the slope was significantly different than zero, and subsequently categorized as follows:

      - Not Stressed: the p-value of the regression is greater than or equal to 0.10.

- Vulnerable: The p-value of the regression is between 0.10 and 0.05 and the slope of the regression was positive and > 0.1.
- Stressed: The p-value of the regression is equal to or less than 0.05 and the slope of the regression was positive and > 0.1.

Quaternary watershed grades were then determined based on the categories of lakes within each watershed as follows:

- Not Stressed: Less than 25% of the lakes in the watershed are vulnerable or stressed.
- Vulnerable: Between 25% and 50% of lakes in the watershed are vulnerable or stressed.
- Stressed: More than 50% of the lakes in the watershed are vulnerable or stressed.

The overall results for the quaternary watersheds can be seen in Table 10.

ABOUT R^2 VALUES, TREND LINES (LINEAR REGRESSION), AND P-VALUES

A trend line (regression line) is a line in a graph that is fitted through data points that best displays the trend of the data. An r^2 value of the line can be calculated, which indicates the goodness of fit of the line, or how close the data points fit the trend line. The closer the r^2 value is to 1, the closer the data points are to the line. For instance, total phosphorus concentrations in Dotty Lake in the Oxtongue River Outlet Watershed are increasing at an r^2 value of 0.54 (Figure 6). The trend line is going through or close to most of the data points. However, for Mainhood Lake in the Lake Rosseau Watershed, most data points are not in contact with the black trend line. Therefore, the r^2 value is low.

P-values determine the significance of the r^2 value. It represents the probability that the trend line is significantly different from zero.

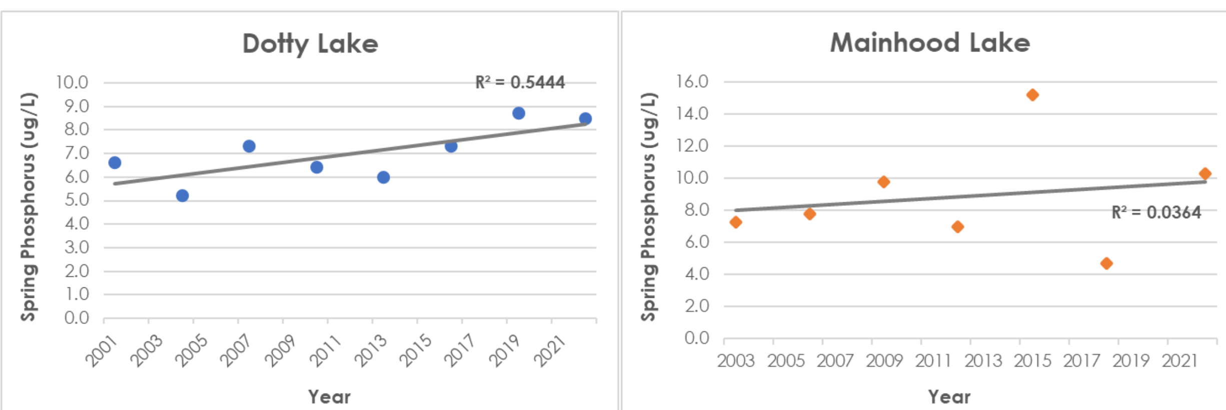

Figure 6. Examples of r^2 values and trend lines.

Table 9. Trends in phosphorus concentrations in lakes sampled between 2001 and 2022 and the category assessed for the Report Card.

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Ada Lake	16.3			Not Stressed
Armishaw Lake	7.2	0.84	0.08	Vulnerable
Atkins Lake	7.6			Not Stressed
Axle Lake	6.2			Not Stressed
Barron's Lake	20			Not Stressed
Bass Lake (GR)	18.6	0.17	0.24	Not Stressed
Bass Lake (ML)	8.4			Not Stressed
Bastedo Lake	7.4			Not Stressed
Baxter Lake	10.3			Not Stressed
Bay Lake	6			Not Stressed
Bear Lake	7.4			Not Stressed
Bearpaw Lake	13.8			Not Stressed
Bella Lake	7.2			Not Stressed
Ben Lake	8.7			Not Stressed
Bigwind Lake	6	0.04		Not Stressed
Bing Lake	5.5	0.12	0.44	Not Stressed
Bird Lake	10.6			Not Stressed
Bittern Lake	7.2			Not Stressed
Black Lake (ML)	15			Not Stressed
Blackstone Lake	7.5			Not Stressed
Bonnie Lake	5.6			Not Stressed
Brandy Lake	18			Not Stressed
Brennan Lake	10.3			Not Stressed
Brooks Lake	8.2			Not Stressed
Bruce Lake	11.5			Not Stressed
Brush Lake	5.2	0.01		Not Stressed
Buck Lake (HT)	11.8			Not Stressed
Buck Lake (LOB)	6.7			Not Stressed
Burnt Lake	6	0.01		Not Stressed
Burr Lake	7.2	0.04		Not Stressed
Butterfly Lake	11.8			Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Camel Lake	8.6	0.01		Not Stressed
Camp Lake	4	0.04		Not Stressed
Cardwell Lake	8.7	0.03		Not Stressed
Cassidy Lake	9.3			Not Stressed
Chub Lake (HT)	8.9			Not Stressed
Chub Lake (LOB)	9.4			Not Stressed
Clark Lake	12.2			Not Stressed
Clear Lake (BB)	5.5			Not Stressed
Clear Lake (ML)	6.1			Not Stressed
Clearwater Lake (GR)	4.8			Not Stressed
Clearwater Lake (HT)	6.6			Not Stressed
Clinto Lake	5.2	0.27	0.37	Not Stressed
Cognashene Bay	5.7			Not Stressed
Cooper Lake	9.2	0.01		Not Stressed
Cornall Lake	9.5			Not Stressed
Crane Lake	4.8	0.05		Not Stressed
Crosson Lake	9			Not Stressed
Dark Lake	8.2			Not Stressed
Deer Lake	5.9	0.13	0.42	Not Stressed
Devine Lake	12			Not Stressed
Dickie Lake	7.9			Not Stressed
Doeskin Lake	15			Not Stressed
Dotty Lake	7	0.55	0.04	Stressed
Draper Lake	7.6	0.01		Not Stressed
Dyson Lake	5			Not Stressed
Echo Lake (LOB)	7.5			Not Stressed
Emsdale Lake	5.9	0.34	0.02	Stressed
Fair Lake	7.4	0.42	0.23	Not Stressed
Fairy Lake	8.8			Not Stressed
Fawn Lake	15.2			Not Stressed
Fifteen Mile Lake	5.4			Not Stressed
First Lake	8.1	0.43	0.11	Not Stressed
Flatrock Lake	7.7			Not Stressed
Flaxman Lake	4.5	0.11	0.67	Not Stressed
Fletcher Lake	6.3	0.05		Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Foote Lake	9.5	0.09		Not Stressed
Forget Lake	5.9	0.21	0.3	Not Stressed
Fox Lake	12.1			Not Stressed
Galla Lake	7.2			Not Stressed
Gartersnake Lake	13.3			Not Stressed
Gerow Lake	9.5			Not Stressed
Gibson Lake	10.7			Not Stressed
Gilleach Lake	9.6			Not Stressed
Gloucester Pool	9.8			Not Stressed
Go Home Bay	6.5			Not Stressed
Go Home Lake	6.7			Not Stressed
Golden City Lake	13.7			Not Stressed
Grandview Lake	5.5			Not Stressed
Grindstone Lake	10.3			Not Stressed
Gull Lake	6.4			Not Stressed
Gullfeather Lake	11.2	0.01		Not Stressed
Gullwing Lake	11.5			Not Stressed
Haggart Lake	10.2			Not Stressed
Halfway Lake	12.7			Not Stressed
Hardup Lake	7.4			Not Stressed
Harp Lake	7.5	0.1		Not Stressed
Healey Lake	7.7	0.12	0.44	Not Stressed
Healey Lake	8.4			Not Stressed
Heney Lake	6.6			Not Stressed
Henshaw Lake	5.2			Not Stressed
Hesner's Lake	7.3			Not Stressed
High Lake	4.6			Not Stressed
Horseshoe Lake	7.2			Not Stressed
Jessop Lake	12.2			Not Stressed
Jevins Lake	13.7			Not Stressed
Kahshe Lake	11.8			Not Stressed
Kapikog Lake	6.1			Not Stressed
Kawagama Lake	4	0.23	0.03	Stressed
Lake Joseph	4.3			Not Stressed
Lake Muskoka	6.1			Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Lake of Bays	5.3			Not Stressed
Lake Rosseau	6.7			Not Stressed
Lake Vernon	9.4			Not Stressed
Lake Waseosa	9.1			Not Stressed
Leech Lake (BB)	7.9			Not Stressed
Leonard Lake	5.9	0		Not Stressed
Little Go-Home Bay	10.3			Not Stressed
Little Lake	10.4	0.01		Not Stressed
Little Lake Joseph	5.6			Not Stressed
Little Long Lake	6.2			Not Stressed
Livingstone Lake	5.1			Not Stressed
Long Lake	6.1			Not Stressed
Long's Lake	9.1			Not Stressed
Longline Lake	6.9			Not Stressed
Loon Lake	7.6			Not Stressed
Lower Fletcher Lake	6.3			Not Stressed
Mainhood Lake	8.9	0.03		Not Stressed
Mansell Lake	10.1	0.42	0.04	Stressed
Mary Lake	9			Not Stressed
McCrae Lake	9.6	0		Not Stressed
McDonald Lake	9.8			Not Stressed
McFadden Lake	8	0.81	0.29	Not Stressed
McKay Lake	10.4	0.01		Not Stressed
McKechnie Lake	5.4	0.06		Not Stressed
McRey Lake	12.4			Not Stressed
McTaggart Lake	10.5			Not Stressed
Medora Lake	7.5			Not Stressed
Menominee Lake	8.8			Not Stressed
Mirage Lake	14.8			Not Stressed
Mirror Lake	6.3			Not Stressed
Mirror Lake	7.6	0.04		Not Stressed
Moon River	6.8			Not Stressed
Moot Lake	13.1			Not Stressed
Morrison Lake	8.7	0.04		Not Stressed
Myers Lake	9.3			Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Neilson Lake	14.3			Not Stressed
Nine Mile Lake	9.7	0		Not Stressed
North Bay	12.3			Not Stressed
North Muldrew Lake	9.3			Not Stressed
Nutt Lake	7.2			Not Stressed
Otter Lake	5	0		Not Stressed
Otter Lake (HT)	8.8	0		Not Stressed
Oudaze Lake	10.4			Not Stressed
Oxbow Lake	6.3			Not Stressed
Oxtongue Lake	7.2	0.01		Not Stressed
Paint Lake	8			Not Stressed
Palette Lake	12.2	0.09		Not Stressed
Pell Lake	11.6			Not Stressed
Pender Lake	5.6	0.88	0.02	Stressed
Penfold Lake	14.9			Not Stressed
Peninsula Lake	9.5			Not Stressed
Perch Lake	11.2			Not Stressed
Pickering Lake	13.4	0.04		Not Stressed
Pigeon Lake	7.5			Not Stressed
Pine Lake (BB)	7.7	0.23	0.19	Not Stressed
Pine Lake (GR)	8.2			Not Stressed
Porcupine Lake	6.6			Not Stressed
Portage Lake	6.2	0.38	0.1	Not Stressed
Prospect Lake	8.2			Not Stressed
Raven Lake	6.1			Not Stressed
Rebecca Lake	5.4			Not Stressed
Ricketts Lake	9.6			Not Stressed
Ril Lake	8.2			Not Stressed
Riley Lake	14.8			Not Stressed
Ripple Lake	10.3	0.85	0	Stressed
Roberts Lake	8.1			Not Stressed
Rose Lake	13.3			Not Stressed
Ryde Lake	17.2			Not Stressed
Second Lake	10.8	0.45	0.15	Not Stressed
Shoe Lake	5.8	0.1		Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Siding Lake	13.2			Not Stressed
Silver Lake (GR)	10.6			Not Stressed
Silver Lake (ML)	8.3			Not Stressed
Silver Sand Lake	8.3			Not Stressed
Six Mile Lake	8.4			Not Stressed
Sixteen Mile Lake	7			Not Stressed
Skeleton Lake	3.7	0		Not Stressed
Solitaire Lake	5.2			Not Stressed
South Bay	14.1	0.33	0.08	Vulnerable
South Muldrew Lake	7.8			Not Stressed
South Nelson Lake	8.2			Not Stressed
Sparrow Lake	11.5			Not Stressed
Spence Lake	8.6			Not Stressed
Spring Lake	6.3			Not Stressed
Stewart Lake	6.5			Not Stressed
Stoneleigh Lake	12.1			Not Stressed
Sucker Lake	5.4	0.1		Not Stressed
Sunny Lake	6.2			Not Stressed
Tackaberry Lake	5.5			Not Stressed
Tadenac Bay	6.2			Not Stressed
Tadenac Lake	7.2	0.06		Not Stressed
Tasso Lake	5			Not Stressed
Thinn Lake	10			Not Stressed
Third Lake	9.9			Not Stressed
Three Mile Lake (GR)	10.5			Not Stressed
Three Mile Lake (ML)	15.6			Not Stressed
Tiffin Lake	6.9	0.09		Not Stressed
Toad Lake	7.4	0.1		Not Stressed
Tooke Lake	4.9			Not Stressed
Toronto Lake	8.3			Not Stressed
Troutspawn Lake	7.5			Not Stressed
Tucker Lake	5.2			Not Stressed
Tucker Lake	8.9	0.29	0.07	Vulnerable
Turtle Lake	7.7			Not Stressed
Twelve Mile Bay	7.4			Not Stressed

Lake Name	Avg TP 2001-2022 (µg/L)	r^2 value*	p-value**	Category
Virtue Lake	9.7	0.35	0.09	Vulnerable
Wah Wah Taysee	3.4			Not Stressed
Walker Lake	5.3			Not Stressed
Webster Lake	16.7	0.81	0.01	Stressed
Weismuller Lake	14.2			Not Stressed
Wildcat Lake	7.2	0.02		Not Stressed
Windfall Lake	7.9	0.81	0.1	Not Stressed
Wolf Lake	5.9	0		Not Stressed
Wolfkin Lake	7.1	0		Not Stressed
Wood Lake	7.1			Not Stressed
Yarrow Lake	9.2	0.14	0.54	Not Stressed
Young Lake	7.3			Not Stressed

** r^2 value only calculated if trendline is increasing.*

*** p-value only calculated if r^2 value is high.*

BB (Bracebridge) GR (Gravenhurst) LOB (Lake of Bays)

GB (Georgian Bay) HT (Huntsville) ML (Muskoka Lakes)

Local Spotlight: Ontario Lake Partner Program

Citizen scientists and lake stewards are key to maintaining and, if possible, enhancing the quality of Muskoka's lakes. You can get involved in monitoring the health of Muskoka's lakes through the Ontario Lake Partner Program, a volunteer-based, water-quality monitoring program established in 2002. This Ministry of the Environment, Conservation and Parks program operates out of the Dorset Environmental Science Centre (DESC) in partnership with the Federation of Ontario Cottagers' Associations. Through this program, volunteers collect lake water samples and return them, postage paid, to DESC, where they are analyzed for total phosphorus and calcium. Consider joining the Lake Partner Program or volunteering with your local Lake Association to assist in water monitoring efforts. Learn more at https://www.ontario.ca/page/water-sampling-and-testing-inland-lakes.

Table 10. Quaternary watershed grades for the phosphorus indicator showing the number of lakes by quaternary watershed that fall into the not stressed, vulnerable, and stressed categories.

Quaternary Watershed	Number of Lakes			Grade
	Not Stressed	Vulnerable	Stressed	
Georgian Bay Shoreline	12	1	0	Not Stressed
Moon River Bay	8	0	0	Not Stressed
Blackstone Harbour	13	1	1	Not Stressed
Musquash River	7	0	1	Not Stressed
Lake Muskoka-Muskoka River	17	0	0	Not Stressed
South Branch Muskoka River Outlet	19	0	0	Not Stressed
North Branch Muskoka River	19	0	0	Not Stressed
Baysville Narrows-South Branch Muskoka River	17	0	0	Not Stressed
Lake Vernon	5	0	0	Not Stressed
Lake Rosseau	33	2	0	Not Stressed
Little East River-Big East River	12	0	3	Not Stressed
Oxtongue River Outlet	4	0	1	Not Stressed
Distress Pond-Big East River	3	0	0	Not Stressed
Hollow River	7	0	1	Not Stressed
Little Lake-Severn River	10	0	0	Not Stressed
Sparrow Lake-Severn River	4	0	0	Not Stressed
Lake St. John-Black River	1	0	0	Insufficient Data
Cache Creek-Black River	6	0	0	Not Stressed
Kahshe River	10	0	0	Not Stressed

WHAT DOES IT ALL MEAN?

Approximately 71% of the lakes sampled have stable or decreasing phosphorus concentrations (compared to over 98% in the 2018 Report Card). Of the remaining lakes, 23% have a slight increase in phosphorus concentrations and 5% have a statistically significant increase.

While overall Muskoka-area lakes continue to have excellent water quality, more recent data indicate that phosphorus concentrations are becoming less stable as we experience greater variation in weather from year to year, a trend that is likely to continue as our lakes respond to warmer temperatures and changes in precipitation patterns.

While phosphorus concentrations, representing trophic status, provide a good general indication of water quality, Muskoka's lakes are changing and are threatened by a variety of stressors in addition to shoreline development (Palmer, Yan, Paterson, & Girard, 2011). The Canada Water Network Research Program carried out in the Muskoka River Watershed from 2012-2015, for example, concluded that the multiple stressors included; increasing concentrations of dissolved organic carbon and chloride, declining concentrations of calcium, invading species populating an increasing number of lakes, and the changing climate with resultant changes in precipitation, temperature, runoff, and evaporation that affect physical, chemical and biological conditions of lakes (Eimers, 2016). The 2023 Muskoka Watershed Report Card reports on a number of these stressors, including calcium, chloride, invasive species, and climate change.

There is also a growing recognition that blooms of cyanobacteria can, and do, occur in oligotrophic lakes (Reinl, 2021) due to their unique physiological adaptations that allow them to thrive under a wide range of environmental conditions, including low-nutrient waterbodies. Of the 21 lakes and bays that are listed in Schedule E2 of the Muskoka Official Plan as a result of having a confirmed cyanobacterial bloom (The District Municipality of Muskoka, 2018), at least 14 of them are classified as oligotrophic. Reinl (2021) suggests that while nutrients contribute to bloom formation and maintenance, there are several mechanisms that allow cyanobacteria to dominate across trophic states, including oligotrophic systems, and that that climate change processes, including lake warming, increased water column stability, and increased frequency and intensity of storm events, will probably favour cyanobacterial blooms in both oligotrophic and eutrophic lakes.

WHAT CAN YOU DO?

There are also some simple individual actions that can be undertaken to help reduce the amount of nutrients going into our lakes:

- Eliminate your use of fertilizer, especially in areas near the water;
- Maintain your septic system, including having it pumped out on a regular basis and limiting the amount of water that goes into the system;
- Use phosphate-free cleaners, soap and detergents; and
- Protect the vegetated buffer zone on your shoreline and enhance it if needed. A healthy strip of native vegetation along your shoreline will absorb nutrients from your property before they enter the water!

Check out the Federation of Ontario Cottagers' Associations' (FOCA) *A guide to citizen science at the lake*, a document that provides lake stewards with the tools and information they need to monitor their own lake.