WHITE LAKE Property Owners Association Preservation Project

Special Report

Historical and Current State of White Lake Water Quality

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Historical and Current State of White Lake Water Quality

1. Introduction

"Good" water quality of the lake ranks as the most important value identified by the White Lake community, and maintaining or improving water quality is the most important issue needed to be addressed by any Lake Stewardship Plan. The community's concern has been heightened with the observation of blue green algae blooms in 2013, 2014, 2015, 2018, 2019, and 2020.

The physical characteristics of White Lake have an important influence on overall water quality. White Lake is shallow (average depth 3.1m; maximum depth 9.1m), has a significant amount (90.3%) of littoral zone (shoreline areas with aquatic plants including wetlands), and has a slow flushing rate of only 0.89 times per year. The main basins of the lake are generally isolated, and there are only a few small tributaries that drain into the lake, which contribute to the low flushing rate, and to a lack of mixing of the various bays of the lake. The water column itself does not experience significant stratification that is common to most lakes when temperatures increase following ice-out. These physical conditions must be considered when the lake's water quality is being assessed. The distinct basins and the lack of stratification make it a somewhat complex task to measure and assess the overall water quality of White Lake without multiple samples being taken from the same locations and frequently over the ice-free season.

In its natural state, the water level of the lake would rise and fall with precipitation and seasonal change. From the time the original dam was constructed in 1845, through until the 1960s, water flows were managed such that the levels fluctuated about 1.5 metres per year, resulting in relatively clear waters and healthy walleye spawning grounds. When the dam was rebuilt in 1968, the water management regime was changed to maintain a high stable water level all summer, to accommodate the interests of the property owners at the time. This led to a gradual deterioration of water quality[1]. In 1977, the management regime was adjusted, primarily to benefit fish habitat, and since that time, the lake has undergone annual drawdowns of about 0.5 metres (18 inches). This regime of summer draw-downs has led to the rehabilitation of walleye spawning beds.

Disposal of Crown land for cottage lots and subdivisions began early in the 20th century and continued through until 1966. Today, the shoreline is comprised of a mixture of Crown land and private land developed with cottages, residences, or commercial enterprises. Shoreline development inevitably has an effect on the water quality of any lake. This happens through:

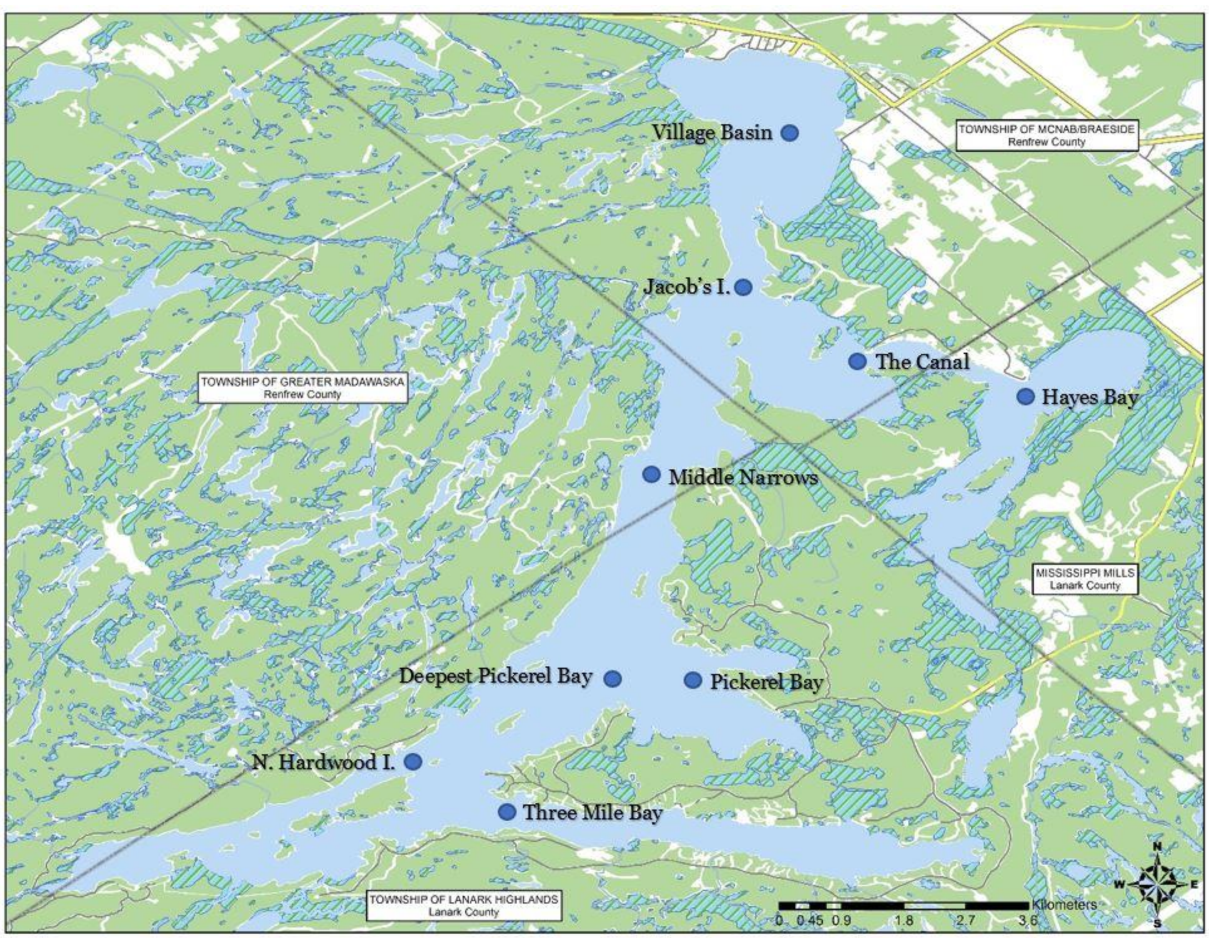
- Removal of natural vegetation (and in some cases, planting of lawns or creation of artificial beaches). This allows or increases soil erosion and run-off, including run-off from septic systems, leading to increased nutrients (phosphorus, nitrates) and sediments entering the water;
- Hardening of surfaces (roads, driveways, rooftops of buildings), which allow for increased runoff and potentially increased nutrients entering the lake;

[1] J.P. Ferris, White Lake Integrated Resources Management Plan, Part I, *Ministry of Natural Resources, Lanark and Renfrew Counties, December, 1985.*

- Use of fertilizers and pesticides;
- Leachate from septic systems that can bring nutrients and bacteria into the lake.
- Faulty or poorly maintained septic systems are more likely to leak bacteria and nutrients than properly maintained systems;
- Increased boat traffic that can stir up sediments in the lake, contribute to shoreline erosion, potentially spill petroleum products, and sometimes disturb fish and wildlife as well as their habitats;
- Intensification of development and redevelopment of cottages to larger all-season dwellings with production of more waste water (dishwashers, washers, multiple washrooms).

2. Measuring Water Quality and Data Sources

The water quality of White Lake has been monitored and analyzed in various ways since the early 1970s. The Ontario Ministry of the Environment and Climate Change (MOECC) started an active program of measuring water quality in Ontario lakes in the 1970s. From the beginning, landowners participated in the process. The Cottagers Self-Help Program began in 1971 as a partnership in which cottagers collected samples and took water clarity readings (using the Secchi disk), and MOE performed the analyses for Chlorophyll a, and in later years, Total Phosphorus. The White Lake Water Quality Committee was established in 1973 to perform sample collection for the program and this committee



became a part of the White Lake Property Owners Association (WLPOA) when it was formed in 1987. The Self-Help program continued to operate through the 1970s and '80s, and was replaced by the Lake Partner Program (LPP) which continues today. Since 2005, the White Lake Property Owners Association have augmented these data by collecting water samples at additional locations and having them analyzed at a private lab for a range of additional parameters including: bacteria (Escherichia coli); volatile organic compounds (VOCs); petroleum products/by-products; and herbicides.

The White Lake Preservation Project (WLPP), which began in 2013, added a significant number of new sites to the Lake Partner Program, and sampled for phosphorus on a monthly basis, and water clarity and temperature on a bi-weekly basis, from May through October, rather than only once per season. This expansion of the number of sites combined with monthly sampling has allowed for a better understanding of the lake's condition. In 2019, the Science Programs of the WLPOA and the WLPP were merged.

The Mississippi Valley Conservation Authority (MVCA) undertook, under contract to the Township of Lanark Highlands, additional sampling in 2007 (total of 3 sites). In addition to the monitoring of water clarity and phosphorus levels, MVCA included sampling and monitoring for Chlorophyll *a*, dissolved oxygen/temperature depth profiles, and pH. In collaboration with the White Lake Preservation Project, similar measurements were performed in 2015 and 2016 by the MVCA and again in 2017 with Watersheds Canada. Since 2014, the White Lake water quality monitoring program has expanded to 9 sites with bi-weekly readings for water clarity (Secchi disk depth) and temperature, and monthly sampling for Total Phosphorus with analysis for Total Phosphorus carried out by the Ministry of Environment and Climate Change (Lake Partner Program). Additional studies were completed at dozens of sites in all parts of the lake studying conductivity, pH, temperature, sediments, etc. of the lake including streams and their estuaries. This report contains only a small part of the data available on White Lake and is presented in full in WLPP/WLPOA annual reports on water quality (see www.WLPP.ca for all reports and more).

The Ministry of Environment and Climate Change has established a set of guidelines for desirable or safe levels of a long list of parameters. These guidelines, referred to as the Provincial Water Quality Objectives (PWQOs), will be referenced in the following discussion of water quality results for White Lake, as they provide scientifically-based levels for most parameters that measure water quality.

Although there has been a considerable amount of monitoring of White Lake's water quality since the 1970s, there was not a consistent or systematic approach taken comparable to data sets produced by the WLPP starting in 2014.

Over the past 45 years there have been changes to the locations of sampling, time of year sampled, parameters measured, and methods of collection and analysis all of which make pre-2014 data inadequate for the delineation of long-term trends in water quality. Also, prior to 2002, measurements for total phosphorus in both private and MOE laboratories had a much higher measurement error than the methods used under the Lake Partner Program today making comparisons of modern data with these older data sets of little value.

3. Historical Overview (to 2016): Lake Trophic Status

Trophic status is a useful means of classifying lakes and describing the general lake process in terms of the biological productivity of a lake. The classification includes three levels of trophic status (Table 1). Low trophic status, or oligotrophic, is typical of the cold-water lakes on the Canadian Shield, with clear waters and low levels of aquatic vegetation and algae. Mesotrophic status is typical of many of the lakes, especially off-shield lakes of Eastern and Southern Ontario; waters are less clear, and moderate levels of vegetation and algae growth can be expected. Eutrophic status is a state to be avoided, typical of highly enriched lakes, often caused by human-induced conditions; eutrophic conditions include heavy growth of vegetation, and frequent algae blooms.

Table 1: Lake Trophic Classification

Lake Trophic Status	Description	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	Secchi Disk Depth (m)
Oligotrophic	Lakes with low nutrient levels, limiting biological productivity. Water is often clear and cold with sufficient oxygen levels in the entire water column throughout the year; often supporting cool to cold water fisheries.	< 10 µg/L	<2µg/L low algal density	> 5 m.
Mesotrophic	Lakes with moderate nutrient levels, resulting in greater biological productivity. Water is often less clear with greater probability of lower oxygen levels in the lower water columns; often supporting cold to warm water fisheries due to a variable range of nutrients.	11 to 20 µg/L	2 to 4 µg/L-moderate algal density	3.0 - 4.9 m
Eutrophic	Enriched lakes with nutrients in higher concentrations. Water has poor clarity, especially in summer months when algae blooms and plant growth peaks. Oxygen levels are greatly reduced in lower water columns throughout the year due to excessive decomposition of aquatic vegetation; often support warm water fisheries.	≥21 µg/L	> 4 µg/L-high algal density	< 2.9 m

Three parameters that are used to establish the trophic status of a lake are:

- **Phosphorus** is the limiting nutrient for the growth of aquatic plants and algae. Phosphorus is present in a healthy lake, as it is needed to allow the growth of the algae and plants that sustain life in the lake. The level of phosphorus, measured as total phosphorus, is an important measure of the productivity of the lake, and high phosphorus levels usually contribute to more and larger algae blooms, and heavier growth of aquatic plants.
- **Water clarity**, as measured by use of a Secchi disk. The Secchi disk is a black and white metal disk that is lowered into the water until it can no longer be seen, at which point the measurement is taken. This is a measurement of the clarity of the water, and is determined by the amount of material that is suspended in the water (algae, phytoplankton, suspended soil sediments, and other materials). These materials are naturally found in our lakes, but if their levels are high, light will not be able to penetrate to deeper levels of the lake, reducing the photosynthesis rates of aquatic vegetation, which reduces oxygen levels, affecting the health and survival of fish and other aquatic life. The Secchi disk reading represents half the distance through which light penetrates the water column.
- **Chlorophyll *a*** is the green pigment contained in algae and aquatic plants that is used in the process of photosynthesis. The Chlorophyll *a* concentration is used to measure the abundance of algae and potential plant growth in the water, and is directly related to the amount of nutrients available. If the concentration of Chlorophyll *a* is high, then it can be assumed that the nutrient levels in the water are high as well, promoting growth of the algae. High concentrations of algae and vegetation can also cause oxygen depletion in the lake. As the algae and vegetation die off, the decomposition uses up available oxygen; if there are more organisms the amount of oxygen needed for decomposition increases.

Trophic classification offers a handy guideline for approximating the productivity level of a lake. These levels have been used by MOECC in the past as benchmarks beyond which water quality should not deteriorate. For example, if a lake measured total phosphorus at mesotrophic levels (between 11 and 20 µg/L), the water quality objective was to maintain levels below 20.

The figures for total phosphorus (in Table 1) and how they relate to the trophic status of a lake need to be read with the following points in mind. They were developed in 1979, as a part of the Provincial Water Quality Objectives (PWQOs). In 1994 it was recognized that the figures were being used "despite incomplete knowledge of relationships between total phosphorus concentrations in water and the corresponding algal growth in lakes and rivers" so their status was changed to "interim". The 2010 Lakeshore Capacity Assessment Handbook points out that "these numeric objectives fail to protect against the cumulative effects of development…." and that the numeric objectives for total phosphorus "ignores fundamental differences between lake types and their nutrient status…". Further, the presence of zebra mussels in a lake, like White Lake, renders traditional trophic level determinations inappropriate because zebra mussels greatly increase water clarity, while at the same time increases the growth of aquatic plants, while fostering algal blooms at very low total phosphorus levels (<10 ppb).

Since the development of the PWQOs some fifty years ago, changes have been taking place: the climate has warmed, and there are longer ice-free periods; there is a major increase in development on the Lake; zebra mussels have invaded the Lake and their population has expanded explosively since 2016; and plant growth appears to be increasing, especially Eurasion milfoil. White Lake has experienced a significant number of both green and blue-green algal blooms and increased plant growth. Also, water clarity has doubled, chlorophyll-a concentrations have collapsed, making determination of trophic level impossible using the criteria given in Table 1.

In addition to the generalized guideline of trophic levels, MOECC has established a set of water quality guidelines, referred to as "Provincial Water Quality Objectives." These offer specific levels for a large array of chemicals and compounds – levels that are set based on public health and aesthetic criteria.

Table 2: Trophic Status 1973-2015

DATE/Source	Water Quality Measurements			TROPHIC STATUS
	Secchi disk (m)	Chlorophyll *a* (µg/L)	Total Phosphorus (µg/L)	
1973[2]	Min 1.5 Max 4.5	Min 1.1 Max 14.0		Low Eutrophic
1975[3]	Min 2.4 Max 4.9	Min 1.8 Max 8.5	Max 38.0	Low Eutrophic
1972-1987[4]	Min 1.8 Max 3.2	Min 3.3 Max 9.6		Low Eutrophic
1987[5]	Min 1.8 Max 4.5	Min 1.3 Max 7.6		Low Eutrophic
2007[6]	Min 3.3 Max 4.7	Min 3.3 Max 5.3		Mesotrophic
2015[5]	Min 2.1 Max 5.0	Min <0.5 Max 3.9	Max 21.3	Mesotrophic

[2] Robinson, MOE, 1974. Enrichment Status of White Lake, Renfrew and Lanark Counties, Ontario

[3] Doyle, MOE, 1975. Cottage Pollution Survey of Three Mile Bay and Pickerel (Bennett) Bay on White Lake, Renfrew and Lanark Counties

[4] Ministry of the Environment, January, 1989. Cottagers' Self-Help Program, Enrichment Status of Lakes in the Southeastern Region of Ontario.

[5] Mississippi Valley Conservation, 2007. State of the Lake Environment Report 2007: White Lake.

[6] White Lake Preservation Project, 2015. Water Quality Monitoring Program 2015 Report.

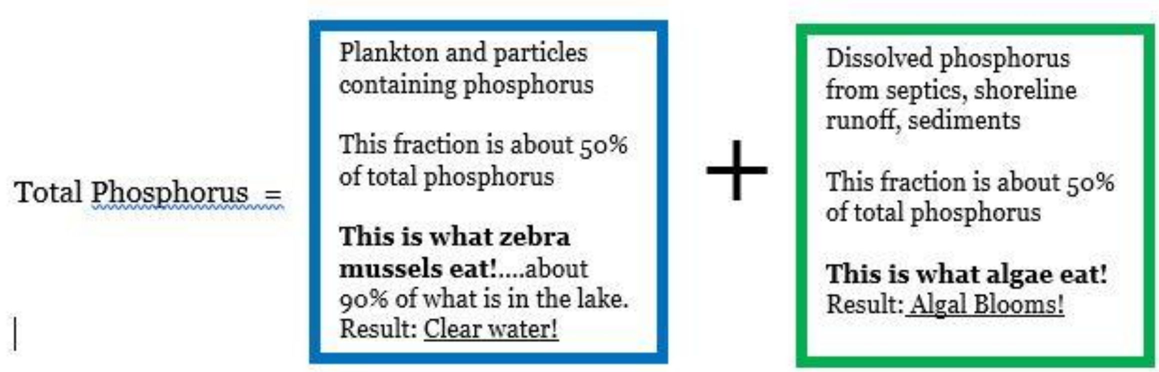
Since the 1970s, when measurements of the lake's trophic status were first established, White Lake has measured in the mesotrophic, or low eutrophic status (Table 2). A Canadian ban on phosphates in detergents significantly reduced the amount of phosphates entering our surface waters in the 1970s and 1980s. As a result, many of our lakes saw some improvement in water quality after that. Changes in dam management in the 1970s also had an effect on water quality of the lake.

Observations - Historic Trophic Status

- There have been various approaches to monitoring and measuring water quality on White Lake over the past 45 years, but not with the consistency needed to provide reliable trends through time.
- Since the 1970's the available data indicate that White Lake has been a moderately productive lake, falling into the category of mesotrophic or low eutrophic.
- The sampling regime for the lake has been broadened to monthly samples taken at locations representing the various distinct basins of the lake, starting in 2015.
- Since the arrival of zebra mussel, the tropic status of White Lake cannot be determined using traditional guidelines.

4. What is Total Phosphorus?

Total phosphorus is the sum of a number of different phosphorus-containing components including plankton and other particulate matter plus phosphorus compounds dissolved in water.



The total phosphorus level is a very important measure of water quality in our lakes and rivers. Phosphorus is the nutrient that is most influential in controlling the growth of algae and aquatic plants. Higher levels of phosphorus lead to higher levels of algae and plant growth. Phosphorus levels above 20µg/L indicate a highly productive (eutrophic) state; when levels approach or exceed 20µg/L, there is a greater likelihood of excess algae blooms and growth of aquatic plants. Phosphorus is a naturally-occurring element in our surface waters, and is necessary for plant growth in a healthy ecosystem. However, phosphorus levels can be elevated as a result of shoreline development, land clearing and agriculture.

Phosphorus moves into the water from different sources including natural, human-induced, and internal loading from phosphorus released from sediments, which have concentrations of phosphorus about 200,000 times greater than that of the water column above it.

Table 3: Sources of Phosphorus Entering Waterbodies

External Natural Sources	· Decay of organic material. · Weathering of rocks/minerals containing phosphorus. · Erosion of soils. · The atmosphere during rain and snow events. · Groundwater.
Man-made Sources	· Erosion and runoff from exposed agricultural lands. · Application of fertilizers and manure. · Septic systems, particularly aging systems that have not been upgraded. · Erosion and runoff from hardened surfaces and roads. developed areas (including lawn Application fertilizers, animal waste, detergents from car washing. · Erosion and runoff from construction sites or logging (exposed soils are prone to higher erosion that vegetated areas).
Internal Natural Sources	· Lake sediments: phosphorus that is held in the lake sediments can be released into the water column if conditions permit. Sediment in the shallow sections of the lake may be stirred up by high winds, waves, or motorboats. Internal loading of phosphorus can be accelerated by low oxygen levels at the lake bottom (<2µg/L), which allow chemical reactions to occur that release phosphorus otherwise locked in the lake sediments. · Presence of zebra mussels – as zebra mussels filter feed from the phytoplankton of the lake, they remove phosphorus that is tied up in the phytoplankton, and deposit this phosphorus into the lake sediment of near-shore areas. · Aquatic macrophytes draw phosphorus from sediments into their stems and leaves. Upon senescence this phosphorus is released into the water column

The sources of phosphorus inputs to White Lake would include all of the above-noted categories. Estimates of the levels of phosphorus entering a lake from different sources can be done through applying the Lakeshore Capacity Model.

White Lake receives phosphorus from each of these categories; and data shows that sediment release is an important source of phosphorus, particularly late in the season when low oxygen levels may be present and water temperatures are high.

Recent studies done on sediment cores from White Lake[7] provides a historical record of nutrient loading in White Lake over the past 150 years. The authors of this study

[7] M. Murphy, C. Grégoire and J. Vermaire, Ecological response of a shallow mesotrophic lake to multiple environmental stressors: a paleolimnological assessment of White Lake, Ontario, Canada., *Lake and Reservoir Management, in press.*

concluded that for the sediments of White Lake, the top layers indicated a higher nutrient enrichment in recent years, suggesting that there has been increased phosphorus added to the lake during this time resulting in a degradation in water quality.

5. Historical Trends in Total Phosphorus Concentrations in White Lake: 1975 to 2015

In 1975, the Ministry of the Environment (Ferris, 1985) completed a study of total phosphorus concentrations at three locations on White Lake. Single samples were collected at approximately two-week intervals starting in mid-May and ending in mid-September. Samples were collected at Three Mile Bay, Pickerel Bay and the Village Basin at the North end of the lake.

Unfortunately, the analytical uncertainty associated with total phosphorus data was approximately ±30%, which was typical for measurements obtained using a now outdated analytical method[8]. This method had a limit of detection (LOD) of 5 ppb (±100% at the LOD) and for this reason was abandoned by the MOE in 2001. Further, prior to 2002, samples were not filtered allowing unwanted large zooplankton to be accidentally included in samples for analysis. This resulted in abnormally high results which were not representative of the actual total phosphorus present. It also gave erratic results because of the particulate nature of the contamination entering the water sample collected.

Since 2002 and up to 2015, the last pre-zebra mussel year, a number of total phosphorus determinations for White Lake were completed. Unfortunately, with the exception of the 2014/5 data, none of the samples were collected in a systematic way, but rather were taken as 'grab' samples at various times of the year and at various locations. It is important to note that all of the sampling sites were located in Zone 1, (see Appendix for Zone Map) the Main Water Body of White Lake, and that all analyses were completed at MOE Laboratories in Dorset, Ontario. This data is presented in the graph below where total phosphorus concentrations are plotted by day of year.

We know from hundreds of measurements made during the last seven years (WLPP/WLPOA reports[9], 2015-2020; see www.WLPP.ca), that the total phosphorus values are not identical at all sampling sites in this zone, but are normally is no more than a few ppb difference from one sampling location to another. This allows us to plot this data on a single graph for illustrative purposes.

Figure 1 shows that total phosphorus concentrations were low in the spring, increased until mid-July and then decreased to lower levels in the fall. The largest number of points were taken in the spring which, for shield-hosted lakes, would give the highest total phosphorus concentrations. For off shield lakes, like White Lake, better data would be

[8] B.J. Clark, Assessing variability in total phosphorus measurements in Ontario Lakes., Land and Reservoir Management, 26:63-72, 2010.

[9] D.C. Grégoire and D. Overholt, White Lake water Quality Monitoring Reports, 2015 to 2020.

gained if sampling dates had been more evenly distributed over the ice-free season, because the minimum TP value occurs in the Spring. The maximum TP value occurs later

Figure 2: Total Phosphorus by day of year for Three Mile Bay sampling site: 2015 - 2019

in the summer, which is needed to evaluate water quality. The best fit line (light blue) on the graph was calculated using a second order polynomial. This line indicates that statistically, total phosphorus concentrations can be in excess of 20 ppb (Provincial limit) from day 188 to day 230 or about 42 days during the ice-free season.

Figure 1: Lake Partner Program Total Phosphorus Data 2002 to 2015

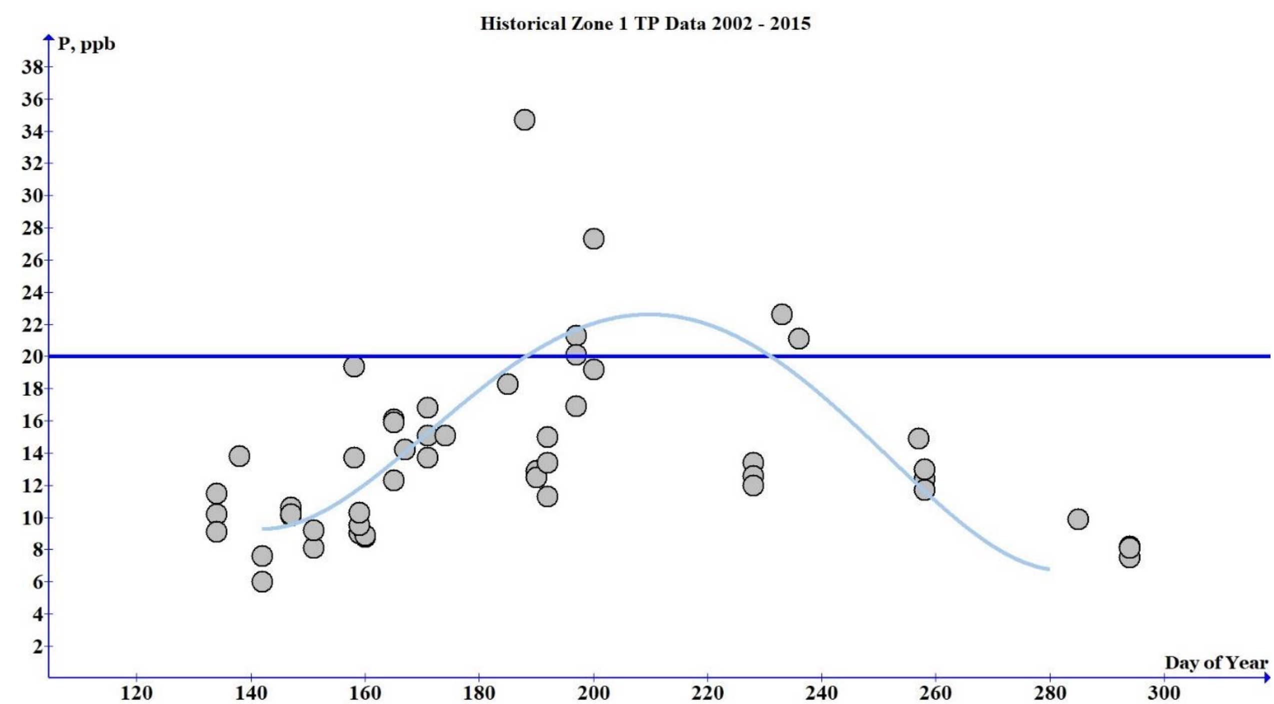
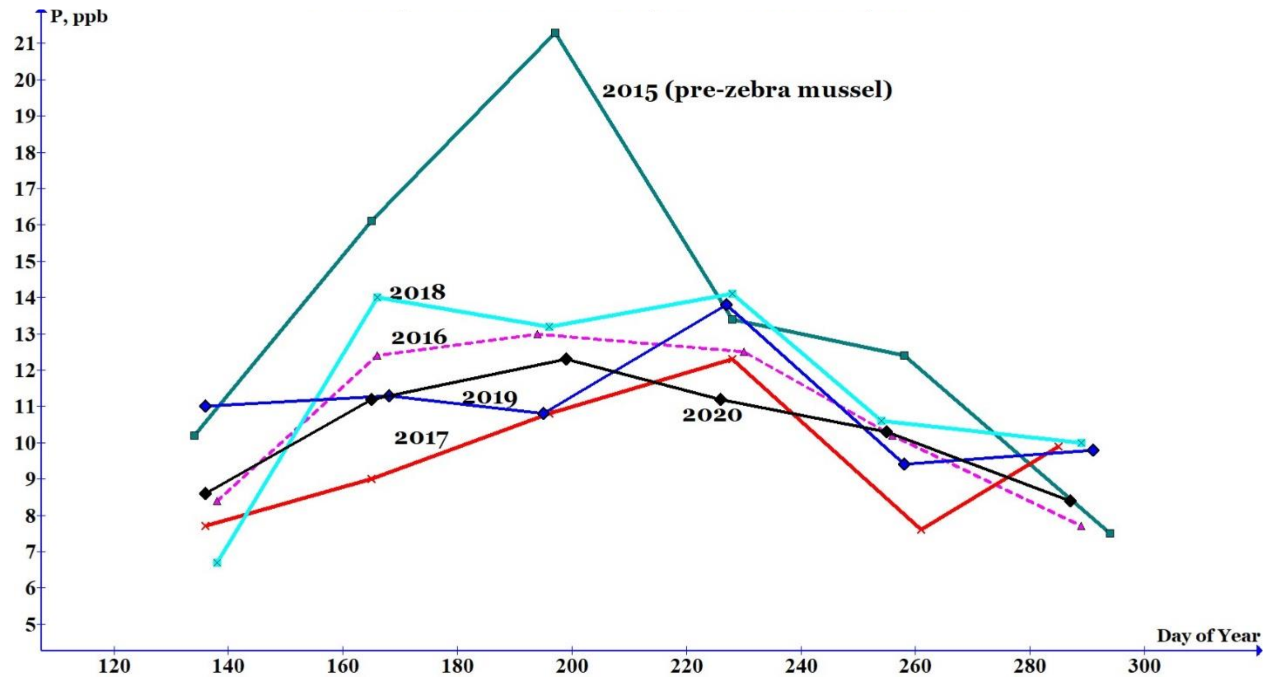


Figure 2 below graphically shows the change in total phosphorus values (Lake Partner Program) for the Three Mile Bay site during the ice-free season for 2015 to 2020. Note that the 2015 curve represents the last year prior to the infestation of White Lake by zebra mussels.

Figure 2: Total Phosphorus by day of year for Three Mile Bay sampling site; 2015 - 2020



Observations - Total Phosphorus – Historical Perspective

- Study of historical total phosphorus levels for White Lake show that for as far back as 1975, total phosphorus concentrations may have exceeded the 20 ppb limit set by the MOE.
- The quality of analytical data has to be taken into account when comparing results from different analytical methods.
- The highest total phosphorus levels were measured in mid-July.
- Shield vs non-Shield Lakes. For lakes on the Canadian Shield, a single sample in the Spring will usually suffice as this is the time when shield-based lakes will show highest readings for phosphorus and lowest for Secchi disc. White Lake is predominantly underlain by limestone rock, which gives the lake the chemical properties of a non-shield lake. In this case, sampling needs to be done on a monthly basis to provide reliable results.
- The use of means or averages for the interpretation of total phosphorus data for an off-shield lake is not accepted practice and leads to erroneous conclusions.
- Up until 2014, the quality and quantity of total phosphorus data collected for White Lake were not good enough to be used in determining long-term trends, although we know that maximum values remained high and above the 20 ppb Provincial limit.

6. Changes in Maximum Total Phosphorus Levels Since the Arrival of Zebra Mussels: 2016 to the Present

When White Lake became infested with zebra mussels in 2016, the chemistry of the lake changed dramatically. Perhaps the most significant change was in the way phosphorus was cycled in the lake. Rather than being relatively evenly distributed in the volume of the lake and then finding its way to the sediments below at the end of the summer, much of the phosphorus is now consumed by zebra mussels and deposited on and in near-shore sediments. This significant increase in phosphorus in the near shore environment is what is responsible for the explosion of aquatic plants along White Lake shorelines as well as promoting the growth of filamentous green algae and microcystis, a blue-green algae which is potentially toxic.

Total phosphorus is not a single compound, but rather a complex mixture of both particulate (living and dead) and dissolved sources of phosphorus. By definition, total phosphorus is the amount of phosphorus derived from all sources (particulate and chemical species) which will pass through an 80-micron filter.

The easiest way to think of total phosphorus is the sum of: 1) particulate phosphorus; and 2) dissolved phosphorus. The scientific literature on lake chemistry suggests that the two 'types' of phosphorus occur in lakes like White Lake in approximately equal parts. Why is this important?

Zebra mussels are filter feeders and are capable of removing from water all particles as small as one micron (a millionth of a metre). Because there are literally hundreds of millions of zebra mussels in White Lake, and because they can each filter up to 1.5 litres of water per day means that they can together remove most of the phosphorus containing particles in the lake over the summer. In other words, they can remove 50% of the total phosphorus which is that portion found in lake particulates. This is why the clarity (see water clarity section below) of the lake has more than doubled since the arrival of zebra mussels.

To illustrate this, the table below gives the maximum total phosphorus concentrations for samples taken from three deep water sites in Zone 1 of White Lake, the Main Water Body.

Table 4: Maximum Total Phosphorus (ppb) by Year: 2015 to 2020

Location	Year						
	2014	2015	2016	2017	2018	2019	2020
Three Mile Bay	-	21.3	13.4	12.3	14.2	13.9	12.3
N. Hardwood I.	21.2	20.1	14.1	12.0	14.1	12.9	13.0
Middle Narrows	-	16.9	12.7	11.3	12.6	13.8	12.2

Shaded areas denote maximum TP in mid-July; unshaded areas denote maximum TP in mid-August. The data for 2014 and 2015 (pre-zebra mussels) show total phosphorus concentrations ranging from 16.9 to 21.3 ppb. Once zebra mussels infested the lake (2016+), the concentration of total phosphorus decreased by about half and have remained relatively low since that time. The shaded area in the table indicates that for these location and dates, the maximum value for total phosphorus occurred in mid-July. Since 2017 and for the unshaded data, these maximum values occurred in mid-August, approximately one month later. TP maxima for 2020 occurred in mid-July. The graph below is a more dramatic presentation of the same data.

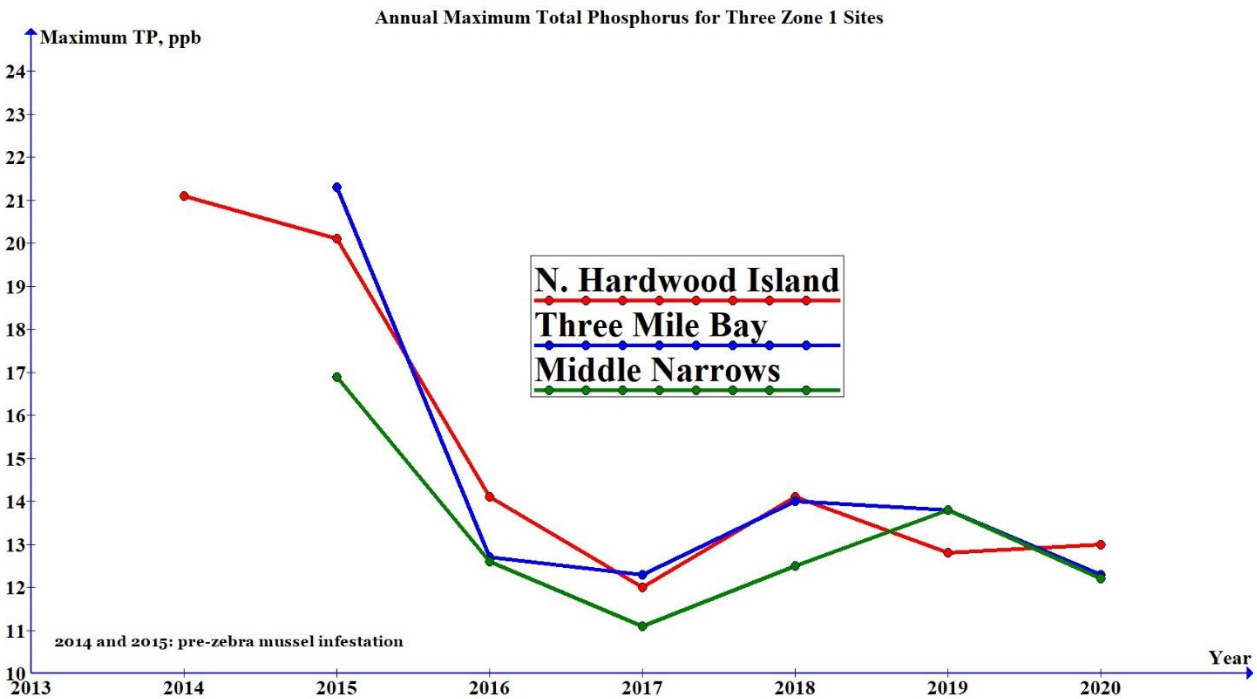


Figure 3: Change in Maximum Total Phosphorus Levels: 2015 to 2019

The phosphorus budget for White Lake is complex. White Lake has an internal[10] load meaning that some of the phosphorus found in sediments is released into the water column above. This can happen because of low oxygen or iron levels in the sediment and by increased warming of the sediments as a result of more sunlight reaching the lake floor. This may explain the shift in total phosphorus maxima from mid-July to mid-August since the invasion of zebra mussels. Also, the health of the zebra mussels, their numbers and size as well as other parameters can all effect the efficiency of lake water filtration by mussels. Taken together, this may be responsible for shifting the date on which the maximum total phosphorus concentration occurs.

[10] D.M. Orihel et al., Internal phosphorus loading in Canadian fresh waters: a critical review and data analysis., Can. J. Fish. Aqat. Sci. 74: 2005-2029 (2017)

7. Consequences of Changes in Phosphorus Cycling Due to Zebra Mussels

One often repeated goal by lake managers is to take steps to keep total phosphorus levels below the 20 ppb Provincial limit. At total phosphorus concentrations at or above this limit, it is said that the possibility of algal blooms increases significantly. Reaching this limit while experiencing frequent and extensive algal blooms is a clear sign that the lake has reached shoreline development capacity.

It is clear from the above discussion that White Lake has frequently exceeded the Provincial limit in years dating back to at least 1975 and is currently still doing so. In addition to this, since at least 2013 White Lake has been experiencing blue-green algal blooms, some of which were toxic. In 2018, there were two extensive blue-green algal blooms in White Lake, one of which was certified toxic and the other presumed to be so[11]. In 2019 and 2020, blue-green algal blooms occurred in Three Mile Bay, but were not tested by the MOE for toxins.

Since 2016, the highest total phosphorus concentration measured in White Lake was 14.2 ppb, well below the Provincial limit. As it turns out, the fraction of total phosphorus remaining in open water after zebra mussels have fed is composed of dissolved phosphorus compounds. This is the phosphorus that algae feed upon. This means that the potential to have an algal bloom is undiminished by the activity of zebra mussels. As far as algae are concerned, the available phosphorus for growth is unchanged from that available before zebra mussels arrived[12].

Now that zebra mussels are present, the proliferation of a species of noxious blue-green algae (cyanobacteria) is favoured: *microcystis aeruginosa*[13,14]. This species of blue-green algae thrives in waters containing low concentrations of phosphorus. It also has the ability to fix nitrogen from the air and successfully compete for nutrients against other species of algae present. Additionally, zebra mussels selectively filter out and excrete undigested *microcystis* further adding to its competitive edge against other algae, which the mussels will consume. During the last two years, White Lake has experienced three significant *microcystis* blooms. At the time when each bloom occurred, the total phosphorus concentration in lake water was less than 10 ppb. Of great importance is the realization that the Provincial target of 20 ppb total phosphorus <u>no longer applies</u> to lakes, like White Lake, which have been invaded by zebra mussels.

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[11] J.G. Winter, A. M. DeSellas et al, Algal blooms in Ontario, Canada: Increases in reports since 1994., *Lake and Reservoir Management,* 27:107-114, 2011

[12] T.M. Higgins et al., Effects of recent zebra mussel invasion on water chemistry and phytoplankton production in a small Irish lake, *Aquatic Invasions (2008) Vol 3, Issue 1: 14-20*.

[13] D.F.Raikow et al., Dominance of the noxious cyanobacterium *Microcystis aeruginosa* in low-nutrient lakes is associated with exotic zebra mussels*., Limnology and Oceanography, 49(2), 2004, 482-487*.

[14] L.B. Knoll, et al, Invasive zebra mussels (Dressina polymorpha) increase cyanobacterial toxin concentrations in low-nutrient lakes, *Can. J. Fish. Aquat. Sci., 65: 448-455 (2008).*

Observations - Total Phosphorus – 2015 to 2019

- Since the arrival of zebra mussels, total phosphorus concentrations in the lake have been reduced by about 50%. The cycling of phosphorus in the lake is now permanently changed.
- The reduction in total phosphorus in lake waters is entirely due to the presence of zebra mussels and not from any human intervention.
- In addition to phosphorus entering the lake by other means (pollen, rain, etc.), phosphorus released from sediments is now being transferred to the near shore environment rather than finding its way back to the lake bottom at the end of the season.
- The increased clarity of White Lake is due to the removal of particulate matter in the water column by zebra mussels.
- Transport of phosphorus to near shore areas by zebra mussels encourages growth of aquatic plants and an increase in algal blooms.

8. Water Clarity (Secchi depth)

Water clarity is determined by measuring how far down sunlight can penetrate into the water by lowering a Secchi disk into the water and measuring the deepest point that it is visible. The Secchi disk depth indirectly indicates the amount of algae/phytoplankton, suspended soil, sediments, and other materials in the water column. The larger the number, the clearer the water, as the number represents the depth to which the Secchi disk is visible.

Monitoring of water clarity by WLPOA occurred for most years at two sites (Pickerel Bay and Three Mile Bay) from 2002 to 2011 (Table 5). Starting in 2014, bi-weekly measurements were made at one site and by 2016, nine sites were being monitored.

Table 5: Secchi Depths at Two Sites

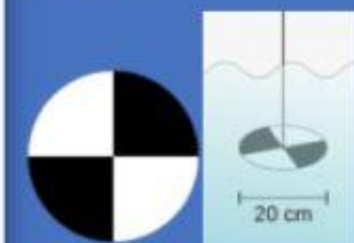
Secchi Depth, metres		
Date	**Pickerel Bay**	**Three Mile Bay**
June 7, 2003	2.9	3.0
July 3, 2004	2.9	2.8
July 19, 2006	2.5	2.3
May 27, 2007	2.7	3.0
June 8, 2008	2.6	2.5
May 31, 2009	2.7	3.1
June 8, 2014	2.9	2.8
July 16, 2015	2.7	2.1
July 12, 2016	3.3	3.3
July 15, 2017	4.6	4.1
July 15, 2018	4.9	5.0
July 14, 2019	4.7	4.7

Results over the period 2002-2016 consistently show most Secchi disk readings in the range of 2.5 to 3.3m, indicating water clarity on the edge of the mesotrophic/eutrophic level.

These data were single measurements, and timing of sampling varied year-to-year. For 2014 to 2019, samples were taken bi-weekly, but sampling sites and dates used in the

WHAT IS SECCHI DEPTH AND HOW IS IT MEASURED?

The Secchi depth is a measure of the clarity or transparency of the water. The Secchi disk, named after an Italian scientist, is used to make the measurement. The disk is segmented black and white and 20 cm in diameter:



The disk is lowered into the water until it is no longer visible. The recorded depth, in metres, is one half of the distance that light can travel through the body of water being measured. A Secchi depth of 6 metres, for example, means that light can travel through 12 metres of water. White Lake is a maximum of 9.1 metres in depth.

table were selected to coincide with older data. The maximum Secchi depth measured for years 2003 to 2013 are not available since only a single measurement was made during this period. For later years, bi-weekly measurements were taken and a maximum Secchi depth during the ice-free season was thus obtained. These are presented in Table 6.

Table 6: Maximum Secchi Depths by Year for Deepest Pickerel Bay Site

The presence of zebra mussels, confirmed in 2015, became an important contributing factor to increased water clarity, as this invasive species eats the plankton that floats in the water, thereby clarifying the water column. Since 2016, the clarity of White Lake waters has more than doubled.

Another way of showing how the clarity of White Lake has been increasing in recent years in all parts of the lake is to consider the number of times volunteers were unable to obtain a Secchi depth (because the water was too clear for its depth) at each of the five deep water sites monitored on a regular basis.

Deepest Pickerel Bay	
Year	**Secchi Depth, m**
2014	4.5
2015	6.0
2016	7.3
2017	7.6
2018	>9.1
2019	7.3

Table 7: Frequency of Secchi Depth Readings Exceeding Sampling Site Depth: 2015 to 2019

Sampling Site	Max. Depth, m	2015	2016	2017	2018	2019
Jacobs I.	4.0	2	8	11*	11	10
N. Hardwood I.	5.0	1	3	5	5	4
Middle Narrows	6.0	0	1	2	2	3
Three Mile Bay	6.0	1	2	5	3	5
Pickerel Bay	7.5	0	0	1	2	1
Total		4	14	24	23	23

*maximum number of measurements made per year

These data give the number of times the Secchi depth exceeded the site depth because of increased water clarity for each year up to 2019. For example, for Jacobs I., in 2015, there were only two occasions out of a possible 11 that the Secchi depth exceeded the water depth at the site. This increased to 8 times in 2016 and finally 11 in 2017 and 2018, and 10 in 2019. Looking at the total number of times Secchi depths could not be read for all sites combined, these increased from 4 in 2015, to between 23 and 24 starting in 2017. These data along with graph above it indicate that water clarity may have stabilized.

Future observations may reveal that changes in Secchi depth may be an indicator of the health of the zebra mussel population in White Lake.

Observations - Water Clarity

- Since the infestation of Zebra Mussels in White Lake, water clarity has more than doubled.
- Increased water clarity means that sunlight can now reach the bottom of the lake in all areas for most of the ice-free season.
- Increased water clarity will result in increased propagation of aquatic plants at greater water depths.

9. Chlorophyll *a*

Water clarity is influenced by the amounts of algae or phytoplankton present in the water. In addition to using a Secchi disk to measure water clarity, "Chlorophyll *a*" can be used to measure the abundance of algae and potential plant growth in the water, and is directly related to the amount of nutrients (particularly phosphorus) that are available. If the concentration of Chlorophyll *a* is high, then it can be assumed that the nutrient levels in the water are high as well, promoting growth of the algae. In addition to the direct effects of algae, high concentrations of algae and aquatic vegetation can cause oxygen depletion in the lake. As the algae and vegetation die off, the decomposition of vegetative matter (algae and aquatic plants) uses up available oxygen. Reduced oxygen will have a negative effect on fish and other aquatic organisms. Measuring levels of Chlorophyll *a* is not routine today, as more precise water quality results are available through measuring Total Phosphorus levels and other parameters.

There are very limited data for Chlorophyll *a* concentrations in White Lake, so no trends through time can be established. Since 1987, sampling was only done in 2007 and 2015. In those two years, the MVCA took three samples over the ice-free season for each location (3 locations in 2007; 5 in 2015) (Table 8).

When zebra mussels colonized the lake, Chlorophyll *a* levels collapsed to levels at or below the limit of detection for the analytical method used. However, this should not be considered an improvement in water quality as the low readings only reflect the presence of zebra mussels and not a sudden decrease of phosphorus inputs into the lake.

Table 8: Chlorophyll *a* (µg/L): Mean values 2007, 2015, 2017

Year	Pickerel Bay	Three Mile Bay	Sunset Bay	North Hardwood	Jacob's Island	Middle Narrows
2007	5.3	3.3	5.3			
2015	1.2	1.6		1.5	1.5	1.4
2016	<0.5*	<0.5	<0.5	<0.5	<0.5	<0.5
2017	0.5	0.5	0.5	0.5	0.5	0.5

Source: 2007, 2015, 2016: Mississippi Valley Conservation Authority; 2017:

*Limit of detection is 0.05 µg/L.

Observations - Chlorophyll a

- Chlorophyll *a* values for 2007 indicate a mesotrophic/eutrophic status.
- Chlorophyll *a* values for 2015 show an oligotrophic trophic status, although this is an anomaly, as results were skewed by the presence of zebra mussels.
- Chlorophyll *a* values for 2016 and 2017 collapsed to near or at the limit of detection likely as a result of the action of zebra mussels filtering out phytoplankton giving rise to low Chlorophyll *a.*
- Chlorophyll *a* now cannot be used as a measure of trophic level or even of biological activity in White Lake

10. Temperature and Dissolved Oxygen Depth Profiles

The concentration of dissolved oxygen (DO) in the water column is a critical factor for the survival of fish and other aquatic fauna. The temperature/oxygen regime determines the type of fish species that can be supported in the lake environment. As the temperature of the water rises, the amount of dissolved oxygen in the water decreases, which affects the survivability of fish deeper in the lake. This is particularly important for cold water fish species such as lake trout, which spend summer months in the depths of the lakes. White Lake, however, supports a warm and cool water fishery (cool water species include walleye and pike; and warm water species include perch, bass, sunfish, etc.). These fish species are more tolerant of low oxygen levels than cold water fish species. Guideline levels have been established by the Ontario MOECC for warm water fish, as a part of the Provincial Water Quality Objectives (Table 9). Cool water fish would generally require a minimum of 3mg/L of DO, but in their early life stages would be less tolerant, and require at least

Table 9: Provincial Water Quality Objective for Warm Water Fish

Temperature °C	DO mg/L
0	7
5	6
10	5
15	5
20	4
25	4

Source - PWQO, MOE, 1994

5mg/L. A determinant of a healthy sport fishery is the minimal oxygen tolerance of the forage fish that support it.

Knowledge of oxygen levels at the lake bottom is also important to help understand whether low oxygen conditions exist, because lack of oxygen will contribute to the release of phosphorus from lake sediments. Depth profiling for temperature and dissolved oxygen took place in 2007, 2015 and 2016, by the MVCA. In 2007, three sites were monitored in May, July, and September: Pickerel Bay, Three Mile Bay, and Sunset Bay. In 2015, six sites were monitored, also in May, July, and September: Pickerel Bay, Three Mile Bay, Hardwood Island, Jacob's Island, The Canal, and Middle Narrows. Results are presented in Tables 10 a, b, and c for the two sampling sites that the 2007 and 2015 monitoring programs had in common: Three Mile Bay and Pickerel Bay. Results obtained in 2016 are similar to those obtained in 2015 and are not duplicated here for the sake of brevity.

Table 10a: MAY Temperature and Dissolved Oxygen: 2007 and 2015

Depth (m)	Three Mile Bay				Pickerel Bay			
	2007		2015		2007		2015	
	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0.1	16.9	4.8	15.9	10.1	16.1	5.0	16.3	10.5
1	16.3	5.7	15.7	10.2	15.4	5.8	15.6	10.7
2	15.7	6.2	15.4	10.2	15.1	6.5	14.8	10.8
3	15.6	6.8	15.2	10.2	15.1	6.8	14.7	10.7
4	15.6	7.2	14.9	10.1	14.9	6.9	14.6	10.6
5	15.5	7.3	14.7	10.1	14.9	6.4	14.5	10.5
6			11.6	4.7	14.7	5.1	14.4	10.4
7					14.7	4.5	12.9	9.4
8					14.4	4.1	12.0	8.0
9					14.4	3.7		

Table 10b: JULY Temperature and Dissolved Oxygen: 2007 and 2015

Depth (m)	Three Mile Bay				Pickerel Bay			
	2007		2015		2007		2015	
	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0.1	21.4	9.6	24.7	8.2	21.9	8.9	24.5	8.5
1	21.8	10.7	23.9	8.1	21.9	9.9	23.7	8.4
2	21.8	10.1	23.5	8.1	21.8	9.0	23.8	8.4
3	21.7	8.0	23.3	7.9	21.8	6.8	23.3	8.2
4	21.4	6.6	23.3	7.7	21.7	6.0	23.2	7.8
5	21.2	5.4	23.2	7.6	21.7	5.0	23.7	7.5
6					21.5	4.4	23.1	7.4
7					21.2	3.7	22.9	6.7
8					19.7	3.2		
9					18.6	2.3		

Table 10c: SEPTEMBER Temperature and Dissolved Oxygen: 2007 and 2015

Depth (m)	Three Mile Bay				Pickerel Bay			
	2007		2015		2007		2015	
	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0.1	21.8	8.5	21.0	8.6	21.7	8.0	21.8	8.2
1	21.8	8.4	20.9	8.3	21.7	6.6	21.4	8.1
2	21.7	6.8	20.7	8.3	21.7	5.5	21.2	8.1
3	21.7	5.6	20.6	8.3	21.6	4.6	21.0	8.1
4	21.6	4.9	20.5	8.0	21.6	4.2	21.0	8.1
5	21.6	4.1	20.5	7.8	21.6	3.7	20.9	8.0
6			20.7	0.6	21.6	3.4	20.9	7.9
7					21.6	3.1	20.9	8.0
8					21.5	2.9		

Table 11: SEPTEMBER 2015 Temperature and Dissolved Oxygen

Depth (m)	Three Mile Bay		N. Hardwood Island		Pickerel Bay		Middle Narrows		Jacob's Island		The Canal	
	Temp (℃)	**D.O.** (mg/L)	Temp (℃)	D.O. (mg/ L)	Temp (℃)	D.O. (mg/L	Temp (℃)	D.O. (mg/L)	Temp (℃)	D.O. (mg/L)	Temp (℃)	D.O. (mg/L)
0.1	20.96	8.61	21.03	7.98	21.75	8.24	21.77	8.66	21.18	8.95	20.30	9.25
1	20.87	8.29	20.98	7.99	21.4	8.12	21.51	8.08	20.67	8.53	18.45	9.54
2	20.67	8.34	20.81	8.05	21.16	8.14	21.19	8.06	20.3	8.46	18.41	9.32
3	20.56	8.29	20.76	8.01	21.01	8.1	21.04	8.10	20.1	8.54		
4	20.52	7.95	20.74	7.93	20.96	8.06	20.92	8.07				
5	20.47	7.76	20.55	7.35	20.93	7.96	20.83	7.88				
6	20.67	0.6			20.92	7.92	20.73	7.67				
7					20.88	7.97						
8												

Dissolved Oxygen (DO) levels in both years fell within the Provincial Water Quality Objectives for warm water fish species (>4 mg/L at temperatures less than 25˚C) with only a few exceptions. The exceptions were deeper samples taken in 2007 from Pickerel Bay throughout the year, and in September 2015, from Three Mile Bay.

In 2015, levels of DO at different depths were lowest at the Hardwood Island site and highest at The Canal. The dissolved oxygen conditions in 2015 meet or exceed the PWQO for warm water fish species (bass, walleye, pike, perch) for all but one instance. The single exception is the September reading for Three Mile Bay, which as previously noted shows 0.6 mg/L oxygen at the 6m depth (Table 11). In the future, it may be helpful to have readings for mid-to-late August, and at the deeper parts of the lake where some degree of stratification may be taking place. (Red highlights indicate oxygen levels below the PWQO recommended level for warmwater or cool water fish).

Observations - Temperature and Dissolved Oxygen Depth Profiles

- Overall, the lake's temperature and dissolved oxygen conditions meet the Provincial Water Quality Objective for warm water fish species (bass, walleye, pike, perch), > 4 mg/L at temperatures less than 25° C.
- There were no instances of anoxic (no oxygen) conditions, but Three Mile Bay was very close to anoxic in September, 2015, and Pickerel Bay levels were below 4mg/L at lower depths in 2007.
- Temperature depth profiles showed only a small difference in temperature through the water column indicating good mixing of lake waters.
- With increasing temperatures due to climate change, and longer ice-free seasons, it would be beneficial to continue to monitor oxygen levels in White Lake.

11. Water Temperature

Temperature is one of the most important parameters when discussing water quality parameters. Changes in temperature affect the rates of chemical reactions, pH, and also the equilibrium concentrations of dissolved gases in the water column such as oxygen and carbon dioxide. Temperature also affects the solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species. For White Lake, increased water temperatures would also increase the release of phosphorus (internal loading) from sediments into the water column. All temperatures reported were taken at the Secchi depth using a thermometer calibrated against a secondary standard mercury glass thermometer.

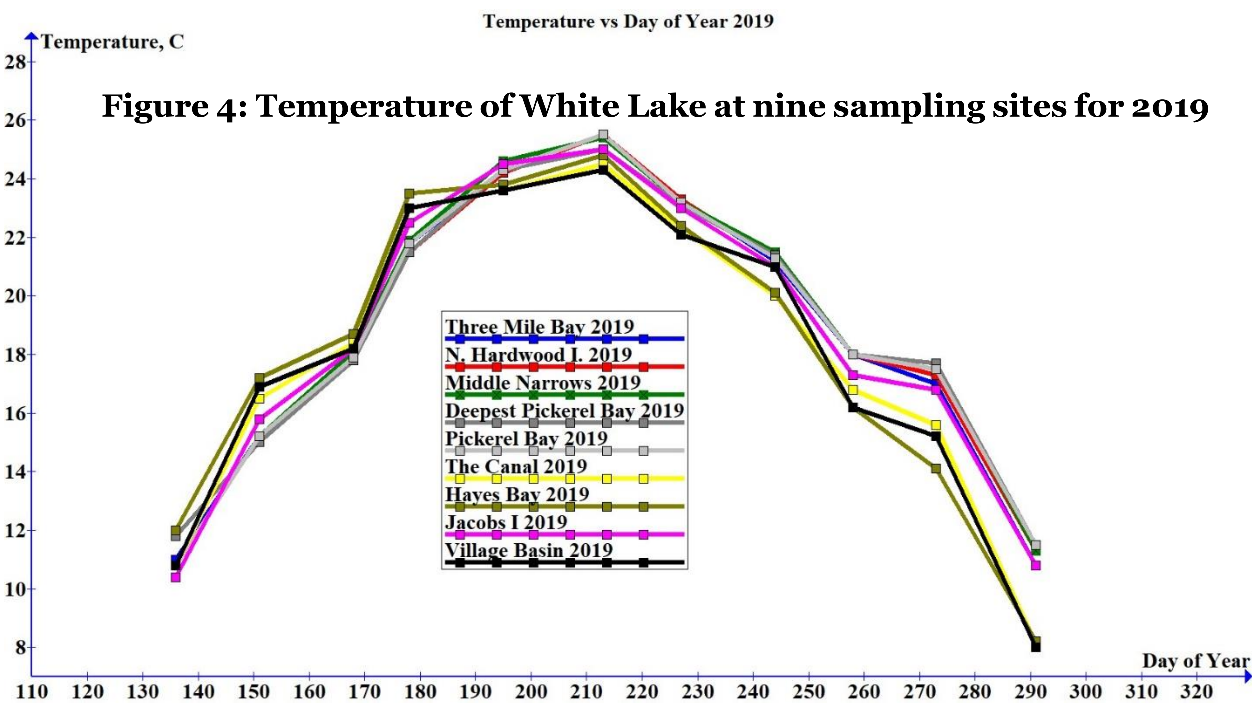


Figure 4: Temperature of White Lake at nine sampling sites for 2019

Although there is clearly some variation in measured temperatures depending on the location of the sampling site, the temperature curves follow a trajectory very similar to those observed in previous years (see below). The noticeable 'dips' in temperature which occur from time to time are usually correlated with significant rain events one to three days prior to sampling. Cooler waters resulting from rain enters the lake via springs in the floor or the lake and surface runoff. Not evident in the figure above, are differences in temperatures at sampling sites. For the most part, water temperatures for all of the deeper sites were almost the same differing by no more than 0.5 °C. However, temperatures for the shallow sites were at times quite different from those of the deeper sites because they are more susceptible to recent or current weather conditions. A full explanation of this topic can be found in the 2016 White Lake Water Quality Monitoring Program Report[15] available on www.WLPP.ca.

Table 12 gives the Zone location for both the low and high lake temperatures recorded for each lake sampling date in 2019. Data highlighted in yellow are for shallow sites.

Table 12: Lake zone location for low and high-water temperatures for White Lake, 2019

Date	Low Temp.	Zone		High Temp.	Zone	Difference, ◦C
May 16	10.4	1		12.0	2	1.6
May 31	15.0	1		18.7	2	3.7
June 17	17.8	1		18.7	2	0.9
June 27	21.5	1		23.5	2	2.0
July 14	23.6	1		24.8	2	1.2
Aug. 1	24.3	4		25.5	1	1.2
Aug. 15	22.1	1		23.2	1	1.1
Sept. 1	16.2	4		21.5	1	5.3
Sept. 15	16.2	2		18.0	1	1.8
Sept 30	14.1	2		17.7	1	3.6
Oct. 8	8.0	4		11.5	1	3.5

Zone 1 = Main Water Body; Zone 2 = Hayes and Bane Bays; Zone 4 = Village Basin

This data shows that the largest differences in temperature occur at the beginning and again at the end of the ice-free season with a maximum difference of 5.3 ◦C. Starting in June and until September, the range between low and high temperatures in White Lake is close to 1◦C.

It is not surprising that, depending on the date, the high and low water temperatures are either found in Zone 1 or Zones 2 and 4 of White Lake. Zone 1 comprises the deepest parts of the lake which would both heat up and cool down more slowly than shallower parts of the lake. Zones 2 and 4 comprises the shallowest parts of the lake with an average depth

[15] D.C. Grégoire and D. Overholt; 2016 White Lake Water Quality Monitoring Report, January, 2017

of approximately 1.5 m. At this depth, waters in Hayes Bay and the Village Basin would both cool and heat up more quickly than in Zone 1 or any deeper location on White Lake.

12. Annual Trends in Lake Water Temperatures

Although there is some year to year differences for temperatures recorded on a given date, the same general pattern in water temperatures with day of year is observed (see WLPP/WLPOA reports at www.WLPP.ca). This indicates, along with the other data in this section, that the temperature regime of the lake is quite regular from year to year, but may be subject to change due to local climatic conditions.

For example, the 2019 data presented in the graph below shows that lake water temperatures were several degrees cooler at the beginning and end of summer when compared to previous years. The very significant rains experienced in the spring and cooler temperatures during the same time period explain this observation.

We now have seven consecutive years of water temperature measurements for the deeper sites (Zone 1: Main Water Body) on White Lake. The figure below gives temperature measurements obtained at the North Hardwood Island site for the years 2014 to 2019.

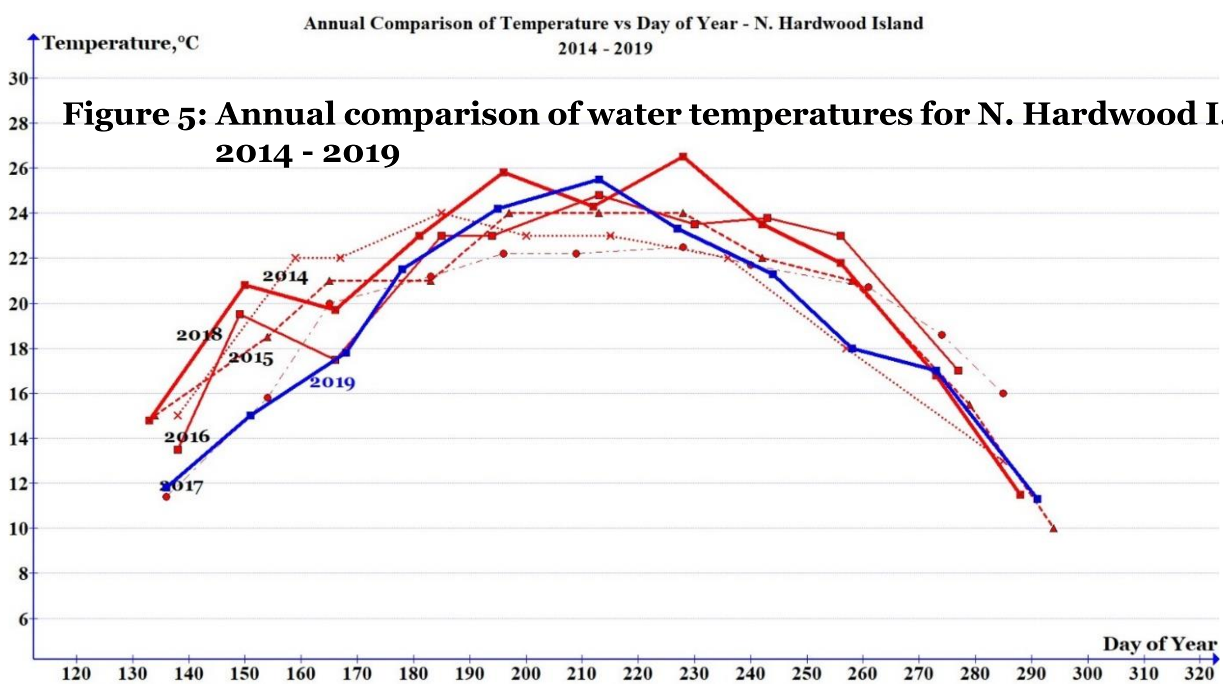


Figure 5: Annual comparison of water temperatures for N. Hardwood I. 2014 - 2019

The table below gives maximum temperatures recorded for White Lake during the past seven years. The year 2020 had the highest temperature and 2017 the lowest giving a range of 3.2 ◦C over the period.

Table 13: Maximum Temperature, ˚C

Year	Day of Year	Maximum Temperature, ˚C
2014	199	24.1
2015	213	26.0
2016	213	24.7
2017	196	22.8
2018	196	26.8
2019	213	25.5
2020	214	26.0

Observations – Water Temperatures

- Water temperatures are governed by weather and ambient temperatures and may vary from year to year.
- Maximum temperatures are achieved in mid-August.
- Deeper parts of the lake respond to changes in air temperature more slowly than shallower areas.

13. pH

pH is a measure of the concentration of hydronium ion in water and indicates how acidic (pH<7) or basic (pH>7) the lake is. The pH of lake water is controlled by dissolved chemical compounds in the water and some biochemical processes such as photosynthesis and respiration. In lake waters like those of White Lake, the pH is mainly controlled by the balance between carbon dioxide, carbonate and bicarbonate ions. Because the pH is dependent on the concentration of carbon dioxide, it is therefore linked to lake productivity. Carbonate containing materials and limestone are two materials which can buffer (prevent changes) pH changes in water. Calcium carbonate ($CaCO_3$) and calcium bicarbonate can combine with both hydrogen or hydroxyl ions to neutralize pH. When carbonate minerals are present in the soil, the buffering capacity (alkalinity) of water is increased, keeping the pH of water close to neutral even when acids or bases are added. Additional carbonate materials beyond this can make neutral water slightly basic.

The PWQO's require maintenance of the water's pH in a range of 6.5-8.5 to ensure a healthy aquatic ecosystem (neutral pH is 7.0 and lower levels indicate higher acidity). White Lake is a relatively high alkalinity lake and according to the diagram (below), the pH can change from about 7.5 to 8.3 during the course of any given day. Typical pH levels vary due to environmental influences, including photosynthesis during the day and respiration during the night.

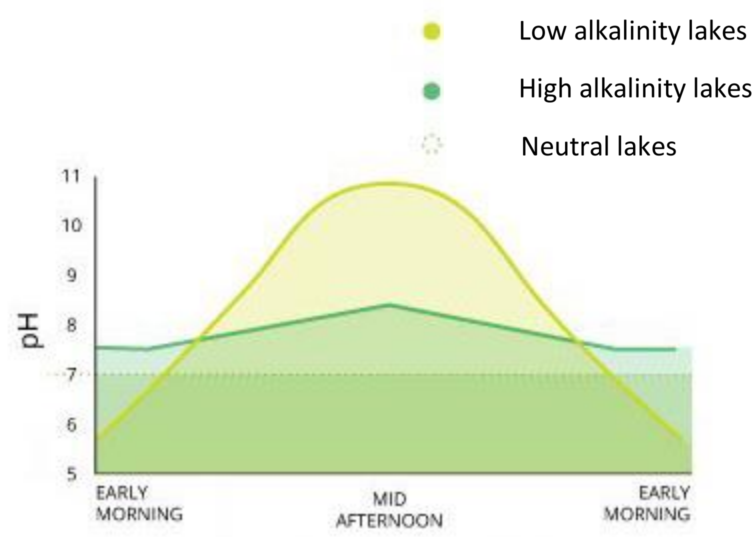


Figure 6: Daily change in pH in lakes

The alkalinity of water varies due to the presence of dissolved salts and carbonates, as well as the mineral composition of the surrounding soil. In general, the higher the alkalinity, the higher the pH; the lower the alkalinity, the lower the pH. The recommended pH range for most fish to thrive is between 6.0 and 9.0.

Figure 7 shows the change of pH values over time during the ice-free season at a number of sites on White Lake. The data is for 2018.

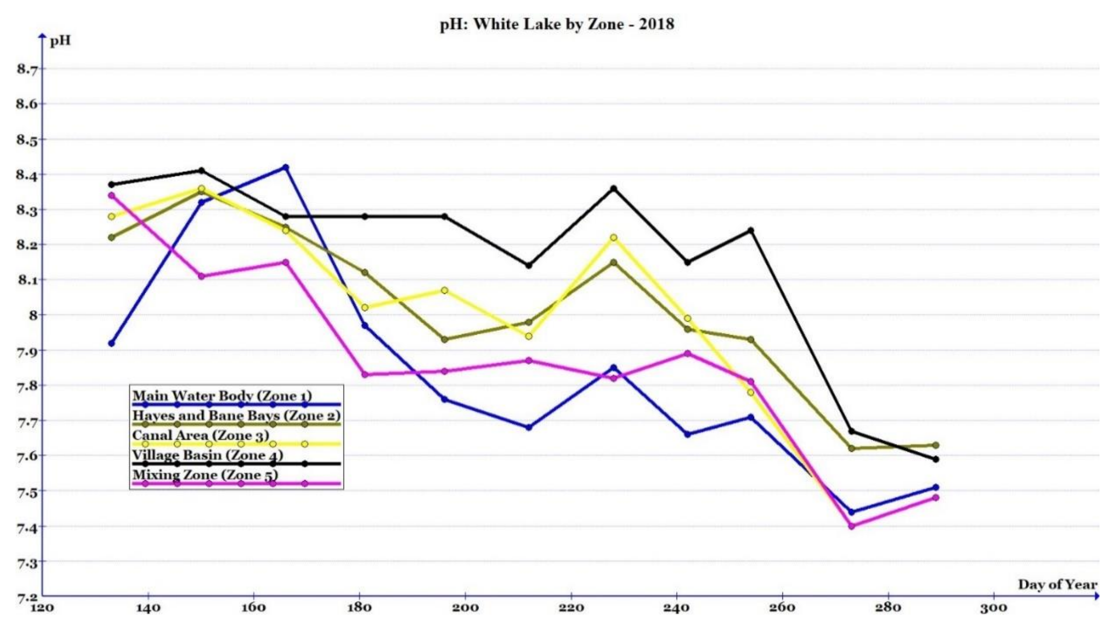


Figure 7: Change of pH during the ice-free season for selected sampling sites, 2018

White Lake has a relatively high pH and has a very high buffering capacity, which means that it is not affected by acid precipitation. The pH of its waters is perfect for the colonization and growth of zebra mussels. High pH also favours the formation of marl deposits in sediments which are commonly found in the shallower parts of White Lake, but also in sediments throughout the lake.

14. Conductivity

Specific conductance is a measure of the ability of water to conduct an electric current. Specific conductance, is also referred to as *conductivity*, *electrical conductivity* or *specific electrical conductance*. In general, the higher the concentration of dissolved salts in the water, the easier it is for electricity to pass through it. Conductivity is reported in *micro-Siemens* (µS) per centimeter (cm). Conductivity measurements can be converted to *total dissolved solids* measurements which are reported in parts per million (ppm). A rough approximation of the concentration of dissolved solids in a freshwater source in ppm (milligrams/liter) can be obtained by multiplying the µS/cm value by 0.66 (the actual conversion factor may range from 0.55 to 0.80 for water of different sources).

The composition of waters entering the lake reflects the chemical composition of the rocks through which these waters flowed before entering the lake. Calcareous rocks containing minerals such as calcite and dolomite are relatively soluble bringing into solution minerals such as Ca and Mg into waters which come into contact with the rock. The amount of minerals transferred from rock to the aqueous phase will depend on the pH of the water as well as the contact time with the rock as well as temperature. The concentrations of bicarbonate in lake waters is also influenced by pH and temperature. Additionally, salts such as sodium chloride entering the lake from saline springs or even road salt will also increase the conductivity of lake waters.

Put another way, any time a body of water, such as a stream, has a distinctly different chemical composition to the body of water it is flowing into, such as a lake, then it is possible to use conductivity as a tracer to determine the influence the incoming stream has on the chemical composition of the lake. This is very much like using coloured dyes to trace water flows. At the same time conductivity measurements were taken, both temperature and pH were also recorded and used in concert with conductivity measurements for interpretive purposes.

Conductivity measurements can be used to gain insights into how water enters the lake and how well mixed the lake is. We can also assess the importance or influence that stream waters entering the lake have on the overall composition of the lake. For more remote parts of the lake such as isolated bays such as Hayes Bay, it is possible to determine if these locations are well drained or exist as backwaters with very little flow to the main part of the lake. Evaporation then could also be a factor increasing the conductivity of waters, especially during hot and dry periods during the summer months.

15. Lake-Wide Conductivity Measurements

Extensive conductivity data were collected[16] for all parts of the lake at two-week intervals throughout the 2018 ice-free season. The figure below gives conductivity values obtained for each of the White Lake Zones from mid-May to mid-October.

Figure 8 shows that for most parts of the lake, conductivity values are nearly the same at any given date for all parts of the lake with the exception of the Hayes and Bane Bays area (brown line) which consistently had much higher values than the rest of the lake. The data for the Canal Area (yellow line) is consistent with values obtained for the rest of the lake, except that at some points during the summer, values are either lower or significantly higher than for the rest of the zones, Hayes and Bane Bays excepted.

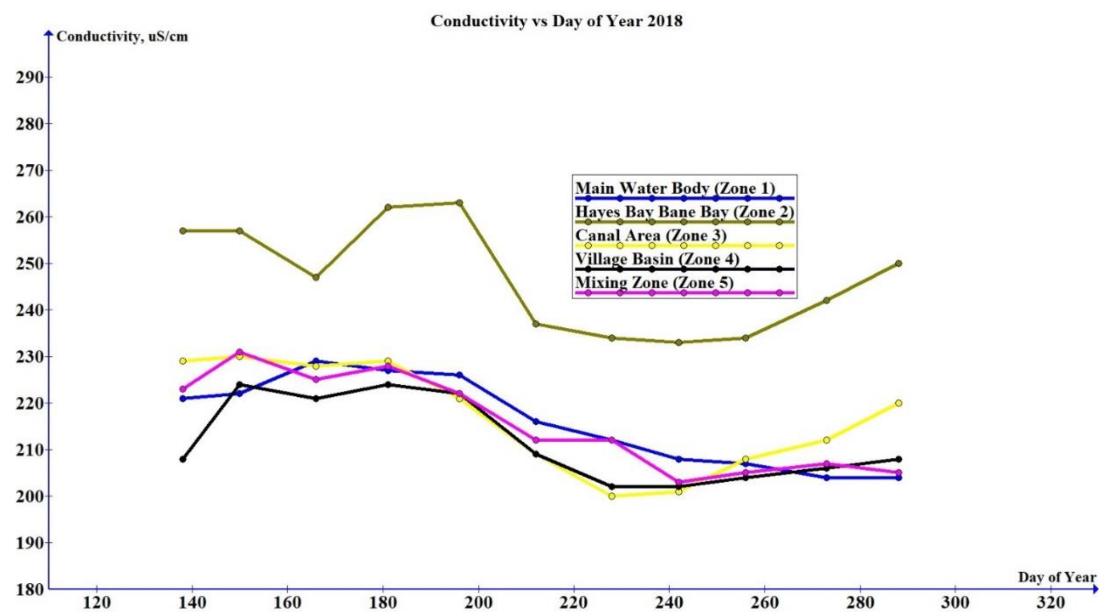


Figure 8: Conductivity vs Day of Year – 2019

The shape of the conductivity data curves can be correlated to the weather starting several days before sampling. Both significant precipitation and hot dry weather are influential. Significant rainfall results in a decrease in conductivity because of simple dilution of lake water with rain and runoff water which is relatively free of dissolved solids. This can be seen for day 166 (June 15) on the above graph. Periods of hot dry weather followed between days 166 and 196 (July 15) resulted in increased conductivity due to evaporation of lake water. Beyond this date, the conductivity is governed by both weather and the beginning of the lake level drawdown at the White Lake dam.

Bane Bay (and hence Hayes Bay) are partially fed from drainage from Lowney Lake which has a conductivity nearly twice as high as the Main Water Body of White Lake. When water levels in White Lake are lowered, more water flows and/or seeps into White Lake

[16] D.C. Grégoire and D. Overholt; 2018 White Lake Water Quality Monitoring Report, January, 2019.

from this source. The year-round high conductivity values for Hayes and Bane Bays are due to the factors discussed above and possibly also from saline ground water springs discharging into that part of White Lake.

Table 14: Minimum, Maximum and Range for Conductivity (C) of Lake Water at Different White Lake Zones – May to October, 2018

Location	Min. C, µS/cm	Max. C, µS/cm	Range, µS/cm
Zone 1			
Main Water Body	201	229	28
Zone 2			
Hayes and Bane Bays	237	272	35
Zone 3			
The Canal	200	256	56
Zone 4			
Village Basin	202	224	22
Zone 5			
Mixing Zone (Jacobs I)	203	231	22
Other Sites			
Lowney Lake Creek	306	410	104
Active Streams, Western Shore			
Boundary Creek	143	339	196
Paris Creek	17	46	29

Table 14 provides a summary of values obtained for conductivity for White Lake waters over the ice-free season. With the exception of Zone 2 and Zone 3 (discussed in detail above) values for minimum, maximum and range of conductivities are similar over most of the lake. This is evidence that White Lake is well mixed and nearly homogeneous for most of the ice-free season.

It is known that stream waters entering the lake may have different compositions than lake water itself. For White Lake it is important to know if stream waters entering White Lake influence the quality of lake water.

Conductivity studies of outflowing stream waters (into White Lake) can be used to estimate the impact of a particular stream on lake water quality. If it is great, then the conductivity of stream waters will have influence for a significant distance into the lake by increasing or decreasing the conductivity depending on the characteristics of the stream. If the impact of a particular stream is small (small volume or flow), then we can expect that these stream waters will have a very small impact as they reach and mix with lake water.

White Lake has a number of streams feeding it, but most of these are freshet streams which flow only during the spring melt or during especially heavy rains. In fact, there are only a small number of streams which flow year-round and these are shown on the map in Figure 9.
The results of these studies are reported in the 2018 White Lake Water Quality Monitoring Report[17] and show that the stream waters entering have a minimal effect on the overall water chemistry of White Lake waters.

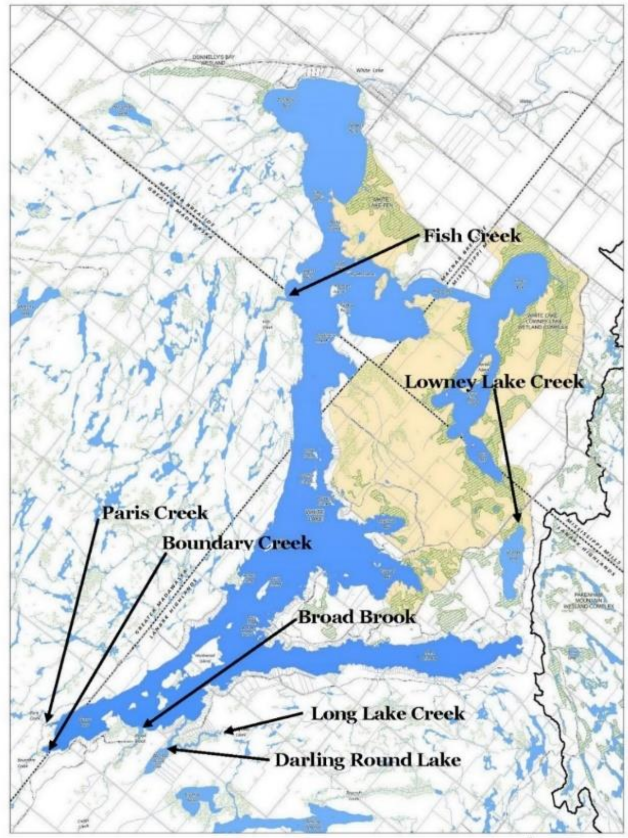


Figure 9: Streams flowing into White Lake

Observations – Conductivity Measurements

- Conductivity data can be used as a 'tracer' to detect movement of lake water and impact of stream waters on lake water composition.
- White Lake waters are well mixed and nearly homogeneous during most of the ice-free season.
- Hayes Bay and Bane Bay are 'backwaters' subject to evaporation and have much higher dissolved mineral content than the remainder of the lake.
- Permanent streams do not contribute significantly to the chemical composition of White Lake waters.
- Streams flowing from the western shore of White Lake are very low in dissolved minerals compared to open lake water.

[17] D.C. Grégoire and D. Overholt; 2018 White Lake Water Quality Monitoring Report, January, 2019

16. Other Water Quality Parameters

15a. Calcium

Table 15 contains values for calcium concentration levels measured in White Lake from 2015 to 2019. Values ranged from 27.3 to 37.8 ppm. It is clear that zone 2 (Hayes Bay) had the highest calcium concentration. This zone is very shallow (1.6 m) and is subject to evaporation and influx of waters from Lowney Lake, which is also high in calcium. It is possible that the different calcium concentrations measured over the years exhibit natural differences caused by the relative inputs of various water sources entering White Lake.

In their 2017 report[18], Grégoire and Overholt (www.WLPP.ca), published a correlation graph of average calcium concentrations, measured monthly from 2015 to 2017, plotted against monthly rainfall. A linear regression analysis of these data indicated that the calcium concentration in White Lake waters was dependent on the amount of rainfall entering the lake. The correlation coefficient (R^2) obtained was 0.783 which is relatively high indicating that the relation between the two parameters is significant. Data from 2018 and 2019 was compatible with this correlation plot and supports the conclusion that about 88% of the water entering White Lake is derived from ground water sources with the remainder coming from rain and surface water runoff.

Table 15: Calcium Concentrations in White Lake

Mid-May: Calcium (ppm)					
Zone	**2015**	**2016**	**2017**	**2018**	**2019**
1	36.2	33.1	28.5	33.1	29.9
2	-	36.6	31.0	37.8	30.4
3	35.8	34.3	29.4	34.4	30.8
4	-	31.0	27.3	31.6	27.9
5	36.2	31.4	27.7	34.0	28.4

[18] D.C. Grégoire and D. Overholt; 2017 White Lake Water Quality Monitoring Report, January, 2018

16b. Magnesium

Table 16: Magnesium

Mid-May: Magnesium (ppm)	
Zone	**2018**
1	8.5
2	7.6
3	8.1
4	7.0
5	8.8

White Lake sits on top of a limestone base and is partially surrounded by calcareous (calcium containing) rocks. A companion mineral to calcium is magnesium. Magnesium occurs naturally with calcium and is often found in significant concentrations in calcite in the form of dolomite, a calcium-magnesium mineral (Bond, 1976).

It is no surprise to see significant concentrations of magnesium in White Lake waters. Magnesium concentrations are about 25% that of calcium. What may be surprising is that concentrations of magnesium in Hayes Bay are about the same or even lower than those found in the rest of the lake. This indicates that the much higher conductivity of Hayes Bay waters compared to the rest of the lake may be due to the presence of chloride and bicarbonate in much higher quantities than those found in the rest of the lake. Only about 12% of Ontario lakes have a magnesium concentration higher than 3 ppm. This is not surprising since many lakes in the province are hosted on shield rocks, which are relatively insoluble and very low in both calcium and magnesium minerals.

16c. Potassium

Table 17: Potassium

Mid-May: Potassium (ppm)	
Zone	**2018**
1	1.01
2	0.99
3	1.03
4	0.89
5	1.00

The main anions contained in natural waters are Cl^-, $SO4^2$, $HCO3^-$, $CO3^{2-}$ and the main cations are $Ca2^+$, Na^+, Mg^{2+} and K^+. Of the four cations, potassium occurs at the lowest concentration.

Potassium is a micronutrient essential to plant growth. About 85% of Ontario lakes have a potassium concentration in the range of from 0.2 to 1.0 ppb. About 10% of Ontario lakes have a 1 ppm concentration of potassium. Generally, the amount of potassium in natural waters is governed by the local geology and the uptake of the mineral by plants.

White Lake has a healthy level of potassium in its waters ensuring sufficient supply for the growth of aquatic plants including algae.

16d. Sodium

Table 18: Sodium

Mid-May: Sodium (ppm)	
Zone	**2018**
1	2.4
2	5.3
3	3.2
4	2.6
5	2.7

Sodium in lake waters is mainly derived from local rocks and also by contributions from the use of road salt. About 40% of Ontario lakes have a sodium concentration of 0.5 to 1 ppm and only about 5% have concentrations in the 2.5 to 3 ppm range. About 15% have sodium concentrations above that of White Lake with less than 1% having a concentration as high as Hayes Bay.

It is possible that the higher sodium concentration in Hayes Bay is due to local geology such as water seeping from a saline spring. However, the contribution of road salt cannot be totally ruled out, although this source of sodium is unlikely because the rest of lake is not similarly affected.

Although White Lake is a bit saltier than most Ontario lakes, sodium levels are not anywhere near toxic levels for local flora or fauna and should not be of great concern.

16e. Chloride

Chloride data for 2015 to 2019 are given in the table below. The data collected in 2015 shows that a concentration of about 3.5 ppm chloride was found at all sampling sites with the exception of The Canal, where chloride values were slightly elevated. The 2016 data shows the same pattern with the new sampling site of Hayes Bay giving a chloride concentration of 10 ppm (not sampled in 2015), which was about three times the concentration measured at all other sites on the lake with the exception of The Canal, which gave a value of 5.35 ppm. For 2017, 2018 and 2019, comparable results were obtained. For all of the sites (except The Canal and Hayes Bay) the average values for all three years were the same within calculation error.

The source of the additional chloride is not likely from road salt since conductance values would have declined over the course of the summer months. Chloride may originate from subterranean brines reaching this part of the lake through the sediment layer. The elevated values for chloride found at The Canal are likely due to the mixing of waters from Hayes Bay with those of The Canal or its own weaker (Cl) source of subterranean brine. This is the only part of the lake where this phenomenon has been observed.

Concentrations for chloride are low, but worth monitoring for future changes which may indicate road salt entering the lake, especially near Hayes Bay.

Table 19: Chloride

Mid-May: Chloride (ppm)					
Zone	**2015**	**2016**	**2017**	**2018**	**2019**
1	3.4	3.4	3.1	3.1	3.2
2	-	10.0	9.5	8.3	7.6
3	3.9	5.4	6.2	4.1	4.1
4	-	3.7	3.8	3.6	3.6
5	3.4	3.7	3.7	3.2	3.6

16f. Sulphate

Table 20: Sulphate

Mid-May: Sulphate (ppm)		
Zone	**2017**	**2018**
1	4.9	3.6
2	4.2	3.1
3	4.2	3.2
4	4.3	3.4
5	4.5	3.4

Sulphates occur naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4•7H_2O$) and gypsum ($CaSO_4•2H_2O$). The reversible interconversion of sulphate and sulphide in the natural environment is known as the "sulphur cycle." Sulphate enters the lake by a variety of ways including dust in the atmosphere, minerals in the local rocks and from human activity.

Sodium, potassium and magnesium sulphates are all soluble in water, whereas calcium and barium sulphates and the heavy metal sulphates are not. Dissolved sulphate may be reduced to sulphide, volatilized to the air as hydrogen sulphide, precipitated as an insoluble salt or incorporated in living organisms.

Sulphate levels in Canadian lakes typically range from 3 to 30 mg/L. Recent data from Ontario show similar levels in small lakes (12.7 ± 11.3 µg/ml); sulphate concentrations were 7.6 µg/ml in Lake Superior at Thunder Bay and 19 mg/L in Lake Huron at Goderich.

The average daily intake of sulphate from drinking water, air and food is approximately 500 mg, with food being the major source. The objective for sulphate concentrations in drinking water is ≤500 µg/ml, based on taste considerations.

The average concentrations for sulphate for both 2017 and 2018 are similar varying by only by 1 ppm. Sulphate concentrations are very low owing to the very high concentration of calcium in the water. Calcium sulphate is very insoluble which means that most of the sulphate entering the lake would precipitate to the lake bottom as solid particles. Sulphate concentrations in White Lake are well below drinking water or even aesthetic concentrations levels and therefore should be of no concern to lake users.

16g. Silica

Table 21: Silica

Mid-May: Silica (ppm)	
Zone	**2018**
1	2.2
2	0.58
3	1.6
4	1.7
5	2.2

Silica is an important component for cell formation of two major groups of phytoplankton; diatoms and chrysophytes. Therefore, silica availability may influence phytoplankton productivity and community succession in lakes. There are only about 4% of Ontario lakes which have concentration of silica higher than that of White Lake.

The relatively low concentrations of silica in Hayes Bay could affect the growth of phytoplankton to some extent. Although most Ontario lakes have silica concentrations in the range of from 0.2 to 1.4 ppm, the levels encountered in White Lake are not considered harmful to the aquatic environment.

16h. Dissolved Organic Carbon (DOC)

Dissolved organic carbon (DOC) is a generic term for all organic materials dissolved in waters. Dissolved organic matter can be found in both surface waters and ground waters. Once organic matter begins to decompose, a large number of high molecular weight water-soluble compounds are formed. These compounds are sometimes referred to as humic and fulvic acids. These compounds are natural and pose no danger to human or aquatic life. When these compounds occur in sufficiently high concentrations, water takes on a tea-colour. Other substances also contribute to the concentration of DOC. These include low molecular weight acids, low-weight substances (which pass through a 0.45 µ filter) and polysaccharides. Polysaccharides are released when phytoplankton are decaying and are one of the substances responsible for the 'foaming' seen every year on White Lake in late fall. Large quantities of foam can sometimes be seen on some shorelines on windy days.

Dissolved organic carbon is an important complex of substances that affects many physical, chemical and biological processes in aquatic environments. For example, DOC binds many metals and nutrients, affects water transparency and thermal stratification, affects pH and alkalinity and is a substrate for microbial production. Most importantly, it attenuates the penetration of harmful ultraviolet radiation into the water column. Interestingly, it is also known that zebra mussel veligers (larvae) readily ingest DOC as a source of food.

The literature suggests that lakes with an average DOC of 30 ppm and with values greater than 30 ppm are classed as dystrophic (tea-colored). These lakes are dark brown and have a very low pH. At the other end of the trophic scale, lakes with an average DOC of 2 ppm with a range of concentrations from 1 to 3 ppm are considered oligotrophic. Mesotrophic lakes have an average DOC of 3 ppm with a range of concentrations from 2 to 4 ppm.

Finally, eutrophic lakes have an average DOC of 10 ppm with a range of concentrations of from 3 to 34 ppm. In some lakes there are substantial amounts of internally generated dissolved organic carbon compounds which are colorless, which can make the use of DOC as a measure of lake dystrophy difficult.

The DOC concentrations found in White Lake fall between the mesotrophic and eutrophic classifications. Waters from The Canal and especially Hayes Bay are very close to eutrophic in status. The much higher DOC values for Hayes Bay may be the result of the higher residence time of water in this area, the very shallow water levels (1.5 m) and the abundance of decaying organic material in the sediment layer. White Lake (DOC ~ 5 mg/L) is at or below the threshold that would indicate dystrophy as defined above.

Table 22: Dissolve Organic Carbon

Mid-May: Dissolved Organic Carbon (ppm)		
Zone	**2017**	**2018**
1	5.1	5.1
2	6.8	6.2
3	5.4	5.7
4	5.5	5.6
5	4.5	5.0

16i. Nitrates

Nitrogen is another chemical nutrient that allows and promotes growth of aquatic plants and algae. Similar to phosphorus, excess nitrogen in the water will lead to algae blooms and excess growth of aquatic plants. In extremely high concentrations, nitrogen compounds may also cause fish kills. The primary sources for lakes and rivers are: runoff of agricultural fertilizers; soil erosion; and faulty septic systems.

The nitrogen compound that is typically measured as a water quality parameter is nitrate. The WLPOA has had a number of samples analyzed for nitrates since 2009 (Table 23). The Canadian Water Quality Guidelines for the Protection of Aquatic Life set a level of 13mg/L as a threshold. All of the samples tested were well below this threshold.

Studies in Lake Erie suggest that elevated levels of nitrogen "often constrains growth of cyanobacteria (blue-green algae) in small lakes." The study showed a significant decline in nitrogen levels from June through September, which could be a causal factor in the September blooms of blue green algae. (Chaffin et al, 2013).

Table 23: Nitrate Results (mg/L) in White Lake 2009 – 2015

Year	Pickerel Bay	Three Mile Bay	Sunset Bay	N Hardwoo	Cedar Cove	Lowney Lake
2009	<0.1	<0.1	<0.1	<0.1	<0.1	-
2010	-	-	-	-	-	-
2011	0.18	<0.1	<0.1	<0.1	<0.1	-
2012	-	-	-	-	-	-
2013	<0.1	<0.1	<0.1	-	<0.1	<0.1
2014	-	-	-	-	-	-
2015						-

(*Source: White Lake Property Owners Association website*)

Observations – Other Water Quality Parameters

- All chemical factors including pH, conductivity, calcium, magnesium, potassium, sodium, chloride, sulphate, silica, dissolved organic carbon and nitrate are within acceptable concentration levels for Ontario lakes.
- The pH and calcium levels found in White Lake are ideal for the propagation of zebra mussels.
- The chemical composition of White Lake waters is governed by the composition of the relatively soluble calcareous rocks on which the lake sits and is bordered.
- The chemical composition of White Lake waters is not affected by the relatively insoluble shield-type rocks abutting the western side of the lake.
- Stream waters do not have an appreciable effect on the composition of White Lake water.

17. Bacteriology

High levels of certain bacteria can cause illness in swimmers, so monitoring beaches and swimming areas for bacteria is relevant from a human health perspective. The Provincial Water Quality Objective uses E. coli bacteria as the parameter to measure, as this bacterium is present in human or animal fecal matter and may signal the presence of other pathogens. From 2009 to 2015, the WLPOA monitored levels of E. coli at a number of sites (Table 24). All results were well within the Ontario government's recreational water quality guideline of 100 E. coli units/100ml.

While it is satisfying to know that bacterial levels of all samples are within the provincial objectives, these measurements were for open water and not shoreline locations. Effective monitoring for bacterial levels would include beach areas at resorts or private cottages as well as shorelines adjoining lawns frequented by geese or pets such as dogs.

Table 24 – E. Coli Results (units/100ml) for White Lake 2009-2015

Year	Pickerel Bay	Three Mile Bay	Sunset Bay	N Hardwo	Cedar Cove	Lowney Lake	Waba Island
2009	0	1	0	0	3	-	
2010	3	0	1	0	0	-	
2011	1	2	-	0	1	-	
2012	0	0	0	-	0	1	
2013	0	0	0	-	0	0	0
2014	3	-	1	15	1	-	
2015	1	3	0	0	2	-	0
Mean	**1.1**	**1.0**	**0.3**	**3.0**	**0.8**	**0.5**	**0**

(*Source: White Lake Property Owners Association website*)

Observations - Bacteriology

- E. coli monitoring from 2009 to 2014 indicates that open lake waters were within safe thresholds for swimming.

18. Other Substances: Volatile Organic Compounds, Petroleum Hydrocarbons & Herbicides

The WLPOA had samples analyzed in 2011 for chemicals in three additional categories: Volatile Organic Compounds (VOCs) and Petroleum Hydrocarbons in 2010; and for agricultural herbicides.

VOCs are a class of organic chemicals that may be found in lakes naturally or be introduced by humans. Naturally-produced VOCs are usually produced by plants, and are the organic compounds that provide the scents of certain plants. The main human-made source of introduced VOCs is through non-combusted fuel entering the water. This can occur through spills of oils or gas (leaks from storage tanks; spills when fueling over the water), or through fuel emissions, usually from older 2-stroke engines.

Petroleum hydrocarbons are chemicals found in or derived from crude oil – typically gasoline or engine oil, and can enter the lake through the same human sources as described for VOCs. All results were within Ontario's Provincial Water Quality Guidelines with the exception of two results taken from Three Mile Bay in front of Cedar Cove (Table 25 below).

Table 25: VOCs (2010); Petroleum Hydrocarbons (2010); and Herbicides (2011). Results

Parameter	Three Mile Bay	Cedar Cove	Three Mile Bay	Pickerel Bay	Lacourse Lane	PWQO
Volatile Organic Components (2010)						
Ethylbenzyene	<.5	<.5				8 µg/L
Toluene	<.5	2.4				0.8 µg/L
Benzene	<.5	<.5				100 µg/L
Xylene (m, p)	<1.0	2.5				2 µg/L
Xylene (o)	<.5	0.8				40 µg/L
Petroleum Hydrocarbons (2010)						
F1	<0.1	<0.1				
F1 – BTEX	<0.1	<0.1				
F2	<0.1	<0.1				
F3	<0.2	<0.2				
F4	<0.2	<0.2				
Herbicides (2011)						
Altrazine	<0.2		<0.2	<0.2	<0.2	
De-ethylated Altrazine	<0.5		<0.5	<0.5	<0.5	
Cyanazine	<1.0		<1.0	<1.0	<1.0	
Metolachlor	<0.5		<0.5	<0.5	<0.5	3 µg/L
Prometryne	<0.25		<0.25	<0.25	<0.25	
Simazine	<1.0		<1.0	<1.0	<1.0	10 µg/L

19. Multiple Stressors

It is important to note that lakes throughout Ontario, including White Lake, are currently being impacted by multiple stressors and especially by climate change, invading species, and the effects of incremental development. Many of our lakes are being overused. Nature is being consumed rather than enjoyed and protected.

For White Lake there is paleolimnological (analysis of sediment cores) evidence of species shifts in algal communities[19], the emergence of blue-green algal blooms, changes in seasonal ice cover (Figure 10), and the presence of invading species.

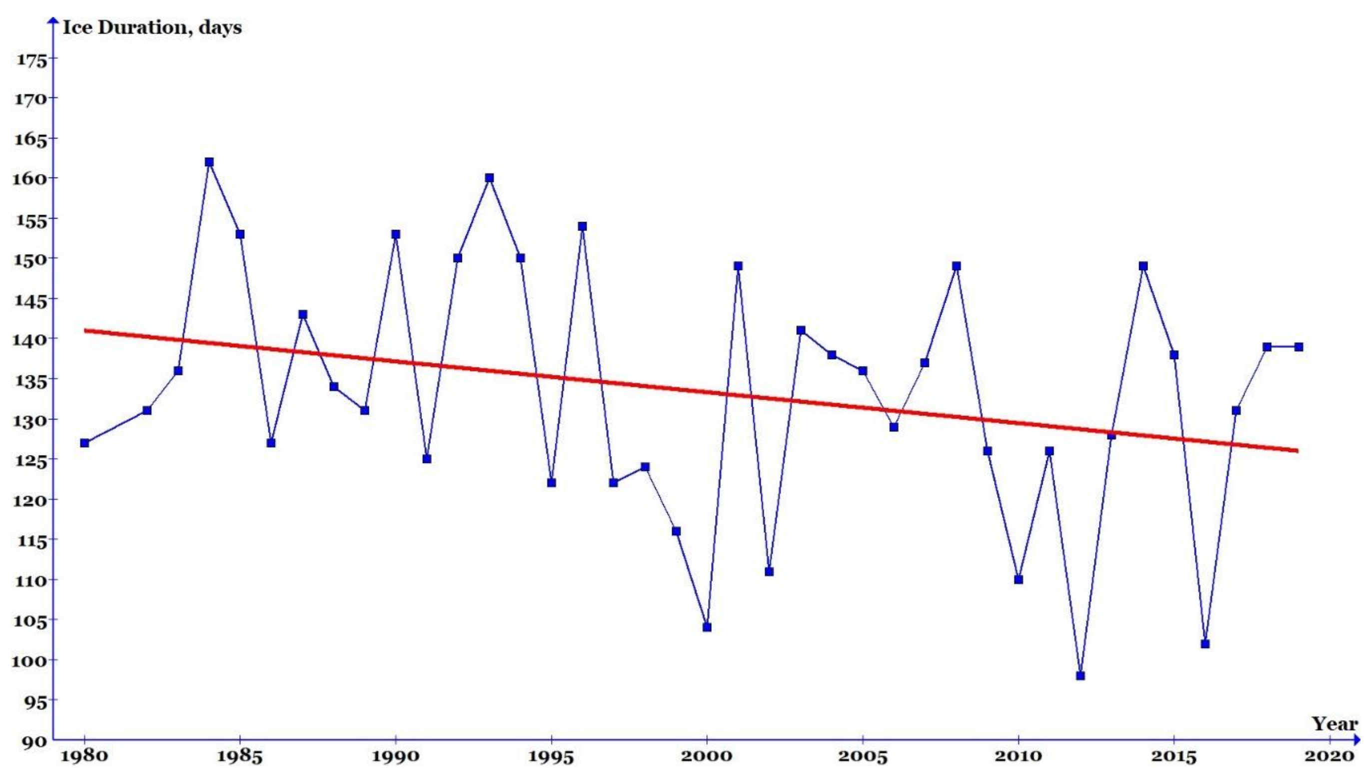
[19] M. Murphy, C. Grégoire and J. Vermaire, Ecological response of a shallow mesotrophic lake to multiple environmental stressors: a paleolimnological assessment of White Lake, Ontario, Canada., *Lake and Reservoir Management, in press.*

A shift towards longer ice-free seasons can impact physical properties of the lake especially aspects of temperature and mixing that will be favourable to blue-green algae (cyanobacteria). Ice on and off data for White Lake shows an average increase of about 15 days of additional ice-free condition since the 1980s (Figure 10). These potential effects from so many simultaneous stressors make it difficult to manage the lake. Monitoring and reducing phosphorus inputs, which has been the traditional method to counteract algal blooms, may not be sufficient under these conditions. It may be necessary to apply more stringent objectives for phosphorus levels, pay more attention to the impacts of new development, preserve riparian areas, conduct ambitious invasive species programs to maintain ecosystem integrity, and conduct the research needed to better understand the way nutrients are entering the lake (especially from sediments).

Observations - Other Substances

- With the exception of two results at Cedar Cove, all analyses for VOCs, petroleum hydrocarbons, and herbicides showed levels below the Provincial Water Quality Objective (PWQO) acceptable limits.

Figure 10: Decline in duration of ice cover on White Lake since 1980
Source: White Lake Property Owners Association website



Observations - Multiple Stressors

- Lakes throughout Ontario, including White Lake, are currently being impacted by multiple stressors and especially by climate change, invading species, and increasing development.
- These stressors can exacerbate algal blooms even in the case where nutrients are not increasing or possibly even decreasing.
- A shift towards longer ice-free seasons can impact physical properties of the lake especially aspects of temperature and mixing that will be favorable to blue-green algae (cyanobacteria).
- Ice on and off data for White Lake shows an average increase of about 20 days of additional ice-free condition since the 1980s.

20. Water Quality and White Lake

White Lake's shallow basin, combined with a slow flushing rate, and a high proportion of marsh and shallow shorelines has resulted in a moderately productive lake sensitive to shoreline development and alteration. The lake's basins are isolated, and mixing from basin to basin is limited.

It is a well-known fact, as expressed by the MOECP, that all nutrients (and other chemicals) released from septic systems or other sources within 300 m of a lake will at some point in time reach the lake. The number of cottages and resort units on White Lake has increased many-fold since the 1950s and so it is inconceivable to think that todays 589 cottages of which 209 are permanent homes, plus 854 resort units has not resulted in a significant increase in nutrients entering White Lake.

Although changes in shoreline development and lake usage are incremental, over time the effects of these are cumulative. White Lake is located near Ottawa and is near increasingly popular resort activities such as skiing, motorcar racing and derby fishing. Boating traffic and individual fishing activities are also increasing. What will White Lake look like in 30 to 50 years if effective stewardship is not practiced? One only has to look back in time and ask people who have lived on the lake for 30 to 50 years about the changes to White Lake which have taken place during their lifetimes[20].

The warning signs are plain to see. A significant issue is that of regular extensive filamentous algal blooms and late-season blooms of blue-green algae. These algal blooms are taking place when recorded levels of phosphorus are at a relatively low level for the lake (< 10 ppb). The lakeshore is now choked in many places with increasing amounts of aquatic plants, including invasive species. Shoreline erosion is also a significant problem.

For White Lake, solutions will require the cooperation of the four municipalities sharing White Lake, the two counties involved as well as lake organizations, individual citizens and the Ministry of the Environment, Conservation and Parks.

It is important to join and contribute to lake associations who could effectively interact at the political level. We can all work together to preserve White Lake for future generations.

[20] White Lake, The Early Years; White Lake Property Owners Association, 2000.

White Lake – Ours to Protect

The Lake

- White Lake is a wetlands lake. Significant portions of the lake are surrounded by extensive fens and marshes that until 2018 were designated by the Ontario Government as candidate Areas of Scientific Interest.
- White Lake is a headwaters lake. The residents on the lake bear responsibility for the quality of its waters. There is no one upstream to blame!
- White Lake is very shallow. The average depth of White Lake is only 3.1 metres.
- There are many bays, such as Three Mile and Hayes Bays, which have very limited flushing during the year as does the lake in general.
- A significant amount of phosphorous is released from sediments (internal loading).
- These elements make White Lake very sensitive to changes in human use, climate and invasive species.

The People

- White Lake has been a popular tourist destination for generations.
- White Lake supports a lucrative sport fishing industry.
- There are now nearly 600 cottages on White Lake.
- There are now about 850 trailer and tent sites on White Lake.
- There are 114 vacant lots of record which will eventually be developed.
- Cottage conversions and expansions to year-round residences are increasingly popular.
- Power boats are getting larger, faster and more numerous than in previous years.

The Science

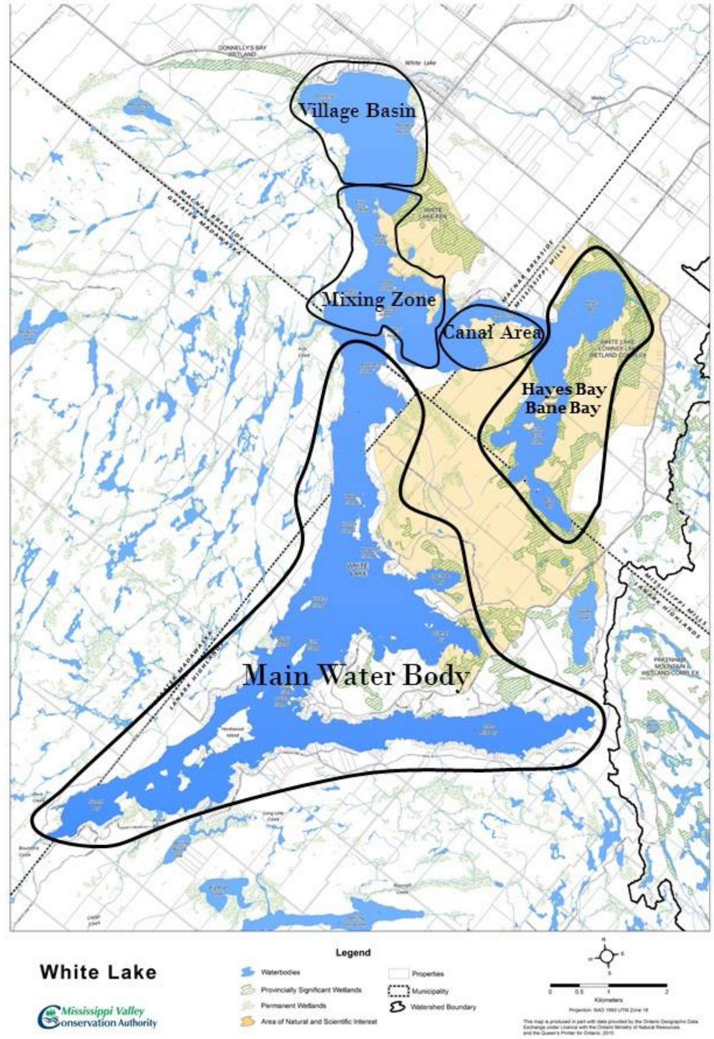
- Water quality has slowly been degrading over recent years.
- After a long period with no reported algal blooms, White Lake is now experiencing annual green and blue-green algal blooms. Some of these are toxic.
- Zebra mussels have invaded all parts of White Lake.
- Zebra mussels concentrate harmful nutrients to the near shore; the area around our docks.
- Zebra mussels promote harmful algal blooms at very low total phosphorus concentrations of less than 10 ppb.
- The quality of the near-shore area of White Lake could now be seriously degrading.

The Solution

- Respect approved setbacks and well-known best practices for shoreline development.
- Restore, regenerate or preserve shorelines to their natural state.
- Consider naturalizing lawn areas and avoid the use fertilizers, herbicides, or pesticides.
- Partner with municipal and provincial governments to enforce by-laws and create new laws to protect the lake, such as septic inspections and prevention of the spread of invasive species coming in or out of White Lake.
- Support your local lake organizations and volunteer to help preserve White Lake.
- The solution is in our hands.

21. Appendix: White Lake Zone Map

Based on our research, we have suggested that White Lake could be thought of as a collection of almost independent interconnected water bodies rather than a unitary lake.



There are a number of criteria which could be used to divide the lake into different zones based on population density, geology, shoreline coverage, etc. We believe that the different zones of the lake can best be described by their chemistry. While all zones have some characteristic in common, there are enough differences between each zone (shown on the map at right) to justify its classification.

As a result of new chemical data, we collected during the past year, we are making some minor changes to the zone map proposed in our 2016 Report. New specific conductivity measurements in addition to temperature measurements in Bane Bay indicate that this water body should be considered as part of the Hayes Bay Zone.

The ***Main Water Body (Zone 1)*** is the part of White Lake which takes in virtually all of the water with a depth greater than four metres. This zone contains Sunset Bay, Three Mile Bay, Pickerel Bay and surrounding areas. This zone existed as a lake before any dam was constructed which raised the level of the lake by about 1.5 metres. Here one finds very deep layers of sediments (up to 6 metres) and very similar water chemistry. The temperature regime, the pH, conductivity, oxygen content, alkalinity and Secchi depths are very nearly the same everywhere. Although the total phosphorus concentrations differ somewhat (with higher levels further South on the lake), the change in phosphorus concentrations over the summer months follows the same pattern with maximum concentrations reached in mid-July.

Hayes Bay/Bane Bay (Zone 2) is a relatively isolated part of the lake and is only 1.6 m in depth at high water in the spring. It is characterized by black gelatinous sediments and is nearly free of aquatic plants in the central basin. The waters there have a slightly higher pH than the rest of the lake and also higher conductivity. The concentration of salt is higher by a factor of three compared to the rest of the lake probably from saline ground water entering through the sediment layer. Because of its dark sediments and shallow depth, this part of the lake heats up the fastest and to the highest temperatures if there had not been a recent rain event. The concentration of total phosphorus is lower here than in the rest of the lake, but slightly higher than concentrations in The Canal area. The waters from Hayes and Bane Bays flow into The Canal Area.

The Canal ***Area (Zone 3)*** on White Lake is characterized by white marl sediments and a depth of 2.4 metres. For both 2015 and 2016, the lowest concentrations of total phosphorus are found here with levels less than half of those found in the Main Water Body. Our temperature data indicates that in this zone, large quantities of subterranean ground waters are infiltrating into the lake and also leaving the lake relatively more quickly than waters from Hayes Bay or the Main Water Body. This is especially evident immediately after a significant rain event. There are no aquatic plants on the lake bed. These waters have a slightly higher salt content than the rest of the lake due to the mixing of waters originating from Hayes Bay. Note that The Canal Area could be described as a marl area. This could impede the growth of phytoplankton and aquatic plants and exhibit lower phosphorus concentrations due to the coprecipitation of calcium and phosphorus.

The ***Village Basin (Zone 4)*** zone is characterized by white marl sediments and an almost uniform depth of 1.65 m at high water. The floor of the lake is largely free of aquatic plants save some bulrush and patches of wild rice. Total Phosphorus levels are about 30% lower than found in the Main Water Body. The water sampled here is representative of the water which is leaving White Lake over the dam and into the creek. Temperature data from this area also shows, as in the case of The Canal and Hayes Bay that there is significant ingress of subterranean ground waters mixing in with lake water.

Hayes Bay, The Canal and the Village Basin have several things in common. Prior to the building of the dam, these areas existed as open water only during the spring freshet and then quickly turned into marshes or wetlands with water depths of perhaps half a metre or less. Another commonality is the lack of aquatic plants in these areas. It could be that since each of these areas is partially flushed by ground water ingress that plants do not have a chance to take hold. Certainly, the white marl of The Canal and the Village Basin would provide a poor source of nutrients to plant root systems. For Hayes Bay, the sediment there is organic but made up of a very fine particulate not offering much of a foothold for aquatic plants. For all three areas, the effect of wind and waves would also contribute to low plant growth.

The ***Mixing Zone (Zone 5)*** encompasses both sides of the narrows including Rocky Island and extends some distance towards the Village Basin. This area is characterized by shallow dark sediments and ranges from 2.5 m to 4 m in depth at high water. In this area, the lake floor is covered with dense mats of aquatic plants. The temperature of the water in this area is intermediate between the waters coming from The Canal and the Main Water Body. The simple reason for this is that this is where waters from both of these zones mix to give water with special characteristics relative to other parts of the lake. Generally speaking, the water in the Mixing Zone is clearer than would be observed in other parts of the lake for a given total phosphorus concentration. Water leaving this area and entering the Village Basin has lost a significant fraction of its phosphorus content to sedimentation and aquatic plants.

Waters originating from the upper four zones have no opportunity to mix with the much deeper waters of the Main Water Basin which contains by far the greatest share of the volume of White Lake. It could be argued that the most vulnerable part of White Lake is Hayes Bay because there is little opportunity for any nutrients entering this bay to be flushed out at a reasonable rate. With the exception of Three Mile Bay whose waters have access to the remainder of the deeper Main Water Body, the shallow areas at the top of the lake contain the densest populated areas with the likely greatest human impact on lake waters.

22. About the Authors

Dr. Conrad Grégoire holds a Ph.D. in Chemistry. He was the Head of the Analytical Chemistry Research Laboratories at the Geological Survey of Canada before retirement where he conducted research in analytical and environmental chemistry. He has authored over 200 scientific papers and other works published in international journals. He was also an Adjunct Professor of Graduate Studies at Carleton University and currently collaborates with Carleton University scientists on White Lake studies. For over 20 years he was a Senior Assessor at the Standards Council of Canada, certifying commercial and government labs for ISO (International Standards Organization) compliance. Conrad is interested in studying the chemistry and biology of White Lake and establishing base line values for water quality parameters. He is the Web Manager of the White Lake Preservation Project website.

Dave Overholt is an avid citizen scientist and has, through his own study and research, become knowledgeable in a variety of areas, such as aquatic macrophytes and microorganisms and introduced species. He spends a great deal of time documenting species inhabiting the lake and following the population levels. He is involved in education about introduced species and has motivated and inspired lake residents to become involved in phragmites eradication programs.