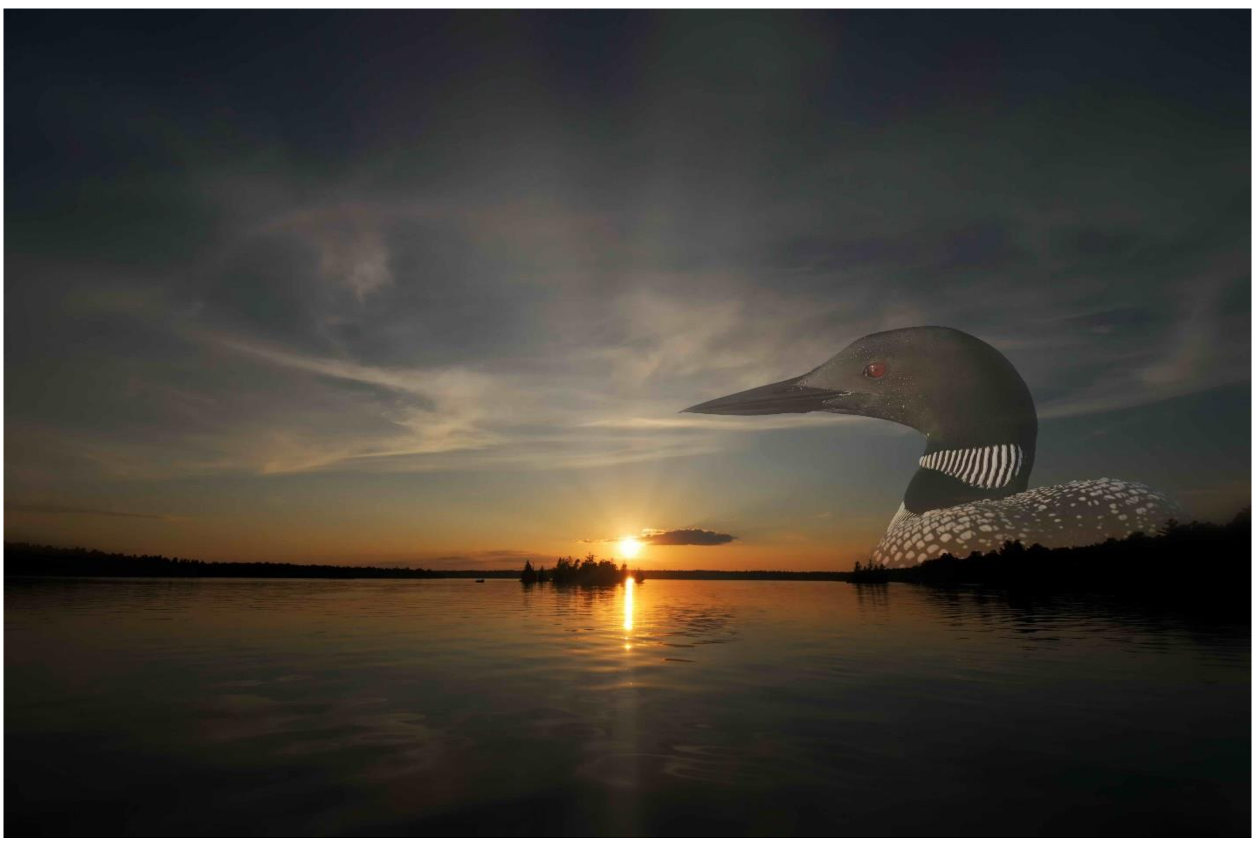
WHITE LAKE Property Owners Association Preservation Project

REPORT

Water Quality Monitoring Program and Research Activities 2020



"Loon Spirit' by Joyce Benham

WHITE LAKE Property Owners Association
Preservation Project

REPORT

Water Quality Monitoring Program And Research Activities 2020

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Water Quality Monitoring Program Overview and Findings

WHITE LAKE Property Owners Association Preservation Project

2020 Water Quality Monitoring Program and Research

Summary and Highlights

Conrad Grégoire and David Overholt

1. Water Quality

Water quality is a term which can mean different things to different people. Depending on your interest, it could refer to clear water, good fishing, or water suitable for drinking free of toxic chemicals or pathogens. In fact, it is all of these and more. Wikipedia defines it as “the chemical, physical, and biological characteristics of water based on the standards of its usage. The most common standards used to monitor and assess water quality convey the health of ecosystems, safety of human contact, and condition of drinking water”.

For most users of White Lake, good water quality refers to the lake’s suitability for recreational activities and its aesthetic appeal.

The Environment Volunteers monitor a number of parameters which are indicative of water quality and report on these annually. Data obtained over a period of years is also studied for long and short-term trends. A detailed assessment of water quality can be found in our full reports available on the White Lake Science and Information Website.

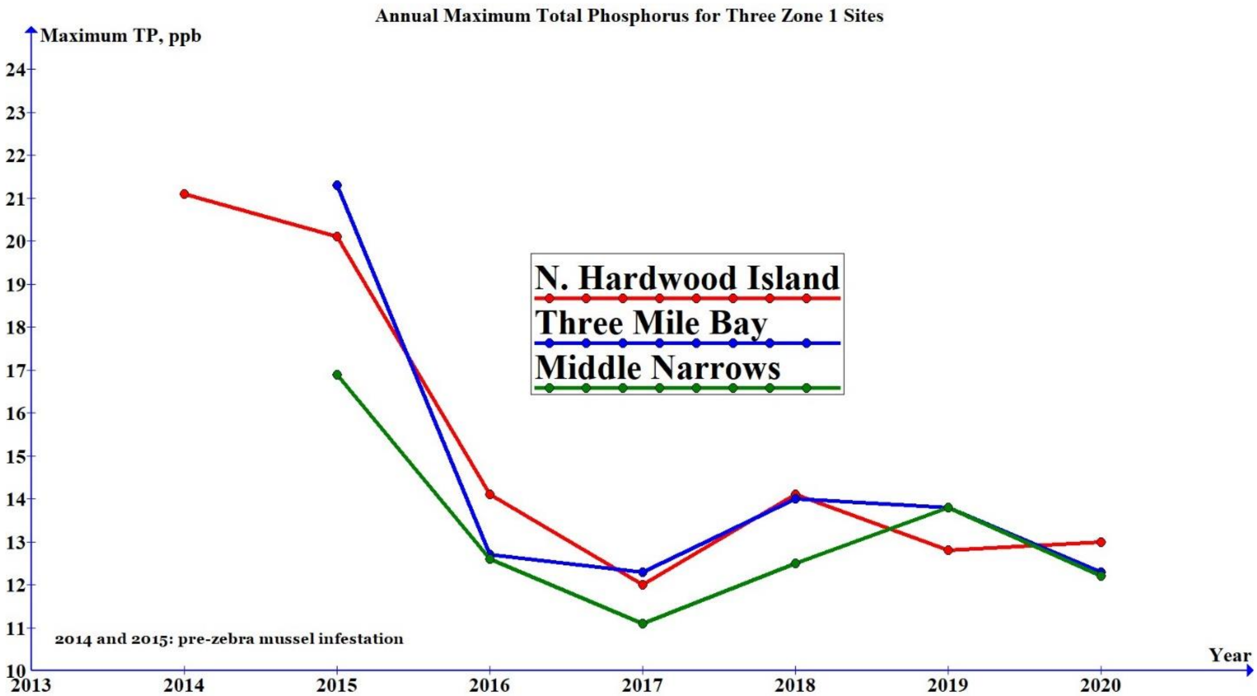
We report here on only a few parameters which are indicative of changes occurring in White Lake as a result of both natural and human factors.

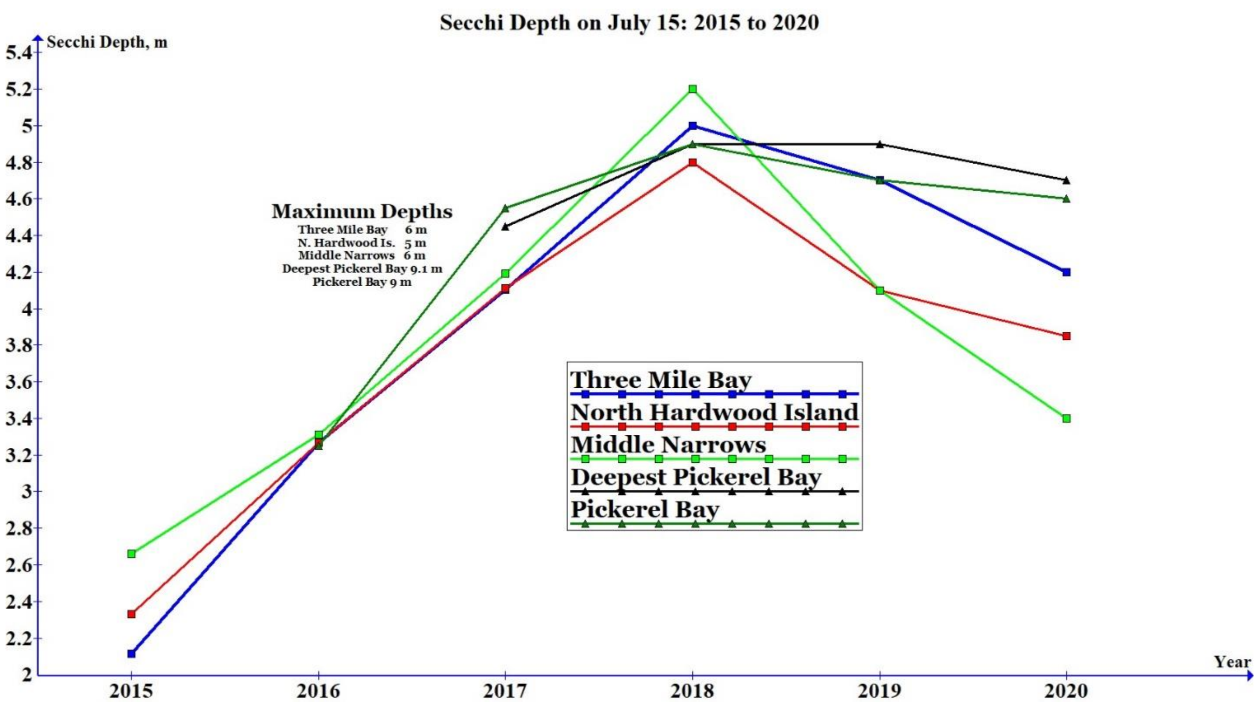
2. Total Phosphorus and Water Clarity

For over seven years we have been monitoring nutrient levels in White Lake in the form of total phosphorus and also keeping track of water clarity. These two parameters have been shown not to be directly related, mainly because of the method used to measure total phosphorous content of White Lake waters.

The defining event effecting both of these parameters was the explosive infestation of White Lake by zebra mussels starting in 2015.

This invasive species has changed the cycling of nutrients in White Lake and for this reason has to be included in any further discussion of water quality in White Lake.





The two graphs above show that since the arrival of zebra mussels, total phosphorus, which represents nutrients available to lake organisms, has decreased by about 50% and water clarity has increased by a factor of two. The graphs also show that even though water clarity has varied somewhat, the concentration of nutrients, expressed as total phosphorus, has changed little since 2017. This is not to say that the total quantity of nutrients entering the lake is not changing. It can still be increasing over time.

What has also not been reduced in recent years are the effects of the presence of zebra mussels on one of the most important water quality parameters: The annual occurrence of nuisance and toxic algal blooms. This important water quality parameter is likely to continue to deteriorate in the coming years.

3. Algal Blooms

One of the well-known characteristics of zebra mussels is their promotion of both green and blue-green algal blooms. There are two reasons for this: 1) zebra mussels are filter feeders and very much like an air filter installed in a corner of your living room, zebra mussels effectively filter out nutrients from lake water and concentrate them where they live, on rocks and aquatic plants in the near shore area; 2) by rejecting toxin-containing algae from their food supply and ingesting only benign algae, they favour the propagation of potentially harmful blue-green algae.

For the past several years we have observed both types of algal blooms in White Lake. The photos below show the now familiar filamentous green algal blooms which occur in early summer and the microcystis algal blooms which occur in the fall.

Filamentous Green Algae: White Lake June 20, 2020

Microcyctis Blue-Green Algae: White Lake September 29, 2020

It is likely that these algal blooms will continue to occur in the coming years. Climate, weather and human activity will determine the severity of these blooms, their duration and extent.

4. Zebra Mussel Update

Anyone snorkeling in White Lake during the summer of 2020 could see thousands of open and empty zebra mussel shells seemingly waving goodbye in concert with surface waves. This event marked the death of the first generation of zebra mussels which infested the lake in 2016. The mussels had reached the end of their natural lifetimes.

A second phenomenon also led to the demise of many other mussels. This was the growth and proliferation of a calcareous (calcium carbonate) forming blue-green algae. The algae covered the surface of rocks in a layer which resembled wet cardboard. Younger zebra mussels covered by this mat likely met their demise from lack of food as well as lack of oxygen during the night when respiration takes place.

In other water bodies where zebra mussels thrive, populations have been found to be cyclical with populations rising and falling due to prevailing conditions. White Lake continues to produce new generations of zebra mussels, which we are confident will thrive into the foreseeable future.

5. Aquatic Plant Study

A major science initiative this year has been the completion of an aquatic plant survey. Some 45 years ago, the Ministry of Natural Resources reported on the presence and density of aquatic plants at nearly 100 sites located in all parts of White Lake.

We have taken on the task of repeating this study and expanding it to different depths. Our goal was to compare the presence of different species of aquatic plants with observations made nearly half a century ago.

We will be writing a Special Report on our observations to be published in 2021. We will also be creating a catalog with photos and descriptions of all of the aquatic plants we have documented in White Lake. This identification guide will be useful to all lake users interested in what is growing along their lakeshore and docks.

6. Loon and Cormorant Counts

2020 was a devasting year for the Common Loon. The overabundance of a species of black fly, which specifically attacks loons, forced them off of their nests. As a result, the number of loons on the lake was reduced by 34% and the number of chicks reduced by 83%. Population levels of this black fly is cyclical, and loon numbers are expected to bounce back in future years.

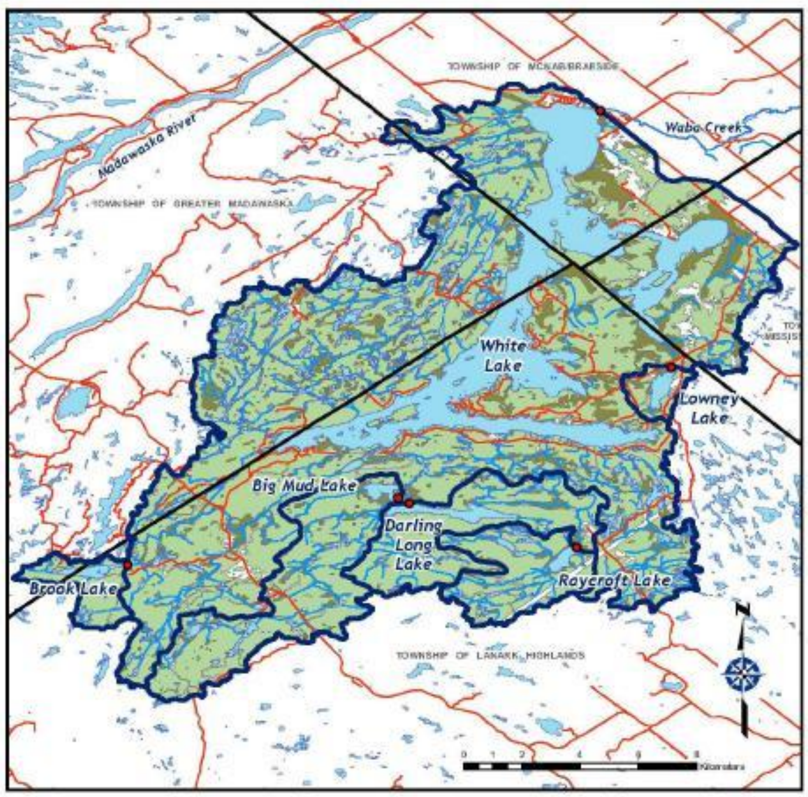
For the past two years, we have been observing the number of double-crested cormorants calling White Lake home. So far, our observations indicate that the population is stable and that there are about three nesting pairs on White Lake.

7. Invitation

For more information on the above topics and more, the reader is invited to read the full Water Quality Monitoring Program Report available on the [White Lake Science and Information Website.]

2.0 Water Quality Monitoring Program And Research Activities -2020

Introduction and Summary



Introduction: White Lake is characterized as a shallow warm water lake. The watershed or drainage basin (pictured in the map) is relatively small compared with the total area of the lake. The western part of the lake shore is comprised mainly of pre-Cambrian (acidic) rocks whereas the remainder of the shoreline and the rocks under the lake are calcium rich in nature (basic). It is the calcium rich rocks that give the lake its chemical signature with a basic pH and high calcium content. Both of these factors strongly favour the growth of zebra mussels, an invasive species which has now been observed in great numbers in all parts of White Lake since 2016.

An examination of the watershed map (above) in concert with topographical maps reveals that the parts of the lake which abut pre-Cambrian rocks are fed by surface and ground waters emerging from heavily forested and hilly terrain. It has been shown that that this terrain does not contribute significantly to the chemical character of White Lake. The remainder of the lake, including areas starting at Hayes Bay and stretching through The Canal, the Narrows and finally the White Lake Village Basin is surrounded by deforested landscape including some farms.

The forested areas, which include numerous beaver dams and ponds, serve as a buffer storing much of the water falling as rain or melting from snow. Trees also have a significant uptake of water during the growing season. On the other hand, the remainder of the drainage basin comprising deforested landscape offers little or no storage of water above the natural water table. In parts of the lake which are surrounded by dense forest, and which also contain the deepest waters, rain and runoff reach the lake at a slower pace relative to the deforested areas. As a consequence of this, the shallowest parts of the lake including parts of The Canal and areas leading to and including parts of the White Lake Village Basin. These areas receive rain and snow melt surface waters as well as ground water infiltration from the bottom of the lake at a much higher rate, especially after a weather event such as a heavy rain.

Water Quality Monitoring: The quality of the water in White Lake is of great importance to anyone wishing to use the lake for recreational purposes and also for the maintenance of a healthy ecosystem including fisheries. The long-term monitoring of water quality will provide a record of how the lake is changing with time. The effects of climate change, increasing use by humans and the influence of invading species on White Lake need to be recorded so that we can take whatever actions are required to ensure the long-term health of the lake.

Many people ask us to describe the condition of White Lake in a word. They ask if it is in good condition or in only fair condition. Although it would be expedient to do so, these terms are subjective, have little meaning, and cannot be used to paint a complete picture which is in reality much more complex. Our objective is to collect valid data in a systematic and scientific manner, to interpret these data taking into consideration the significant body of knowledge available in the published scientific literature, and in turn inform you of changes taking place in White Lake over time. We publish all of our raw data and invite anyone to suggest alternate interpretations. The only requirement is that adherence to scientific principles is respected. This is how science works. The word '*Preservation*' looms large in our work because one of our main objectives is to keep the lake from further degradation and if possible, improve its current condition.

In 2016, White Lake experienced an explosion in populations of zebra mussels, with numbers estimated to be up to one billion individuals. Zebra mussels have been found in every part of White Lake and are especially prevalent attached to aquatic plants. In 2018, the extent of the infestation continued to increase, but in 2019 and especially 2020 it was clear that zebra mussel populations were decreasing somewhat. This was largely due to natural die-off due to age and the growth of calcareous algae. It will likely take a number of years before an equilibrium is reached and zebra mussels numbers, or more accurately zebra mussel biomass, becomes stable.

The most obvious effect of the presence of zebra mussels is the greatly increased clarity of the lake. Looking back at 2015 and years previous, such a finding would have been welcomed as an improvement in water quality. However, attendant effects of zebra mussels are serious and transformative. Zebra mussels are filter feeders and can lead to the wholesale (~90%) transfer of nutrients from lake waters to waters and sediments, especially near the shoreline. White Lake is only 9.1 m deep at the deepest location and has an average depth of 3.0 m. Secchi depth readings which measure water clarity reached over 9 m in 2018. This means that virtually the entire floor of the lake is illuminated with sunlight during the ice-free season.

Since 2015, the concentration of measured total phosphorus in the lake has declined by about 50%. Total phosphorus levels in 2018, 2019, and 2020 marginally increased from 2016 and 2017 levels, but not significantly so. The general reduction in total phosphorus levels in no way indicates that there was less phosphorus entering the lake. There is, in fact, no evidence of any changes in human activity or other factors which would result in lower total phosphorus levels in all parts of the lake other than those resulting from zebra mussels infesting the lake.

The *Summary and Highlights* section of this report summarizes the current status of White Lake based on our observations and the best available science published in the open literature. Reported is the influence of zebra mussels in transferring particulate phosphorus from the deeper parts of the lake to near shoreline environments while leaving behind that fraction of total phosphorus responsible for algae propagation. This means that we can no longer point to lower total phosphorus levels as a positive indicator of lake health.

In 2020 White Lake experienced at least 2 algal blooms. As predicted by the scientific literature, there were blooms of filamentous green algae. Also predicted was the occurrence of blooms of *microcystis aeruginosa* blue-green algae. The filamentous green algal bloom was widespread and intense. The blue-green algal bloom was concentrated in the water column, with isolated small areas experiencing significant surface coverage.

We now can show that White Lake is at capacity meaning that the lake cannot tolerate additional nutrient inputs such as phosphorus. We also know that the lake is experiencing annual green and blue-green algal blooms. These two issues taken together present us with our greatest challenge in preserving White Lake and should be the driving force motivating us to take action!

The effects of zebra mussels as well as climate change are only two of the multiple stressors affecting White Lake which, taken together, make the lake more susceptible to algal blooms and other undesirable consequences due to human activity. The results contained in this report highlight the importance that we, the caretakers of White Lake, do whatever we can to minimize our impact on White Lake ecosystems.

In the meantime, we have to become more vigilant and press our politicians to work with our lake associations and other interested parties to ensure that existing bylaws are used properly in planning decisions and enforced, and that we take measures to protect and preserve the lake. These measures could include septic inspections, shoreline rehabilitation, limits on boat sizes and the control of damaging wakes. There are many things we can do to mitigate the effects of other stressors we cannot control, notably the care, restoration and preservation of the 15 metre 'ribbon of life' along the water's edge.

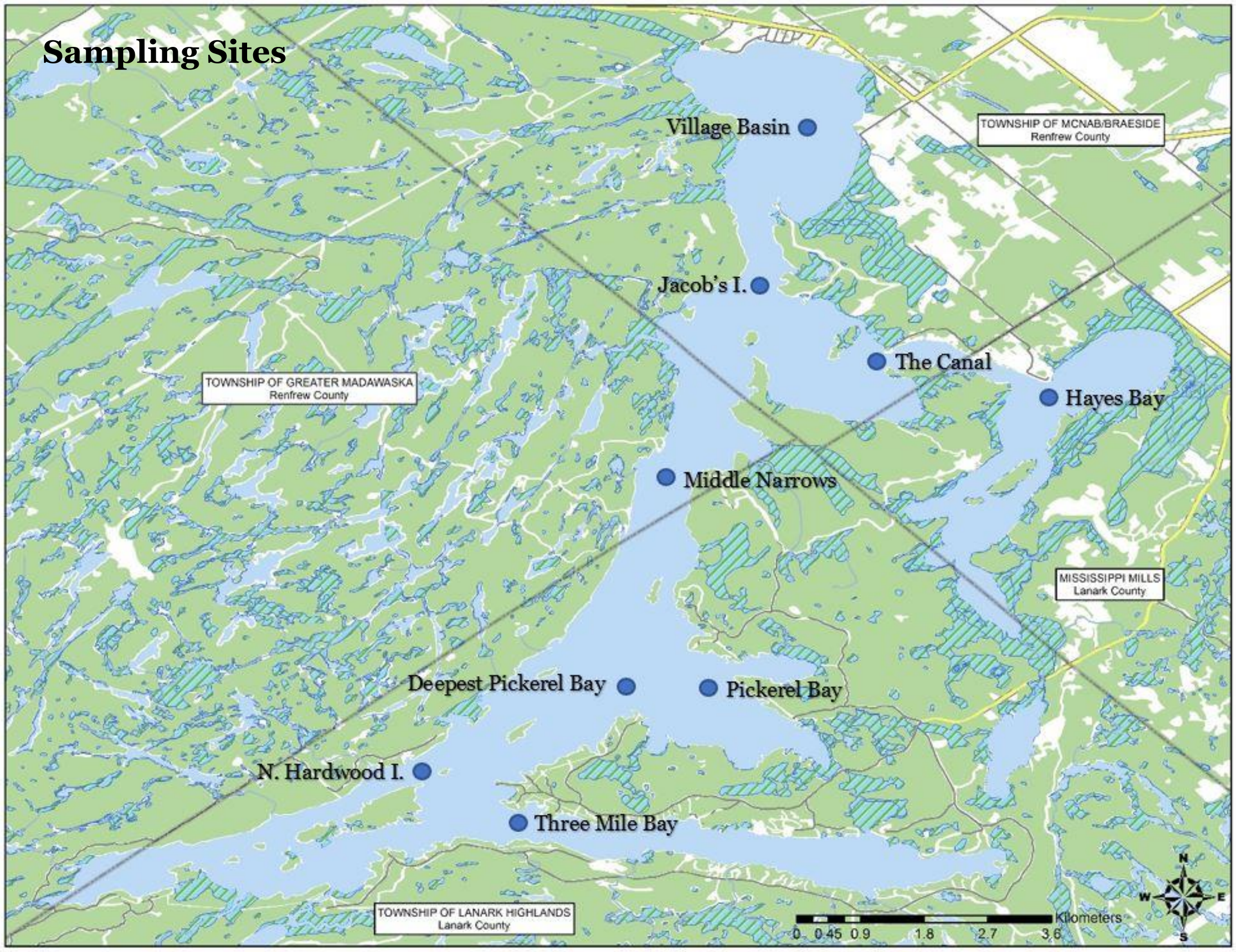
We should also become organized as a society to pro-actively work to prevent the infestation of White Lake with other invasive species some of which have effects far worse than zebra mussels. They are just around the corner!!

Other Research: In addition to water quality measurements, we have completed a number of research projects aimed at increasing our knowledge of White Lake allowing us to better characterize its nature and processes, such as water flow.

These studies include: 1) Annual Common Loon and Cormorant Surveys; 2) The health of the pickerel fishery; 3) The continued propagation of zebra mussels in White Lake; 4) the assessment of long-term trends in total phosphorus concentrations and its implications in interpreting water quality and lake health; 5) a major study of the distribution and population density of aquatic plants at nearly 100 sites on White Lake. This work repeats and extends similar research done in the 1970s, and will give us an appreciation of changes occurring in the lake since that time.

White Lake Water Quality Monitoring Program

The water quality monitoring program for 2020 was carried out by volunteers and involved the collection of water samples mid-month for 6 months starting in May. Duplicate water samples were collected for phosphorus analysis and a single separate sample was collected for calcium and chloride measurements Water samples were filtered through an 80-micron mesh filter to remove any large biota such as daphnia which would skew analytical results. Note that the total phosphorus data obtained is for both phosphorus available as free phosphorus (there are many phases or chemical species of phosphorus suspended and in solution) as well as phosphorous contained in small phytoplankton and zooplankton. Secchi depth readings as well as temperature at the Secchi depth were recorded at the same time. Additionally, Secchi depth and temperature readings were taken every two weeks during the summer season providing additional data



for these parameters. Throughout the summer we monitored biota populations in the lake and monitored the lake for algal blooms.

All water samples collected for the determination of total phosphorus content were shipped to the Dorset Environmental Science Centre (Ontario Ministry of the Environment Conservation and Parks) for analysis under the auspices of the Lake Partner Program. The method used for the determination of phosphorus is described in the publication: B.J. Clark et al, *Assessing variability in total phosphorus measurements in Ontario lakes*, Lake and Reservoir Management, 26:63-72, 2010. The limit of detection for phosphorus using this method is 0.2 parts per billion (ppb).

3.0 Historical and Current State of White Lake Water Quality

D. Conrad Grégoire, PhD and David Overholt, BA

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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-

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

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;
- 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 Lake Association Science Volunteers 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.

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 which is presented in full in Water Quality reports available on the White Lake Science and Information website.

The Ministry of Environment and Climate Change has established a set of guidelines for desirable or safe levels for 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 lake association scientists 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

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

[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.

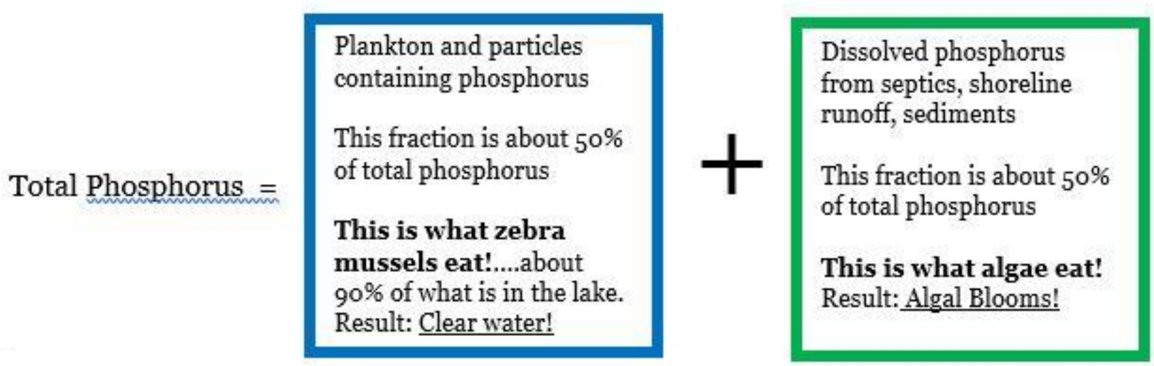
[6] White Lake Preservation Project, 2015. Water Quality Monitoring Program 2015 Report.

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[7].

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[8] provides a historical record of nutrient loading in White Lake over the past 150 years. The authors of this study 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.

[7] Ontario Lakeshore Capacity Model.
[8] 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.*

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[9]. 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 1 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 reported in Water Quality reports[10], 2015-2020), that the total phosphorus values are not identical at all sampling sites in this zone, but are normally 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 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 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

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

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

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

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

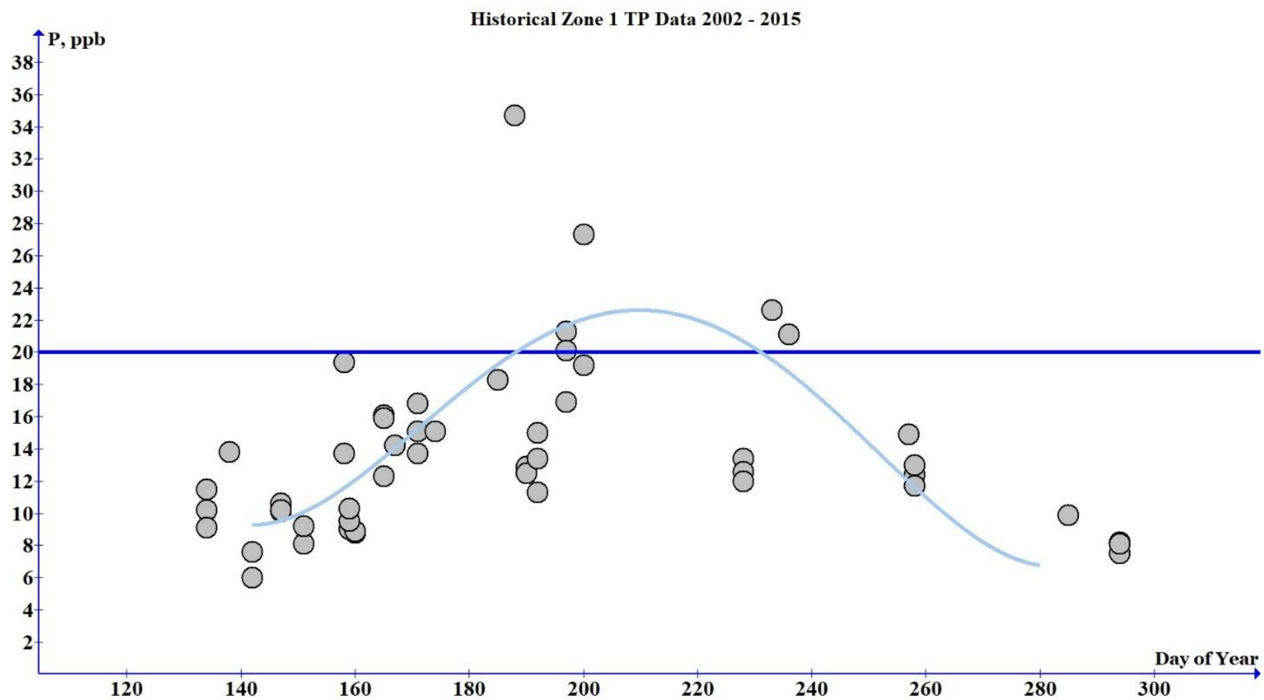
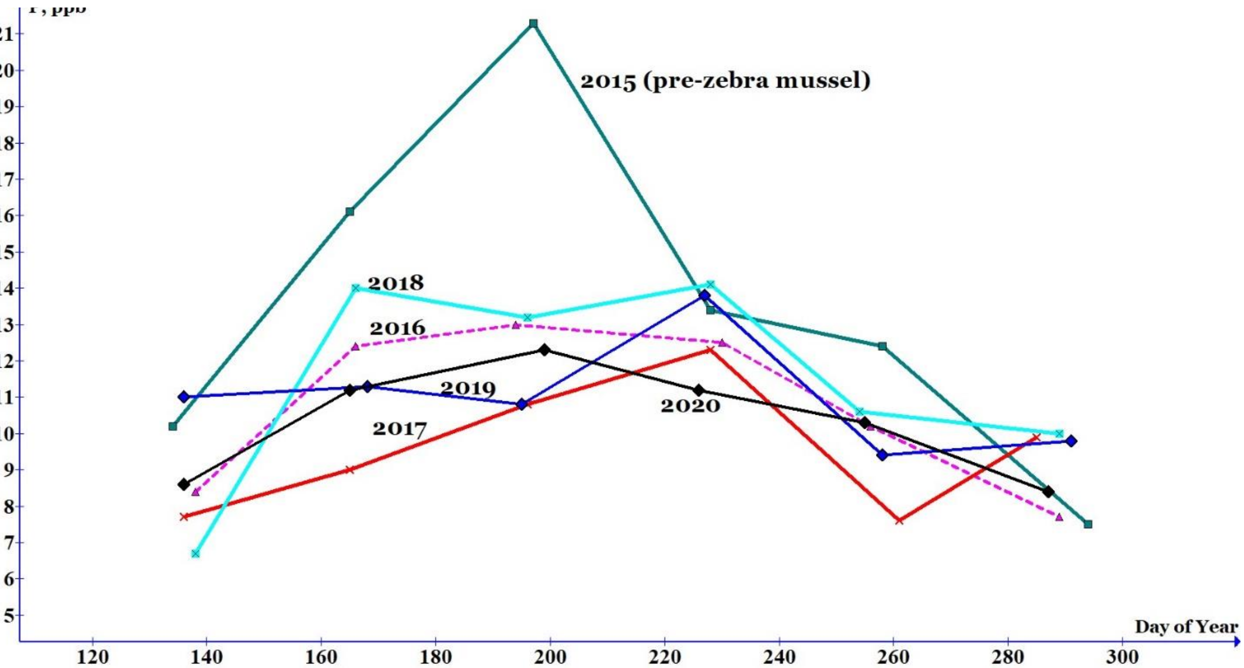


Figure 2 below graphically shows the change in total phosphorus values (Lake Partner Program) for the Three Mile Bay site during the ice-free season for 2015 to 2020. Note that the 2015 curve represents the last year prior to the infestation of White Lake by zebra mussels.

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.

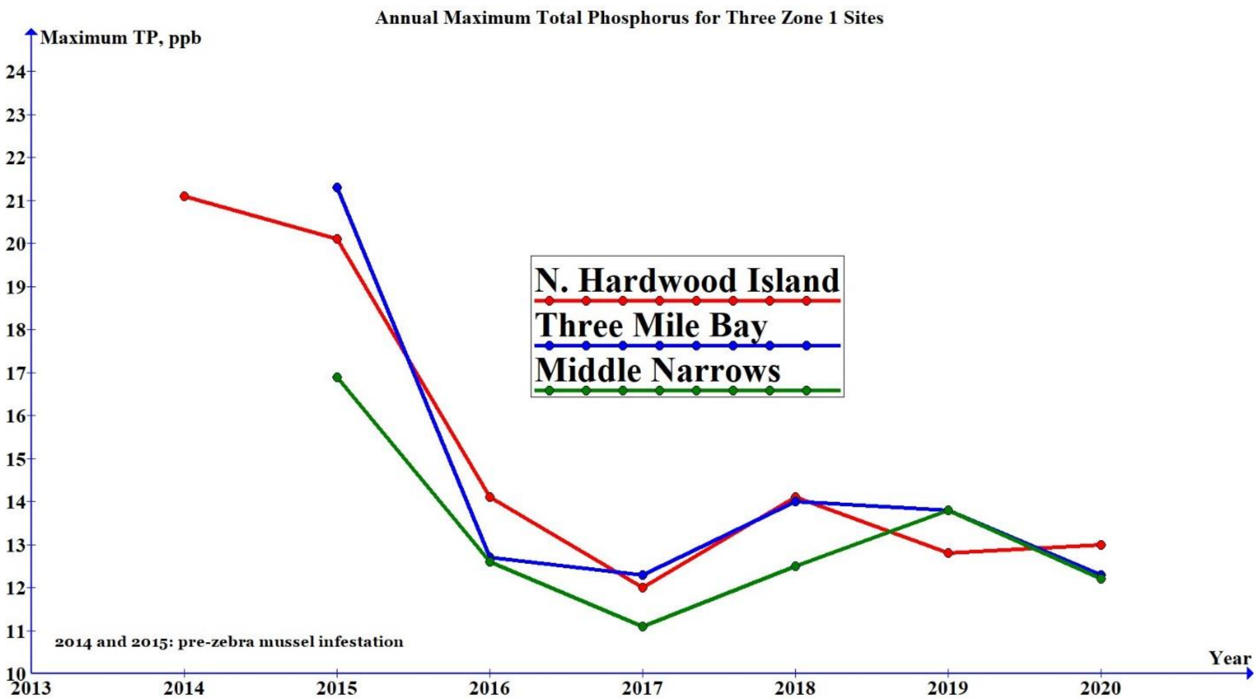


Figure 3: Change in Maximum Total Phosphorus Levels: 2015 to 2019

The phosphorus budget for White Lake is complex. White Lake has an internal[11] load meaning that some of the phosphorus found in sediments is released into the above water column. 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. These factors may be responsible for shifting the date on which the maximum total phosphorus concentration occurs.

[11] 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[12]. 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[13].

Now that zebra mussels are present, the proliferation of a species of noxious blue-green algae (cyanobacteria) is favoured: *microcystis aeruginosa*[14,15]. This species of blue-green algae thrives in waters containing low concentrations of phosphorus. Also, microcystis likely responds to a temporary abundance of nitrogen compounds from plant die-off and can access these faster than other cyanobacteria by changing its buoyancy. It has adapted better to a low phosphorus availability than have its cyano-counterparts. 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

[12] 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

[13] 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*.

[14] 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.*

[15] 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).*

total phosphorus no longer applies to lakes, like White Lake, which have been invaded by zebra mussels.

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.

Sunset on White Lake – Sue Munro

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

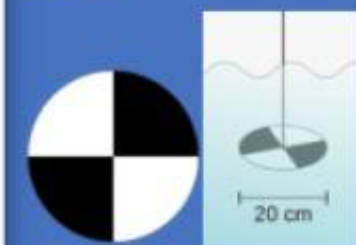
Secchi Depth, metres		
Date	**Pickerel Bay**	**Three Mile Bay**
June 7, 2003	2.9	3.0
July 3, 2004	2.9	2.8
July 19, 2006	2.5	2.3
May 27, 2007	2.7	3.0
June 8, 2008	2.6	2.5
May 31, 2009	2.7	3.1
June 8, 2014	2.9	2.8
July 16, 2015	2.7	2.1
July 12, 2016	3.3	3.3
July 15, 2017	4.6	4.1
July 15, 2018	4.9	5.0
July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

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 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.

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

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.

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

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

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.	8.61	21.	7.98	21.	8.2	21.	8.66	21.	8.95	20.	9.25
1	20.	8.29	20.	7.99	21.	8.1	21.	8.08	20	8.53	18.	9.54
2	20.	8.34	20.	8.05	21.	8.1	21.	8.06	20	8.46	18.	9.32
3	20.	8.29	20.	8.01	21.	8.1	21.	8.10	20	8.54		
4	20.	7.95	20.	7.93	20	8.0	20.	8.07				
5	20.	7.76	20.	7.35	20	7.9	20.	7.88				
6					20	7.9	20.	7.67				
7	20.67	0.6			20	7.9						
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.

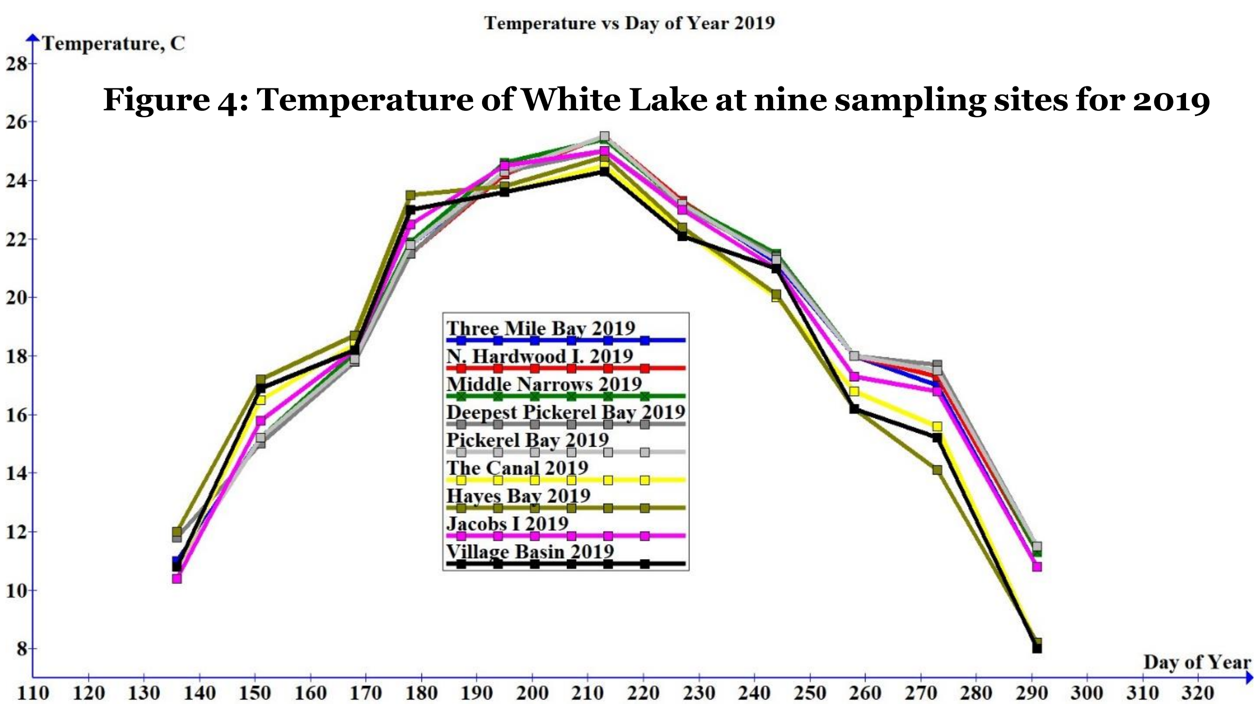


Figure 4: Temperature of White Lake at nine sampling sites for 2019

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[16].

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 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.

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

12. Annual Trends in Lake Water Temperatures

Although there are 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 Water Quality reports). 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.

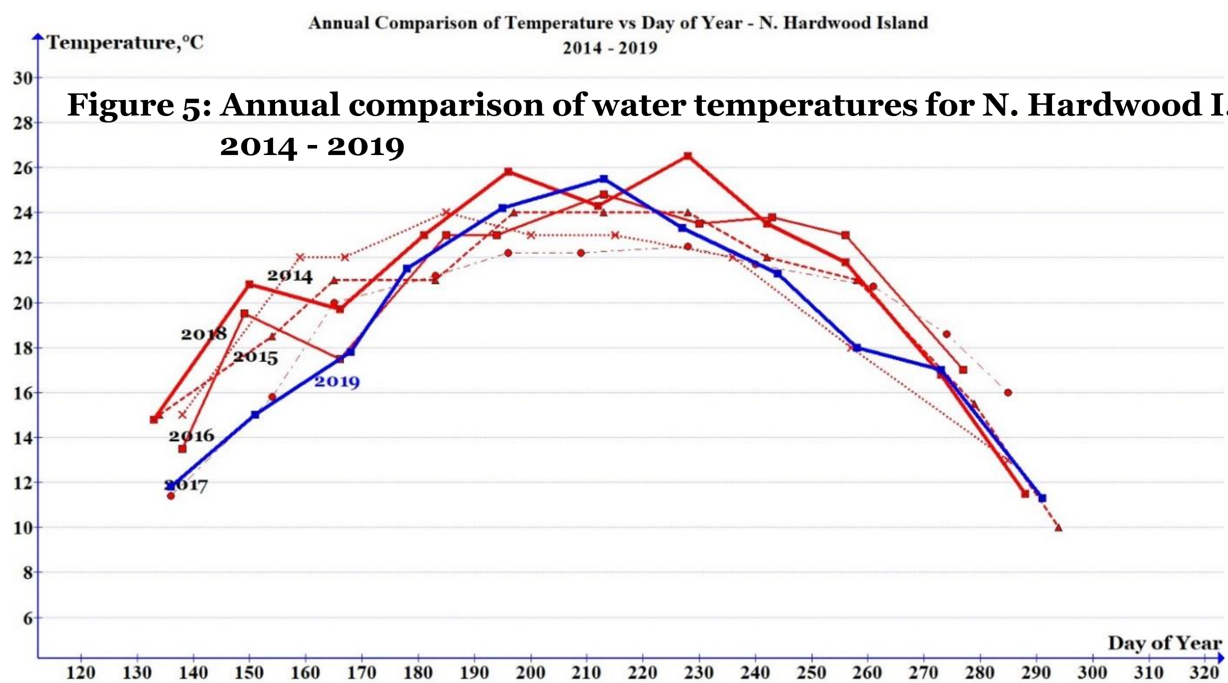


Figure 5: Annual comparison of water temperatures for N. Hardwood I. 2014 - 2019

The table below gives maximum temperatures recorded for White Lake during the past seven years. The year 2018 had the highest temperature and 2017 the lowest giving a range of 4.0 ◦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.

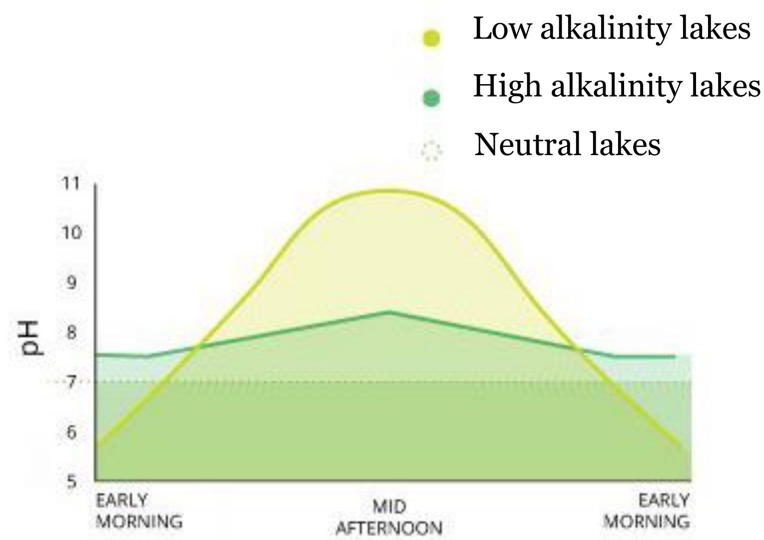


Figure 6: Daily change in pH in lakes

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.

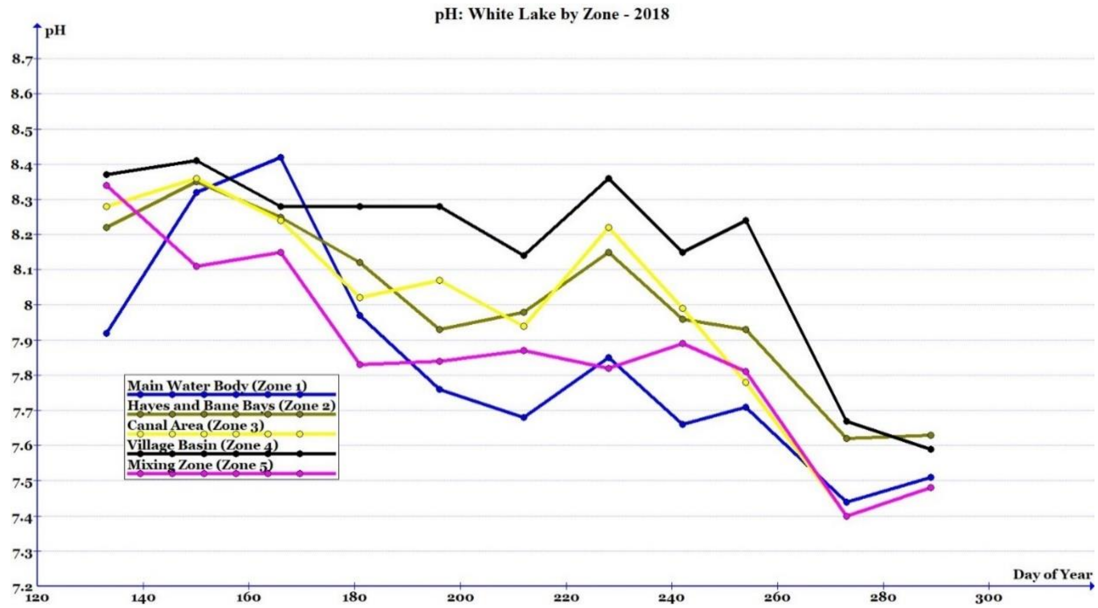


Figure 7: Change of pH during the ice-free season for selected sampling sites, 2018

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 concentration 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[17] 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.

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

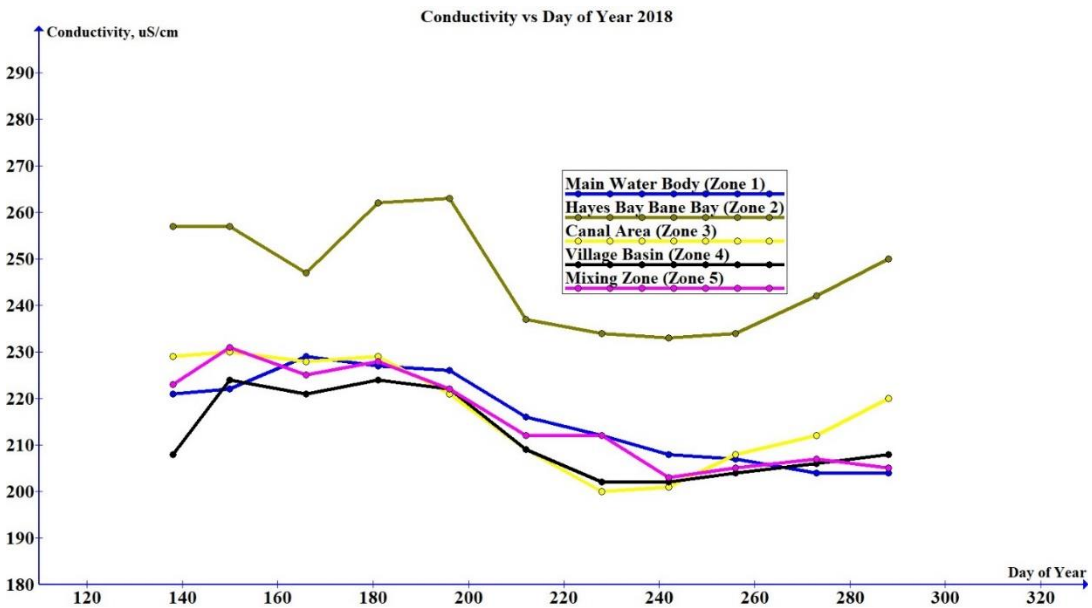


Figure 8: Conductivity vs Day of Year – 2019

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 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[18] and show that the stream waters entering have a minimal effect on the overall water chemistry of White Lake waters.

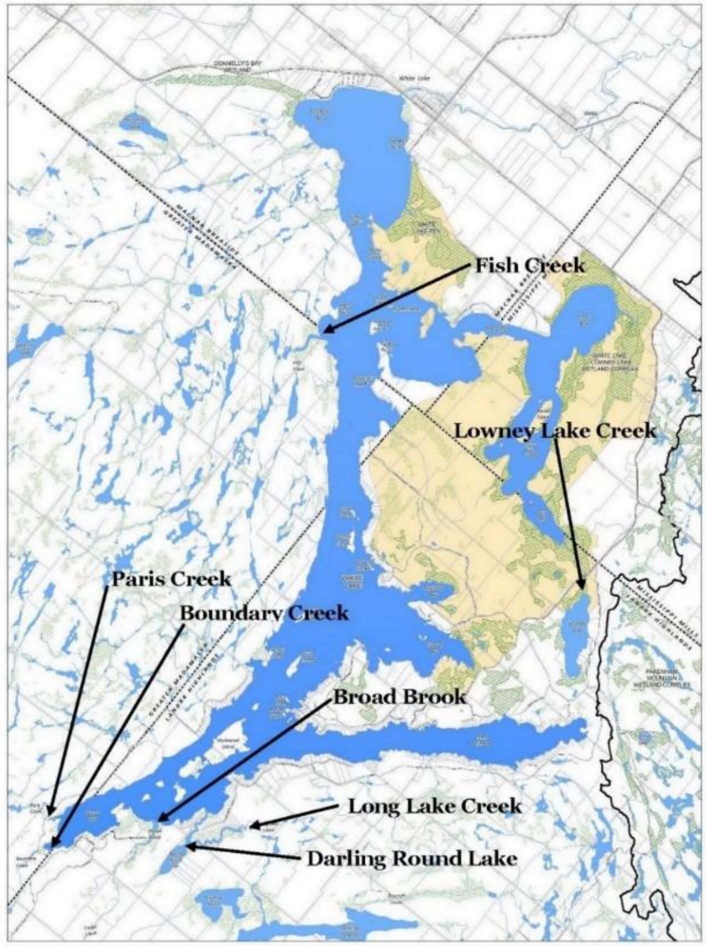


Figure 9: Streams flowing into White Lake

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.

[18] 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[19], Grégoire and Overholt 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

16b. Magnesium

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).

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

Table 16: Magnesium

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

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 ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). 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						-

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).

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[20], the emergence of blue-green algal blooms, changes in seasonal ice cover (Figure 10), and the presence of invading species.

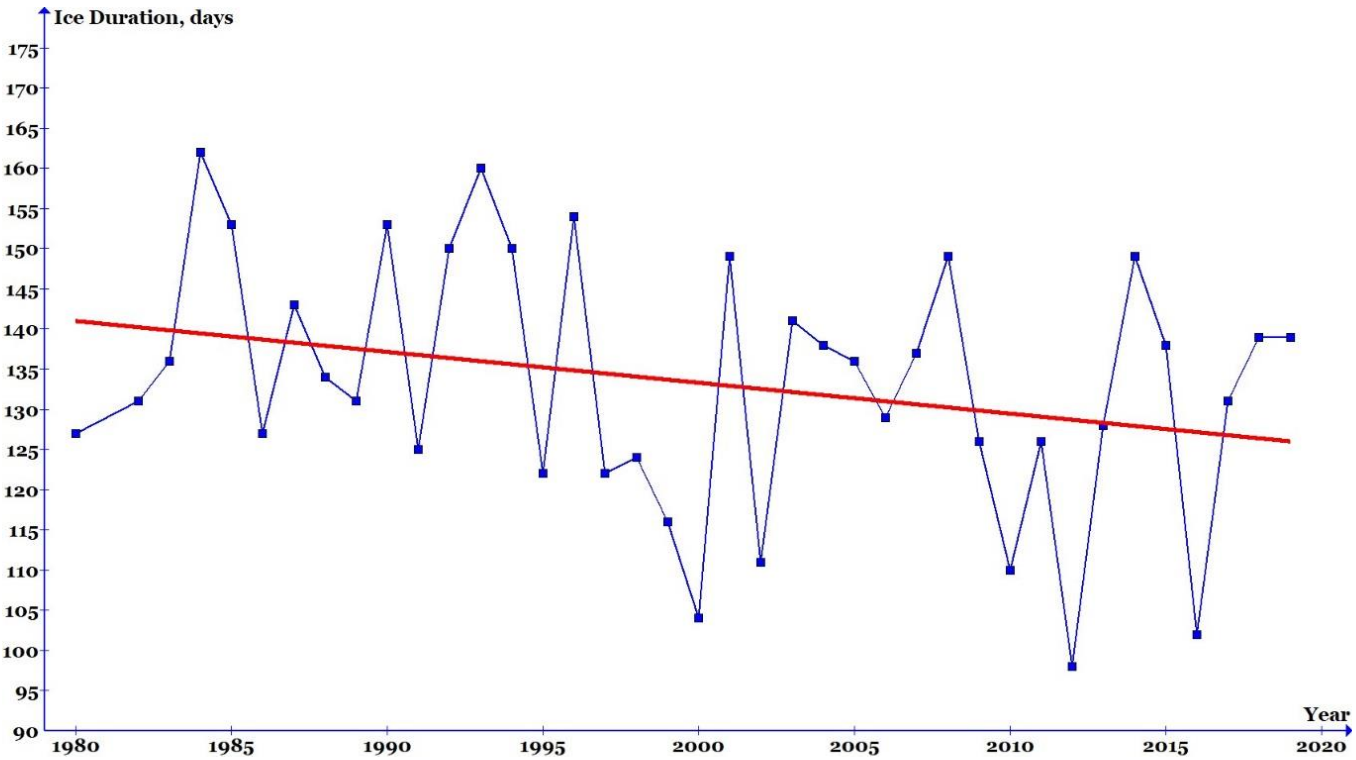
A shift towards longer ice-free seasons can impact physical properties of the lake especially aspects of temperature and mixing that will be favourable to blue-green algae (cyanobacteria). Ice on and off data for White Lake shows an average increase of about 15 days of additional ice-free condition since 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.

[20] 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.*

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[21].

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.

[21] 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.

PART II

Water Quality Parameters

4.0 <u>Algal Blooms – 2020</u>

This year two algal blooms were recorded. The first type of algal bloom which occurred was from filamentous green algae. This bloom lasted, as in previous years, from mid-June until mid-September.

The second type of bloom was from a blue-green alga which occurred in Three Mile Bay and into the main water body, especially on the western side of the lake. In September of 2018, there were two blue-green algal blooms which occurred in the same area of the lake. The first of these blooms was certified as toxin producing, the second was not tested. This year, the bloom was not intense and mostly confined to the water column. Note that the Ministry of the Environment policy towards blue-green algal blooms is: "MOE regards any cyanobacterial (blue-green algae) bloom as potentially toxic, whether or not toxins are detected in the water upon testing"[22]

We emphasize that the algal blooms observed by our team are the minimum number for White Lake, and there may very well have been others on the lake which went undetected or unreported. No Provincial or local authority monitors water bodies for algal blooms. The Ministry of the Environment and local health units respond only to reports from the public at large. Currently only two volunteers are monitoring the 22 Km^2 of White Lake, which has a shoreline stretching nearly 100 km!

4.1 <u>Green Algal Blooms</u>

The first algal bloom of the year started in mid-June and continued until the end of September. This bloom was of a filamentous green alga, which grew in large patches along the shoreline. Nutrients, such as phosphorus, supporting this alga comes from sediments, and shoreline runoff where shorelines are disturbed, as well as dissolved in lake water.

In order to assess the extent of this bloom, we mapped the occurrences of this bloom over a large part of White Lake. We toured the entire shoreline of White Lake south of Fish Creek in order to present a 'snapshot' for June 20, 2020 of algal bloom locations. We also collected samples at each site for microscopic examination. We were not able to examine the entire shoreline of White Lake (~ 97 km) due to time constraints, and so cannot report on other areas of the lake, in particular Hayes and Bane Bays, The Canal and the White Lake Village Basin. Below is a map of the survey area which includes insets of photos of the actual blooms.

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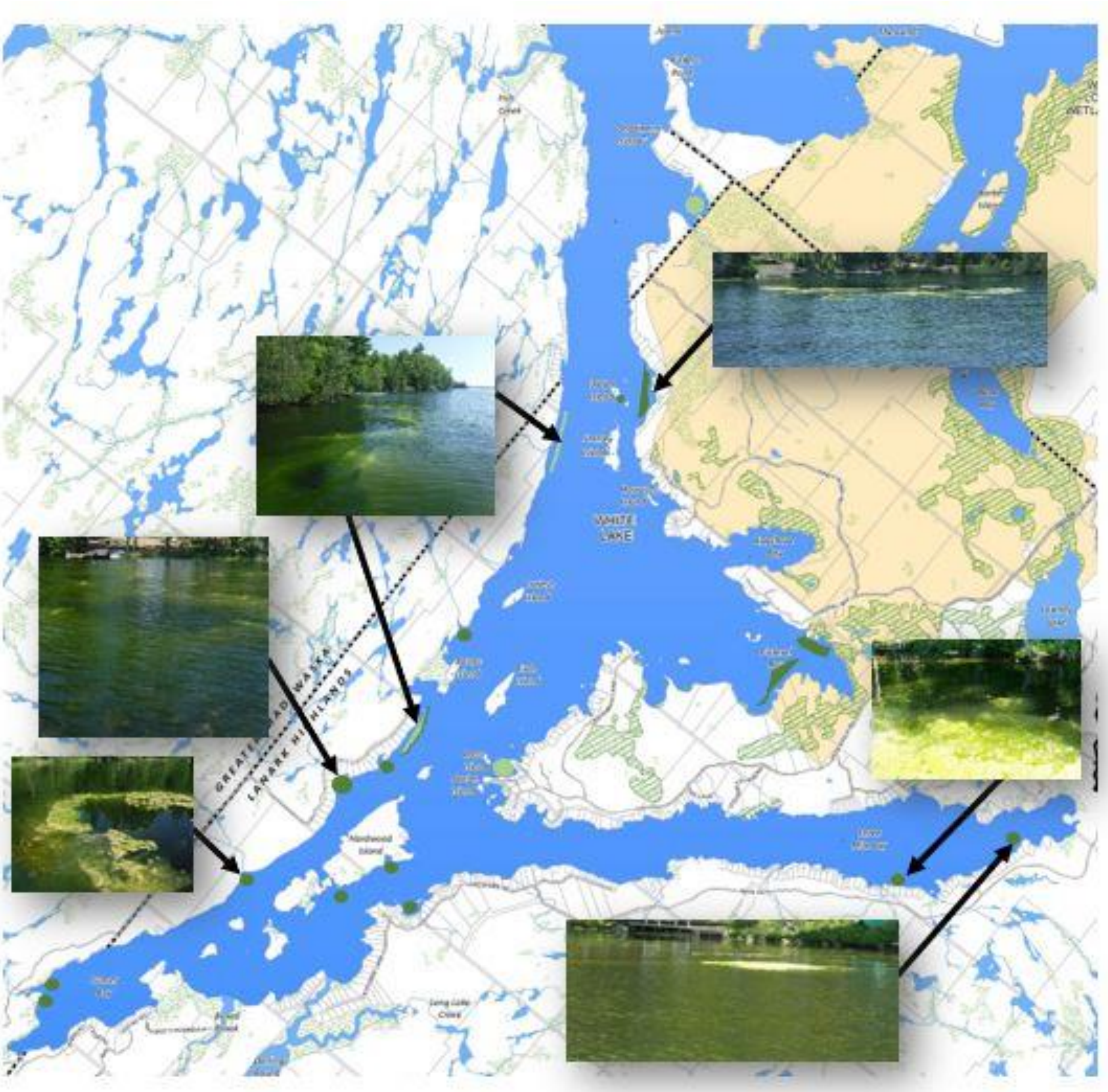
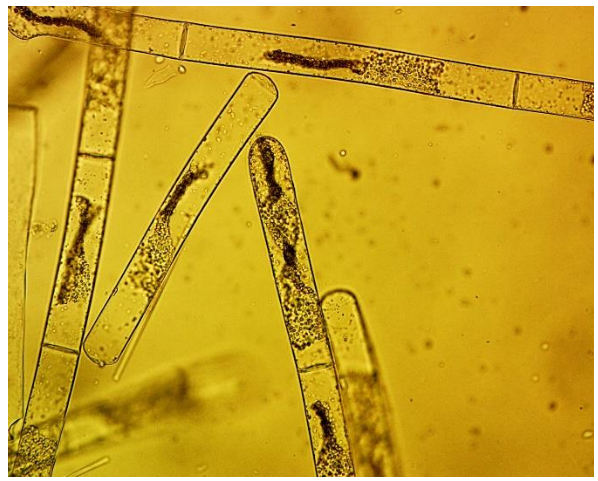
[22] Algal Blooms in Ontario, Canada: Increase in reports since 1994; J.G. Winter, A.M. DeSellas, R. Fletcher, L. Heintsch, A. Morley, L. Nakamoto, and K. Utsumi (all Ontario Ministry of the Environment scientists); *Lake and Reservoir Management*, 27:107-114, 2011.



In the map above, dark green is used to denote simultaneous surface and submerged filamentous green algae, and light green for submerged only. The size of the green dots indicates the relative size of the algal bloom area at each site, as does the length and width of lines for affected shoreline. The attached photos provide a visual representation of the algal bloom itself.

Thirteen sites with algal blooms were sampled for purposes of identification. All sites sampled showed that the lime-green algal “clouds” forming under the surface represent just one genus of filamentous green algae: a type called Mougeotia, which is also commonly known by the unappetizing name of ‘elephant snot’. This alga does not produce toxins in the water and so the bloom is considered a nuisance bloom. The photo below shows a mass of their filaments magnified 200 times.



In addition to the blooms shown on the map, we observed numerous free-floating masses of the algae on the surface of the lake in locations where there were no visible fixed blooms. Many of the blooms occurred in bays or small embayments along the shoreline. During its lifetime, this alga produces gases which become trapped in the fine mesh of the algal mat and serve to raise the bloom from the lake floor to the surface, where it can be affected by the wind.

When large mats of algae die and decompose, the water column can become anoxic (no oxygen) causing the release of phosphorus trapped in sediments. Sediments contain about 200,000 times the concentration of phosphorus found in lake water. The released phosphorus can trigger a secondary bloom which could be larger than the original event.

Although there were large patches of this algal bloom in areas near unaltered forested shorelines, the most serious and largest blooms were found immediately adjacent to newly de-treed and landscaped cottage lots, and areas of severely altered shorelines. The occurrence and extent of these blooms have increased in recent years which may reflect the growth of zebra mussel populations, climate change and lake overuse.

Filamentous green algae of the type we are seeing in the lake has been resident in the lake for likely a good part of the existence of White Lake. Similar algal blooms have been reported recently in the news, in particular in the Rideau Canal, so the bloom in White Lake is not an isolated event.

Algae bloom when conditions are right for its rapid and uncontrolled growth. These conditions include the presence of excess nutrients (phosphorus), favourable water temperature and clarity, sunlight, and the action of wind and waves. For White Lake, the presence of zebra mussels is an additional factor promoting the growth of filamentous green algae. These mussels tend to concentrate nutrients from open waters to the shoreline area where filamentous algal blooms occur. The severity of the algal bloom resulting from the sum of the above factors can be intensified by the runoff of nutrients from areas of shoreline which have been de-treed or altered in such a way that nutrients can enter the lake unmoderated by the presence of trees and other natural shoreline vegetation which prevents or slows nutrients from entering the lake.

Viewed from underwater, the algae mass forms very large volumes extending from just below the surface of the lake all the way down to the lake floor. Other aquatic plants become enveloped within the growing mass. Over time, the algae die, collapses into itself and sinks to the bottom of the lake.

It is interesting to note that similar algal blooms occurred in 2019 (with lower intensity), but were of another species of filamentous green algae Sirogonium, one of a large family of filamentous green algae found in White Lake.

4.2 Blue-Green Algal Blooms

Blue-green algal blooms are not benign and so warrant special attention. When these blooms occur, they can create a public health hazard and anyone using the lake should be apprised of the seriousness of this issue.

This year, White Lake hosted one blue-green algal bloom. The bloom occurred in Three Mile Bay and the main water body, especially on the Western side of the lake. The bloom was identified as the blue-green algae as *microcystis*, which is known to produce toxins.

The bloom was limited to the water column and was not intense enough to warrant testing by the MOE and because the bloom did not result in a surface scum which signals the large-scale death and decay of the algae. Microcystin toxins are usually released at this stage of the algal bloom.

However, the tell-tale surface scum of decaying *microcystis* was observed at several locations including the southern shore of Stanley Island, the eastern shore of Birch Island and the area adjacent to the entrance to Pickerel Bay.

Southern Shore of Stanley Island, September 29, 2020

Fortunately, this surface algal scum dissipated over a period of a few days and it was not necessary to call the MOE for further study. The occupants of the cottages affected were advised of the dangers associated with this type of algal bloom and were asked to treat the bloom as potentially toxic, as is recommended by the MOE.

In recent years, an annual pattern of algal blooms on White Lake is emerging. During early summer, we observe nuisance filamentous green algal blooms, and in the fall, we observe either high concentrations of or blooms of the potentially toxic microcystis blue-green algae. Only time will tell if this becomes a lasting pattern.

5.0 Water Clarity – Secchi Depth

One of the most dramatic changes in White Lake water quality which we have observed since the arrival of zebra mussels in 2016 is the increase in water clarity. So how much clearer is the water now compared to 2015 when the lake was in its natural state?

It turns out that the water clarity has changed differently in different parts of the lake. In areas close to shorelines (where most zebra mussels are found) like Three Mile Bay, water clarity has increased by 138%! At locations further away from shorelines, the Secchi depth has increased by about 109%. In the middle of the lake, the increase is about 95%.

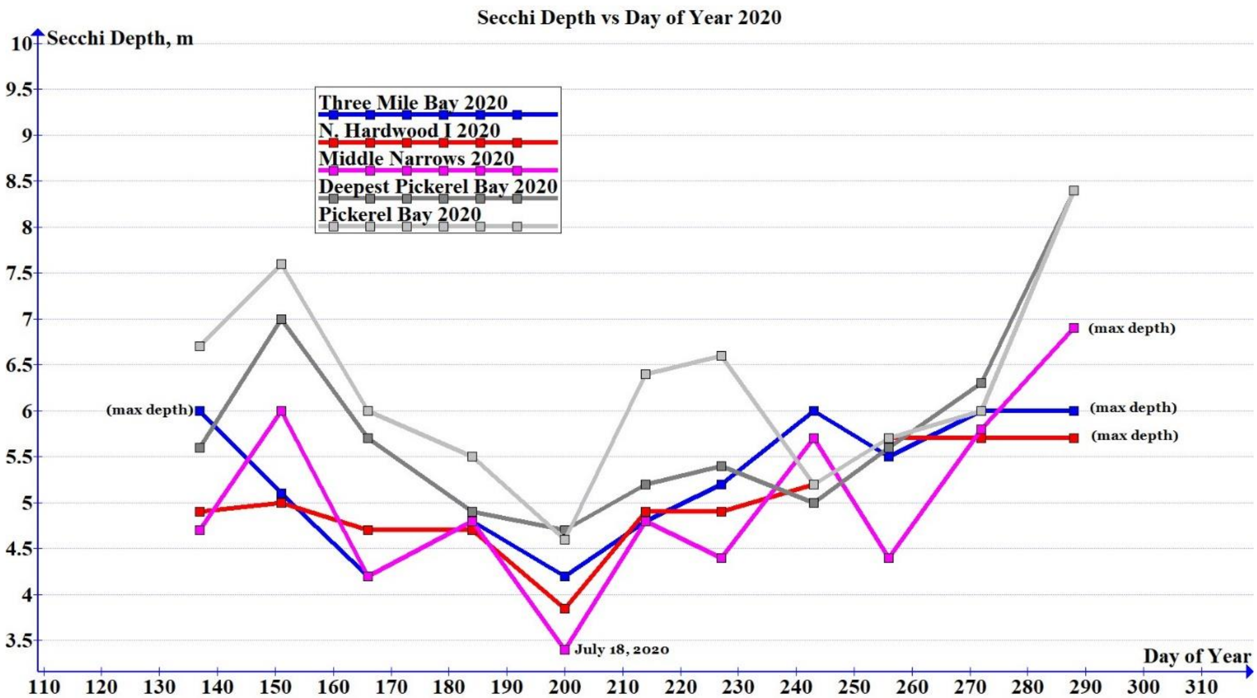
In July of 2015, the Secchi depth in Three Mile Bay was 2.1 metres and by July 2018, the Secchi depth had increased to 5.0 metres. We are now measuring Secchi depths of over 9 metres at some locations. So what?

Water clarity on the surface appears to be a good thing. However, there are some important consequences to consider, especially since the increased clarity is due to the presence of zebra mussels in White Lake:

- Aquatic plants will propagate in deeper parts of the lake.
- Aquatic weed beds will thicken in shallow areas where weeds currently exist.
- More zebra mussel habitat will be created on new plant beds.
- Enhanced water clarity means less food for small creatures, including fish.
- The presence of filamentous green algae along shorelines will become more prominent. This ‘green angel hair’ was visible in nearly all parts of the lake this year.
- Fish will have a harder time hiding from predators in clear water.
- Currently, there are no approved ways of reversing any of the changes noted above.
- We must now prevent the spread of zebra mussels from White Lake to other water bodies.

5.1 Secchi Depth Data:

Below is a graph containing the Secchi depth readings for White Lake taken during the 2020 ice-free season.

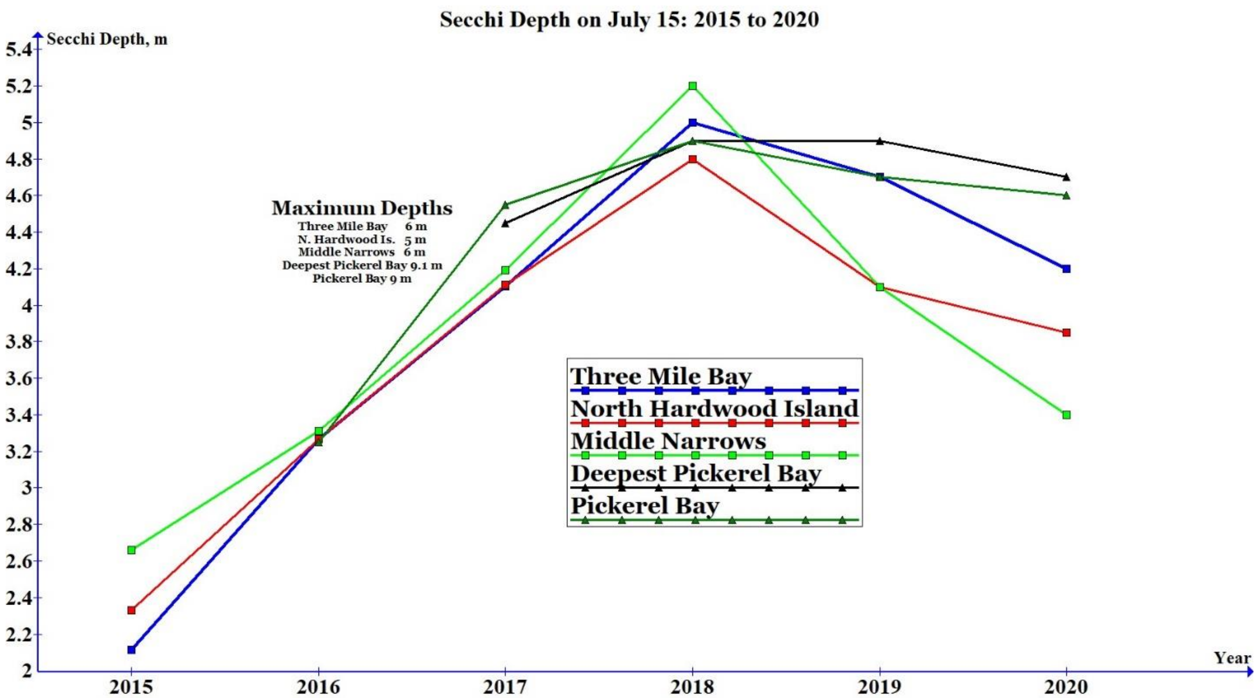


Of the nine sites we sampled, there were only five that had measurable Secchi depths. The remainder of sites were too shallow or the water was too clear at all times. The pattern of Secchi depth readings in 2020 is similar to that of previous years. Secchi depths increase as the lake water column becomes uniform in temperature in the spring and then decreases as the temperature of the lake increases. At higher temperatures there is more biological activity as well as supply of nutrients. Minimum Secchi depths of about 3.5 m (lowest water clarity) were recorded in mid-July with a maximum of 8.5 m recorded in mid-October. In 2019, minimum Secchi depths were recorded in mid-August.

It is difficult to explain why this pattern occurred. One can speculate that it may be related to weather. Alternatively, the presence of reduced numbers of zebra mussels may also have had an effect in decreasing water clarity. This year, there was a significant die-off of zebra mussels for reasons discussed elsewhere in this report. This would tend to result in a reduction in water clarity. Please refer to section on zebra mussels for more information on this.

The graph below shows that the water clarity, expressed as Secchi depth, increased significantly during the years 2015 to 2020. The reason for the increased water clarity has been attributed to the growing presence of zebra mussels in White Lake. The slope of the lines in the graph below were positive during these years as water clarity continued to increase every year.

In 2019, this trend was suddenly reversed with Secchi depths decreasing from values obtained in 2018. This trend continued into 2020 with even lower values recorded. To put this in perspective, the Secchi depth for Three Mile Bay in 2020 is still twice the Secchi depth obtained in 2015, and only reduced by 16% from the maximum value obtained in 2018. This change in Secchi depth with time may be linked to populations of zebra mussels approaching an equilibrium or a net decrease in zebra mussel populations resulting from the death of the first large generation of zebra mussels present starting in 2016. More information will be derived from new data obtained in 2021 and future years.



5.2 Frequency of Secchi Depth Readings Exceeding Sampling Site Depth

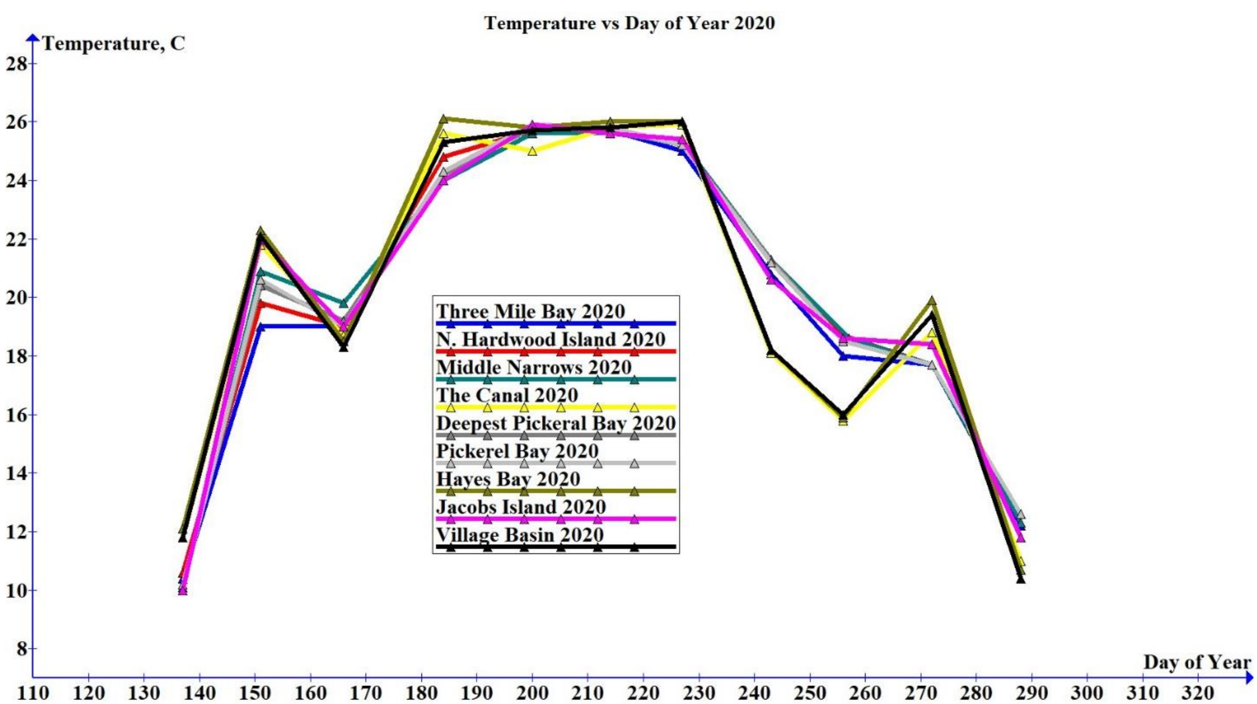
Another way of showing how the clarity of White Lake has been changing in recent years is to consider the number of times we were unable to obtain a Secchi depth (because the water was transparent to the bottom) at each of the five deep water sites monitored on a regular basis. The maximum number of measurements made per year is 11*.

Sampling Site	Max. Depth, m	2015	2016	2017	2018	2019	2020
Jacobs I.	4.0	2	8	11*	11	10	11
N. Hardwood I.	5.0	1	3	5	5	4	3
Middle Narrows	6.0	0	1	2	2	3	2
Three Mile Bay	6.0	1	2	5	3	5	4
Pickerel Bay	7.5	0	0	1	2	1	0
Total		4	14	24	23	23	20

These data show that the total number of times the Secchi depth could not be read, because of high water clarity, increased with each year up until 2019 and began to decrease in 2020. These data along with graph above it indicate that water clarity has not reached equilibrium and is still changing from year to year. Future observations may reveal that these numbers track the total biomass (total weight) of zebra mussels in White Lake.

6.0 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 (back or internal loading) from sediments into the water column. All temperatures reported in this study were taken at the Secchi depth using a thermometer calibrated against a secondary standard mercury glass thermometer.



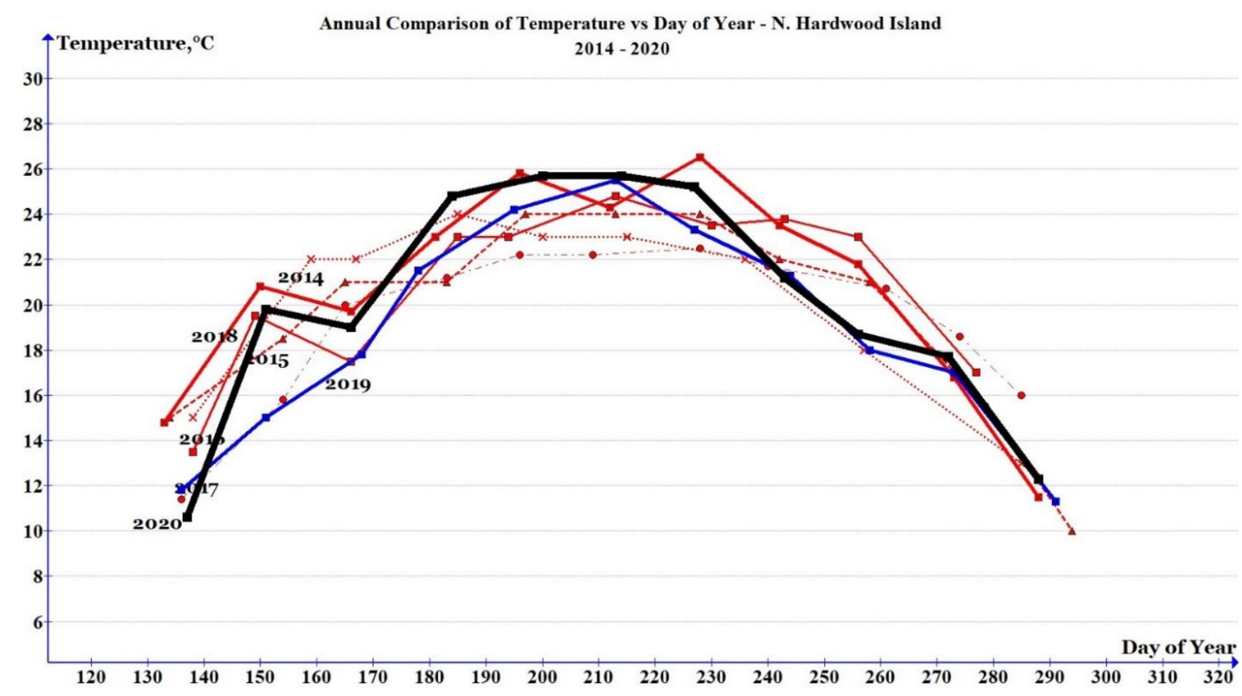
The graph above shows the temperature of White Lake water over the course of the ice-free season.

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. 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 and 2019 Water Quality Monitoring Program Reports available on the White Lake Science and Information website.

6.1 Annual Trends in Lake Water Temperatures

Although there are 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 previous reports). 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 six consecutive years of water temperature measurements for the deeper sites (Zone 1: Main Water Body) on White Lake. The figure above gives temperature measurements obtained at the North Hardwood Island site for the years 2014 to 2020.

The 2020 data (black line) shows that temperatures were generally comparable to other years in both the spring and fall. However, from about July 8 to August 17, water temperatures were relatively high compared to previous years and virtually remained unchanged for period lasting 40 days.

The table below gives maximum temperatures recorded for White Lake during the past six years. 2020 had the highest water temperature which was 3.1 ◦C higher than the lowest temperature recorded from 2014 to 2020.

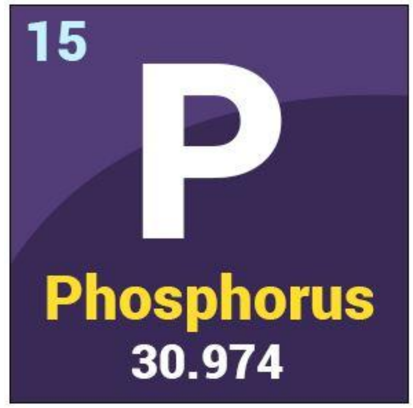
Year	Day of Year	Maximum Temperature, ˚C
2014	199	24.1
2015	217	24.0
2016	223	24.7
2017	216	22.9
2018	196	27.0
2019	213	25.6
2020	214 and 227	26.0

Higher temperatures, especially along shorelines could result in more prolific aquatic plant growth and also encourage propagation of algae, including blue-green algae.


Beaver Pond Wabalac Road – C. Grégoire

7.0 **Phosphorus**

What is Total Phosphorus?



Phosphorus is element 15 of the Periodic Table. It is so important because life cannot exist without it. Phosphorus is one of the building blocks of DNA and hence proteins, and is integral to any ecosystem including lakes like White Lake. However, if there is too much of it, then we can have problems such as dangerous or nuisance algal blooms. For this reason, we monitor the levels of phosphorus in the water so that we can assess the health of the lake and hopefully modify our behaviour to prevent excess quantities of phosphorus from entering the lake.

But what are we measuring anyway? We report our results for phosphorus as 'Total Phosphorus' which implies that total phosphorus is not just one thing but the sum of many things. This is the case!

Phosphorus is a very reactive element and can exist in many oxidation states, which is to say that it likes (as much as an element can 'like') to combine with other elements in many different ways.

But where does it come from? Phosphorus occurs in nature mostly as the mineral apatite which is also called calcium phosphate $Ca_5(PO_4)^+$. It can enter lake water by a number of ways including: rain which contains atmospheric dust; pollen which is high in proteins; fertilizers, detergents, septic systems, etc.; surface soil runoff, and ground water containing dissolved phosphorus compounds. It has been estimated[23] that the concentration of total phosphorus in White Lake waters prior to the arrival of Europeans was about 7.5 parts per billion or nanograms/ml.

When it comes to lakes, we are not really interested in ALL forms of phosphorus, but only the forms which can affect living creatures including fish, plankton (including certain algae, bacteria, protozoans, crustaceans, mollusks) and us!

In lake water, the term 'Total Phosphorus' includes all of the phosphorus that can be measured in water which has passed through an 80-micron (micro or millionth of a metre) filter. The 80-micron filter is used only to remove large zooplankton and, for example, colonies of chrysophyte algae which can form into relatively large 'clumps'. For example, everything else including phytoplankton, small zooplankton, particles

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

containing phosphorus, dissolved inorganic and organic phosphorus compounds pass through the filter and are measured together as total phosphorus. If one took a 1 mm-sized daphnia, placed in distilled water and analyzed it for phosphorus, one can get a result of 35 µg/L (ppb)[24]. For this reason, these larger organisms must be filtered out prior to analysis. The filtration of water samples as described above has been adopted by the scientific community as standard practice, so that results can be better compared between different studies.

The dissolved phosphorus-containing fraction is sometimes called the bioavailable phosphorus. This definition is great for most people, but chemists and biologists will want to tell you that the term' Total Phosphorus' includes all forms of organic phosphates, inorganic phosphates and also organic and inorganic soluble reactive phosphates as well as small particulate phosphate-containing materials.

Since zebra mussels have established themselves in White Lake, the total phosphorus concentrations measured in the lake have decreased by about 50%. This is because zebra mussels are filter feeders and they very efficiently remove all particulate material (down to 1 micron) containing phosphorus. The phosphorus which remains in solution is not filtered out by mussels, but remains available for algal growth. In effect, even though overall phosphorus concentrations have diminished, the amount of phosphorus which algae feed on has not changed at all. Therefore, the total phosphorus concentrations we are now obtaining (much lower than before) do not reflect a reduced risk for algal blooms!

The phosphorus contained in sediments is just as complex if not more so. It is easy to realize that the study of lakes as well as other bodies of water is very challenging and requires the highest levels of science and ingenuity to completely describe the complexity of an aquatic system.

One final note: It is important to realize that the 'Total Phosphorus' we are measuring in White Lake waters only accounts for a small portion of the total amount of phosphorus which enters the lake. Most of the phosphorus entering the lake falls to the bottom of the lake (such as pollen) and once there, eventually decomposes and becomes available to animals and plants. This is why the concentration of phosphorus in lake sediments is literally hundreds of thousands of times greater than in the water just above it!

Now we can discuss the total phosphorus results for White Lake for 2020.

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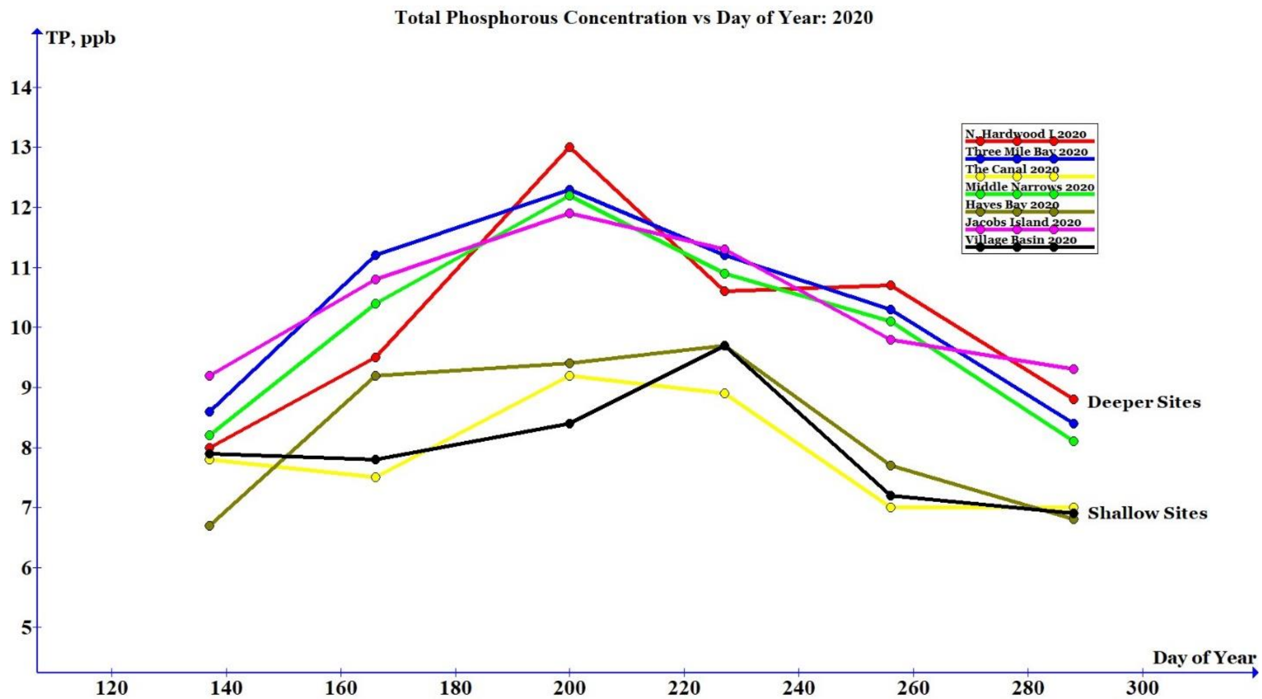
[24] B.J. Clark et al, *Assessing variability in total phosphorus measurements in Ontario lakes*, Lake and Reservoir Management, 26:63-72, 2010.

The graph below shows the change in total phosphorus concentrations during the 2020 ice-free season.



The data for 2020 (above) show an increase in the total phosphorus concentration over the summer months reaching a peak or highest value in mid- July. After this date, the total phosphorus concentration decreases towards the end of summer and into the fall. These data also show that the highest total phosphorus values were obtained at the southern part of the lake nearest the N. Hardwood Island and Three Mile Bay sampling sites. These results and trends are in agreement with measurements recorded during the last ten years by government agencies and lake association volunteers.

The total phosphorus curves in the figure above can be separated into two groups. The first group are those representing the deeper sampling sites, which have higher concentrations. The second group of curves are those representing the shallow sampling sites, located in the northern part of the lake. These sites uniformly have significantly lower total phosphorus concentrations.

There are two main reasons for which shallower locations have lower total phosphorus concentrations. The first is because of more effective mixing of the water column all the way to lake sediments. More oxygen-rich conditions reduce the amount of phosphorus released from sediments.

The second factor contributing lower total phosphorus values in shallow areas is the nature of the sediments themselves and their ability to sequester (physically entrap) phosphorus contained in waters entering the lake from below and through sediments.

Marl sediments are formed when groundwater rich in bicarbonate enter the lake and upon reaching the sediment surface where temperatures are higher and pressures are lower. Under these conditions, bicarbonate can spontaneously decompose releasing carbon dioxide and leaving behind finely divided (small partical size) insoluble calcium carbonate (marble). When this process occurs, phosphorus can be trapped in the calcium carbonate matrix resulting in lower total phosphorus concentrations.

Parts of the lake such as the Village Basin, The Canal and Hayes Bay are all shallow areas underlain by marl deposits, a process which is still unfolding today. If one takes a sample of these sediments and adds droplets of 10% hydrochloric acid, the mixture fizzes releasing carbon dioxide while forming calcium chloride. This test is a positive for marl. Sediments devoid of calcium carbonate will show no reaction when this test is applied.

The table below gives the concentration of calcium carbonate in sediments from four shallow areas of White Lake[25].

Location	**Percent Carbonate***
Village Basin	47.2
The Canal	46.6
Hayes Bay	37.5
Bane Bay	18.2
*average of two measurements	

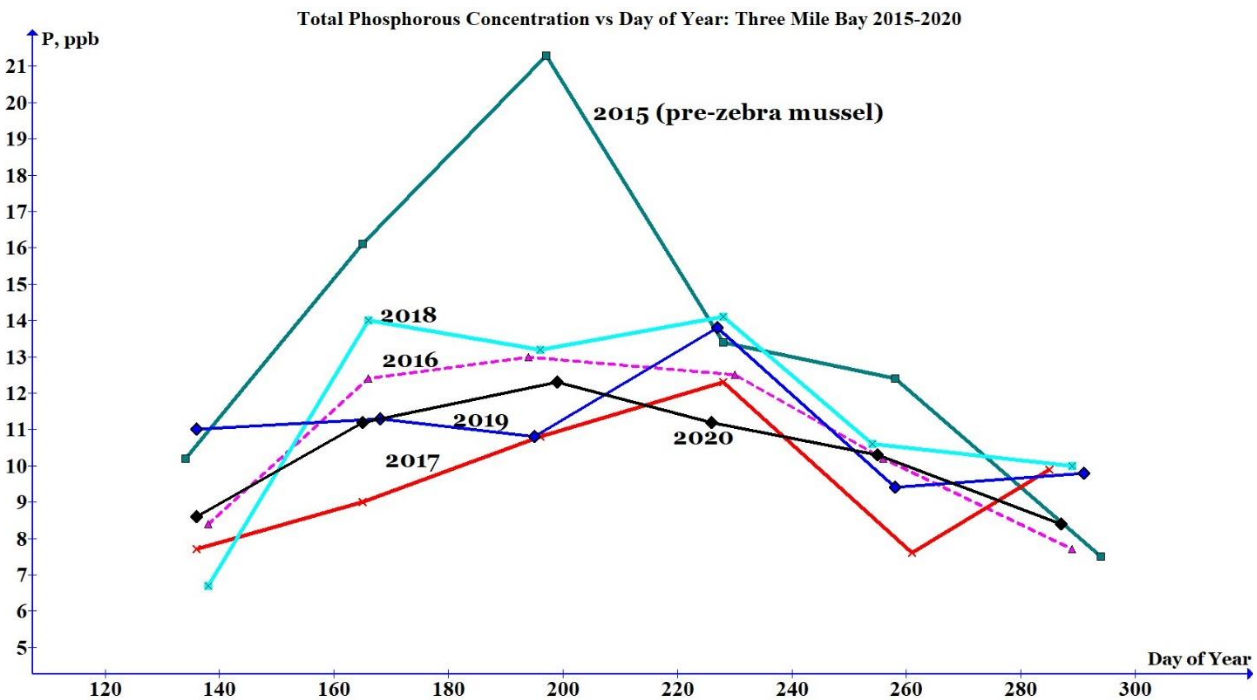
Sediments from the first three locations: Village Basin, The Canal and Hayes Bay, all have very high carbonate content and are documented sources of marl[26]. Although there is a relatively high percent content of carbonate in Hayes Bay sediments, it is less than for the two other sites. Bane is even further away from the marl-producing sediments and shows even lower carbonate levels.

We do not have carbonate content values for the organic sediments at the deeper sites, but we do know that these do not react with acid to release carbon dioxide. From this we infer that there is a low concentration of carbonate in these sediments.

[25] M. Murphy and J. Vermaire, Carleton University, 2019; personal communication.
[26] W.E. Logan, The Geology of Canada, Geological Survey of Canada; 1863, p. 765.

7.1 Annual Trends in Total Phosphorus Concentrations

The figure below shows total phosphorus values for the Three Mile Bay sampling site over a six-year period.



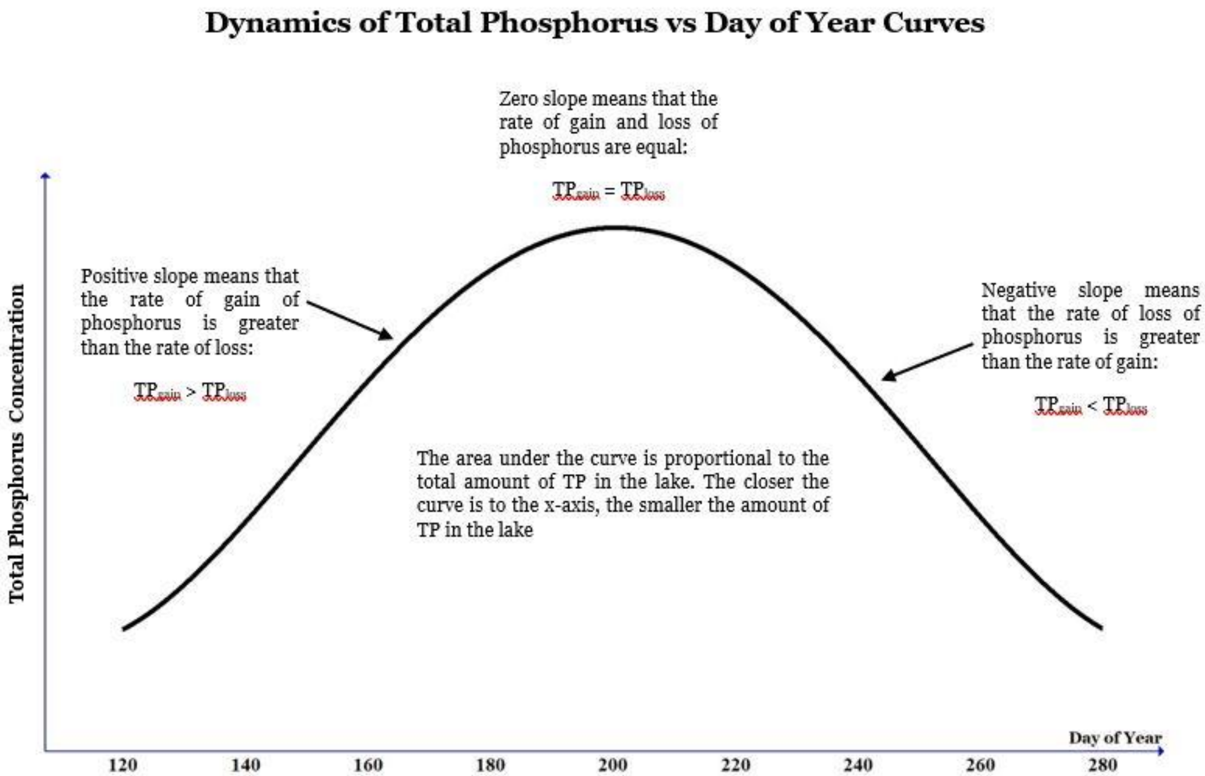
Total phosphorus concentrations declined significantly from those in 2015 and previous years starting in 2016 when the zebra mussel infestation took full effect. Maximum phosphorus concentrations declined by about 50% or more from that date on.

Before continuing with the discussion on phosphorus, it is important to discuss at some length the reason and implications for the actual shape of the total phosphorus vs time curves being discussed.

At any given time, phosphorus is entering the lake from a variety of sources including the atmosphere, surface runoff, ground water ingress, sediment back loading, septic systems, etc. At the same time, phosphorus is leaving the water column as it is taken up into living organisms, precipitated as part of an insoluble compound, etc. The total phosphorus concentration measured in lake water at any given time is the balance between the rates of phosphorus entering and leaving the water column. Starting in April and continuing until mid-June or July (depending on the year), the total phosphorus concentration in the lake steadily increases. This, in turn, means that the amount of phosphorus entering the water column exceeds the amount of phosphorus leaving the water column. In mid-June or July, the total phosphorus concentration reaches a maximum and at that point in time the rate of phosphorus entering the lake water is equal to and balanced by the rate of phosphorus leaving the water column.

Beyond mid-July, the total phosphorus concentration in the lake water steadily decreases indicating that the rate of phosphorus input into the lake is less than the rate of loss of phosphorus from the water column.

This dynamic can be shown graphically:

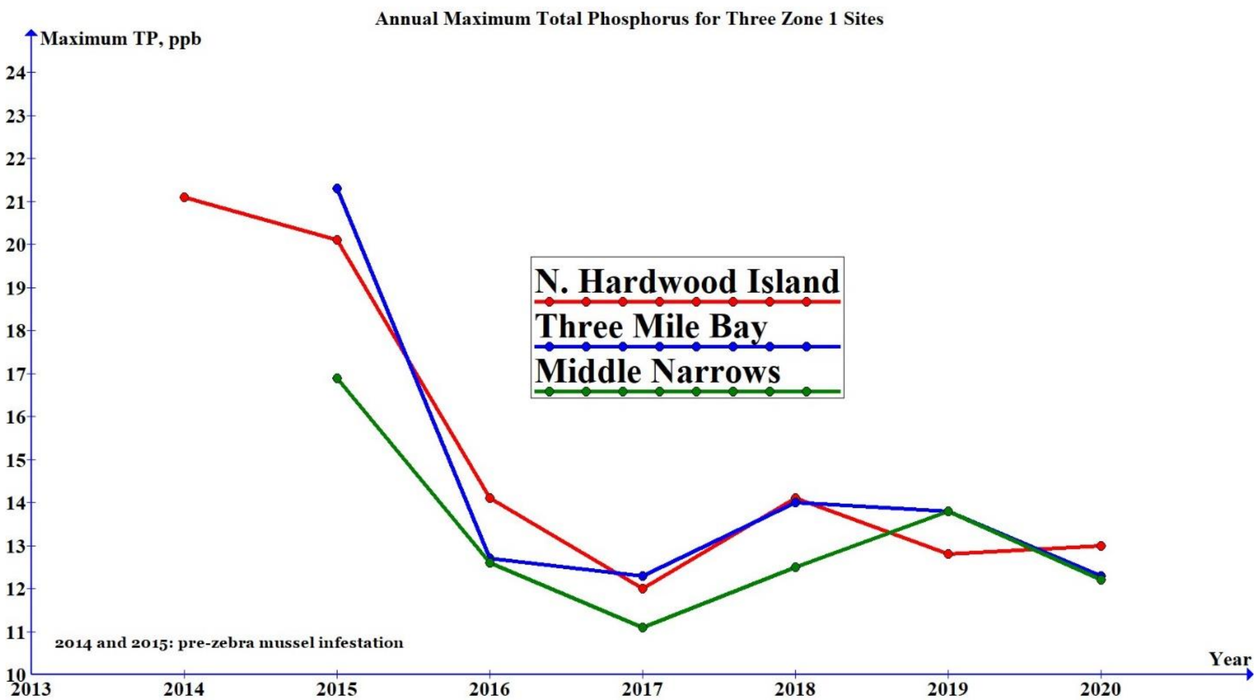


Returning now to the results obtained for total phosphorus from 2016 to 2020: One might be tempted to explain the sudden decrease in total phosphorus levels to lower levels (compared to previous years) as a decrease of <u>input</u> into the lake. Unfortunately, there is no evidence to support this assertion. More likely, however, is the introduction of a new pathway by which phosphorus is <u>removed</u> from the water column and it is this phenomenon which results in lower overall total phosphorus measurements.

Measured total phosphorus concentrations are derived from water samples filtered through an 80-micron (80 one-millionth of a metre) filter. Phosphorus taken up by certain algae which form colonies larger than 80 micrometres (e.g. chrysophyte), would tend to lower the <u>measured</u> total phosphorus in the water column as these would be filtered out.

However, the explosion of zebra mussel populations in White Lake during the 2016 season explains why total phosphorus levels have decreased significantly over previous years. Zebra mussels can remove over 90% of the plankton and other particles normally found suspended in unaffected lake water. Zebra mussels are efficient at removing particulate phosphorus from the water column and transferring it to sediments via feces and pseudo-feces. It is also reported that the concentration of soluble reactive phosphorus remains unchanged allowing for further phytoplankton production. However, it is known that this type of phosphorus is a primary food for zebra mussel veligers (larvae). The phosphorus transferred to sediments by zebra mussels eventually becomes available for algae growth and results in an increase in both green and blue-green algal blooms. This is exactly what we have observed in White Lake over the past four or five years.

Although shown in another section of this report, it is worth reproducing here the graph of maximum total phosphorus values measured in White Lake for years before (2014 and 2015) and after the invasion of zebra mussels:



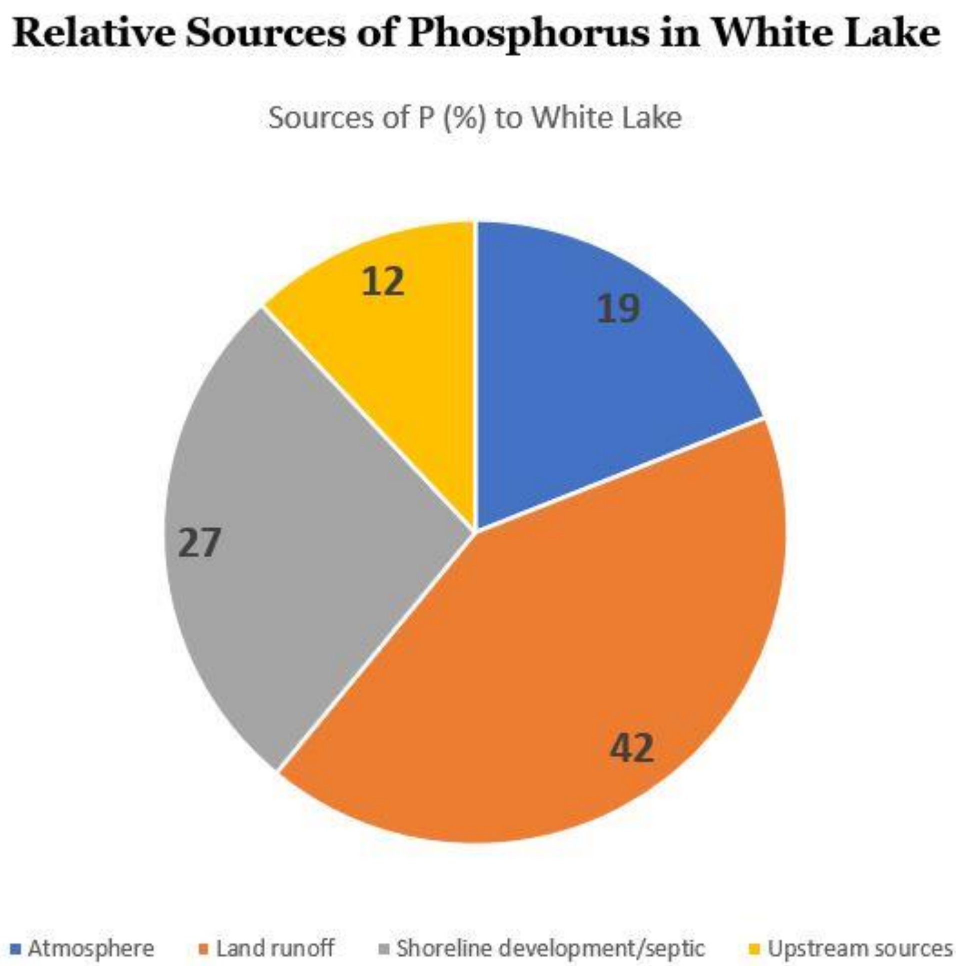
It may be useful to remind ourselves of the relative sources of phosphorus entering White Lake[27] and note that not all of the phosphorus is converted to the 'total phosphorus' that we measure every month during the ice-free season.

The pie chart below indicates that taken together land run-off, septic systems and shoreline development account for about 70% of the phosphorus entering White Lake.

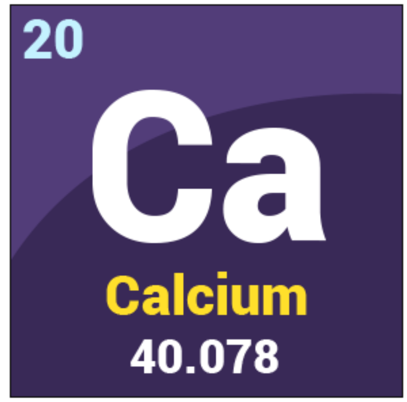
[27]These data are outputs of the Lakeshore Capacity Model for White Lake reported by Bev Clark. Bev Clark is a retired senior career research scientist from the Ministry of the Environment, Conservation and Parks. He was the director of the Lake Partner Program from its inception and both collected research data and contributed to the development of the Lakeshore Capacity Model used by the Ontario Government.

This clearly shows the importance of effective shoreline management to water quality and especially for the control of nuisance and toxic algal blooms which we have been documenting during the past eight years.

The chart also shows that we, as users of the lake, can have an effective role in influencing and even improving White Lake water quality.



8.0 Calcium



The table below contains values for calcium concentrations measured in White Lake waters. Data are tabulated on a monthly basis and also for each individual site sampled. Analyses were performed by the Lake Partner Program laboratories in Dorset, Ontario.

Across the entire lake during the ice-free season, the concentration of calcium varied from a low of 29.9 ppm to a high of 34.5 ppm. Although the mean values for all individual sites (green) are within one standard deviation of one another, the absolute values for Hayes Bay are somewhat higher. This site, in particular, has a total dissolved solid content which is 20% higher than at all other sampling sites on White Lake.

When looking at mean calcium values for all sites for a given month (red), variation is very small and within one standard deviation. This indicates that lake waters are well mixed.

Calcium (ppm) – Sampling Site by Month: 2020

Sampling Site	May	June	July	August	Sept	Oct	Mean
Three Mile Bay	31.2	32.0	31.2	30.9	28.4	29.7	**30.6±1.2**
N. Hardwood I.	31.9	32.6	31.6	30.9	28.8	29.0	**30.8±.4**
Middle Narrows	31.6	33.1	31.4	30.6	29.6	30.6	**31.2±1.1**
Jacob’s Island	31.6	32.4	31.1	30.4	28.8	29.0	**30.6±1.3**
The Canal	32.0	32.4	31.2	27.9	29.2	31.5	**30.7±1.8**
Hayes Bay	34.5	33.8	34.0	31.1	29.4	32.5	**32.6±1.8**
Village Basin	29.4	32.4	31.7	28.9	28.4	29.0	**30.0±1.5**
Mean	31.7±1.4	32.7±.6	31.7±.9	30.1±1.1	28.9±.4	30.2±1.3	

The table below compares calcium concentrations for individual sites over a six-year period. With the exception of 2015, where values appear to be anomalously high, calcium concentration at each individual site in White Lake do not appear to be changing appreciably.

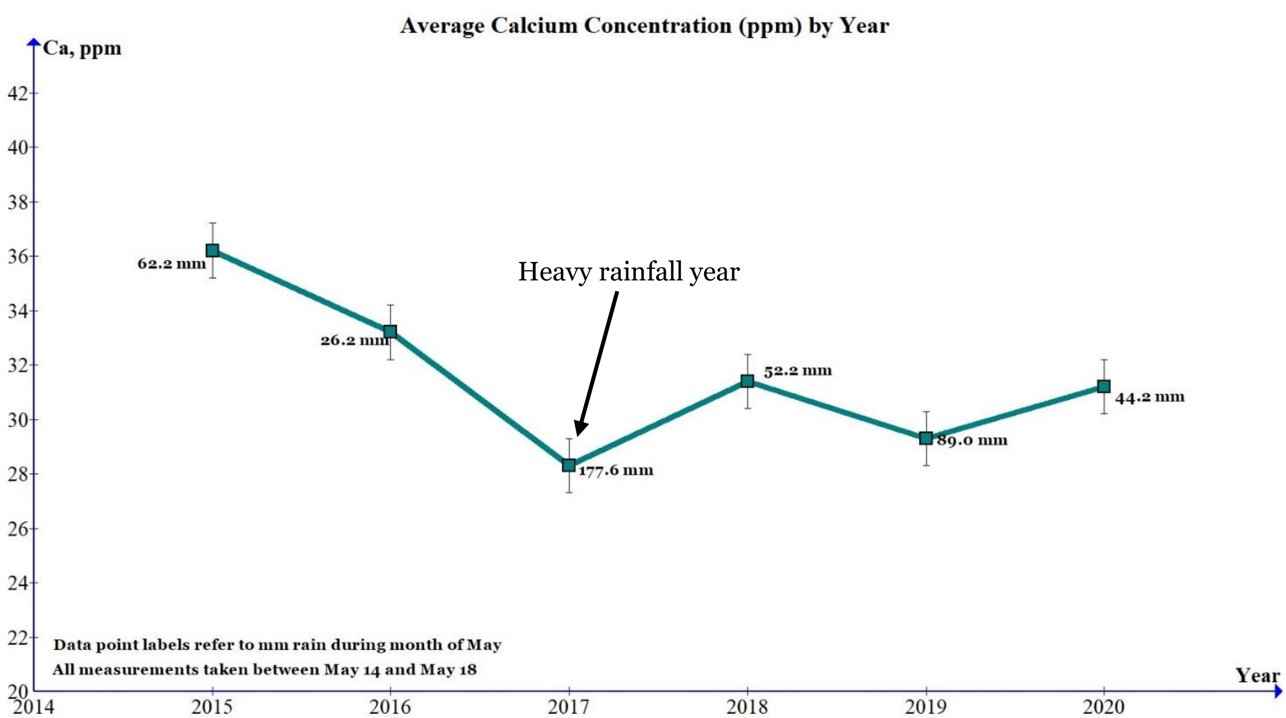
Calcium (ppm) – 2015 to 2020

Sampling Site	2020	2019	2018	2017	2016	2015
Three Mile Bay	30.6	28.8	32.8	28.4	36.4	36.2
N. Hardwood I.	30.8	28.6	33.0	28.5	31.8	37.3
Middle Narrows	31.2	30.3	33.4	28.4	31.1	35.3
Jacob's Island	30.6	28.4	34.0	27.7	31.4	36.2
The Canal	30.7	30.8	34.4	29.4	34.3	35.8
Hayes Bay	32.6	30.4	37.8	31.0	36.6	-
Village Basin	30.0	27.9	31.6	27.3	31.0	-

The table below compiles the average value of calcium concentration in parts-per-million (ppm) at all sampling sites for the month of May for years 2015 to 2020. The calculated standard of deviation is approximately 1 ppm for each of the annual average calcium concentration. With the exception of 2015 values, as noted above, the concentration of calcium in White Lake is unchanging at approximately 30 parts per million.

Average Calcium Concentration (ppm) 2015 to 2020

Year	Average ± SD
2020	31.1 ± 2.0
2019	29.3 ± 1.0
2018	31.4 ± 1.0
2017	28.3 ± .74
2016	33.2 ± 2.5
2015	36.2 ± .7



The above graph shows these values plotted. Individual data points are provided with an error bar indicating the standard deviation of ± 1 ppm. The size of the error bars relative to the actual plotted value indicates that the changes in calcium concentration from year to year are significant.

In our 2017 report we 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. When the correlation plot was extrapolated to zero rainfall, a calcium concentration of 36.8 ppm was calculated. This concentration was taken as the actual calcium concentration of water entering the lake from springs or other ground water sources. The variance in the actual measured calcium concentrations, which accounts for the different monthly values obtained, were the result of a dilution effect from rain water and surface runoff, which contain little or no calcium.

At each point in the above plot is given the total precipitation for the month of May for each year. When this data is plotted, as was done in 2017, but including all data to 2020, 'zero rainfall' intercept gave a calcium value of 35.1 ppm calcium. This value is (within error) identical to the value obtained in 2017.

These results support the conclusion (see 2017 Water Quality Monitoring Report report) 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.

9.0 Chloride

The table below contains values for chloride concentrations measured in White Lake waters. All samples were collected between May 14 and May 18 of any given year. Analyses were performed by the Lake Partner Program laboratories in Dorset, Ontario.

The concentration of chloride does not vary significantly from site to site especially when comparing deeper water sites (such as the first three in the table below) with values obtained for shallower sites, such as Hayes Bay. Hayes Bay has higher chloride concentrations that at any other location on the lake. These concentrations are nearly three times those of other locations, especially those in Zone 1, the main water body. Water draining from Hayes Bay into the Canal Area and downstream on the way to the Village Basin is responsible for elevated chloride values at The Canal sampling site as well as the Village Basin sampling site.

Chloride (ppm) – May, 2015 to 2020

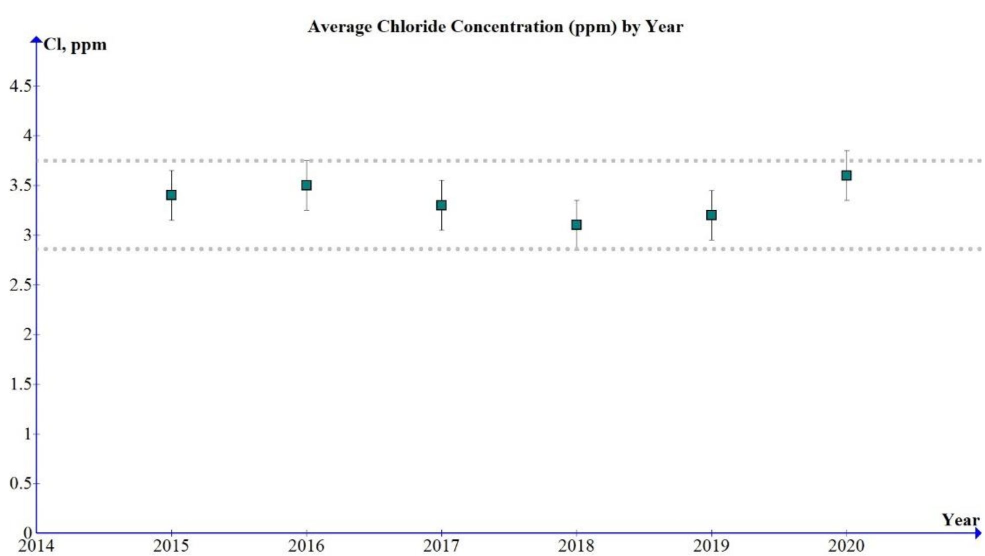
Sampling Site	2020	2019	2018	2017	2016	2015
Three Mile Bay	3.4	2.8	2.9	2.8	3.4	3.5
N. Hardwood I.	3.4	2.8	2.9	3.1	3.4	3.3
Middle Narrows	3.5	3.2	3.5	3.3	3.5	3.5
Jacob's Island	3.7	3.6	3.2	3.7	3.7	3.5
The Canal	4.7	4.1	4.1	6.2	5.4	3.9
Hayes Bay	9.0	7.6	8.3	9.5	10.0	-
Village Basin	4.0	3.6	3.6	3.8	3.7	-

Average chloride data for 2015 to 2020 are given in the table below. Data from The Canal and Hayes Bay were excluded from this table so as not to skew results for the remainder of White Lake.

Average Chloride Concentration (ppm) 2015 to 2020

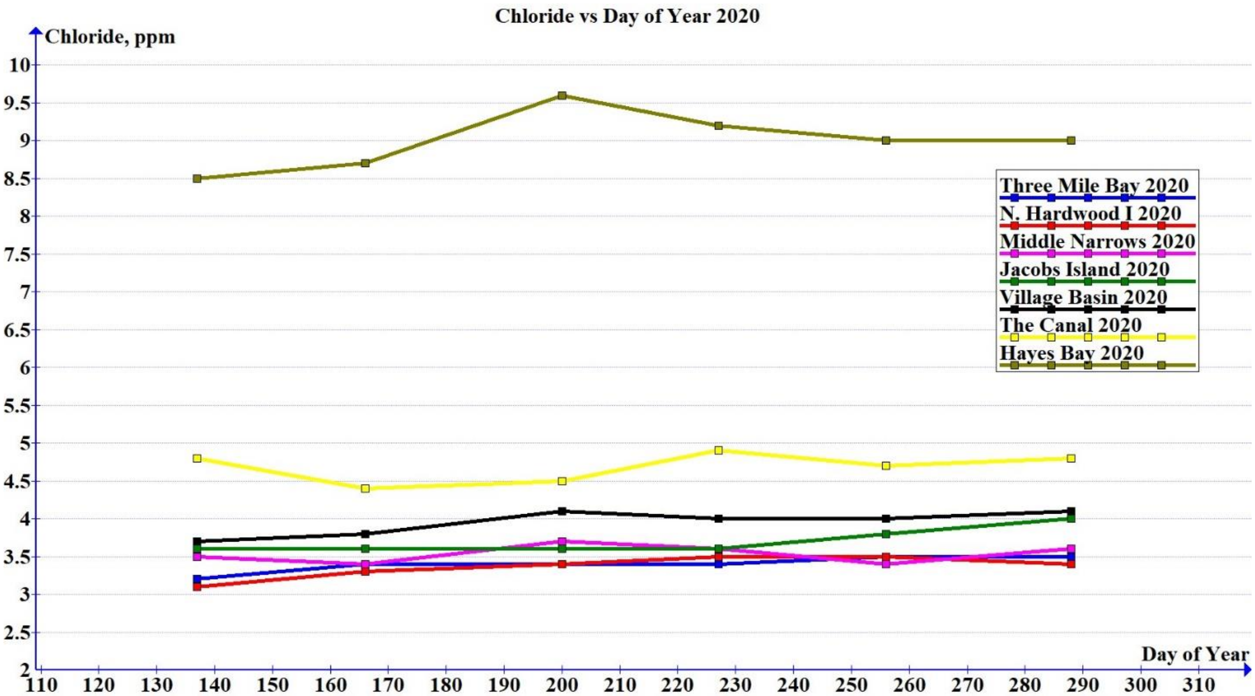
Year	Average ± SD
2020	3.6 ± .3
2019	3.2 ± .2
2018	3.1 ± .3
2017	3.3 ± .4
2016	3.5 ± .2
2015	3.4 ± .1

When these data are plotted (below), it is clear from the error bars on each point that there was no significant change in chloride concentrations between 2015 and 2020.



Conductivity measurements (see 2018 Water Quality Monitoring Program Report) showed that the total dissolved solids in Hayes Bay waters were 20% higher than in any other part of the lake.

The figure below shows chloride data plotted for all sampling sites over the ice-free season.



The source of the additional chloride in Hayes Bay waters (top line in graph) could be from the intrusion of road salt from the nearby road. A second possibility is that Hayes Bay receives additional chloride from subterranean brines fed by a spring(s) or aquifer. Road salt may not be the source of the chloride because year over year, the concentration of chloride is not increasing significantly. Also, if road salt were significantly involved, one would expect that the concentration of chloride would rise from a low value (like other sites), rise and fall again, as the source of chloride is diminished. As water leaves Hayes Bay towards Waba Creek, concentrations of chloride in The Canal (yellow line) increased as did the concentration of chloride in the Village Basin (black line). A dilution pattern is clearly evident in the graph above with Hayes Bay having the highest chloride concentrations, followed by The Canal and finally the Village Basin. This is the only part of the lake where this phenomenon has been observed.

10.0 Weather Conditions: 2014 – 2020

When interpreting data such as total phosphorous and calcium concentrations as well as other parameters, it is often useful to take into account weather conditions. This report contains comparisons of data and interpretations of such data from 2014 to 2020. For this reason, we have included meteorological data from all of these years. The data contained in these tables are those taken at the Ottawa International Airport. Available data from other locations near White Lake (e.g., Pembroke, ON) show similar trends and are not substantially different from those reported below.

An examination of the table below indicates that, with the exception of 2017, total precipitation during the ice-free season for White Lake is generally about 0.5 metres. 2020 was an average year for precipitation when compared to values for other years, however the number of rain events of greater than 1 mm is lower compared to most years with the exception of 2017, which was exceptionally wet.

Total Precipitation April to October: 2014 to 2020

Year	Total Precipitation, mm	Number of Days with Precipitation of 1mm or More
2014	561	81
2015	518	61
2016	431	44
2017	990	81
2018	553	70
2019	631	77
2020	532	56

During the six-month period from April to October 2020, White Lake received **531.9** mm of rain and experienced **56** days with precipitation of 1mm or more of rain. Monthly meteorological tables for previous years starting in 2014 can be found in our previous annual reports on White Lake Science and Information website.

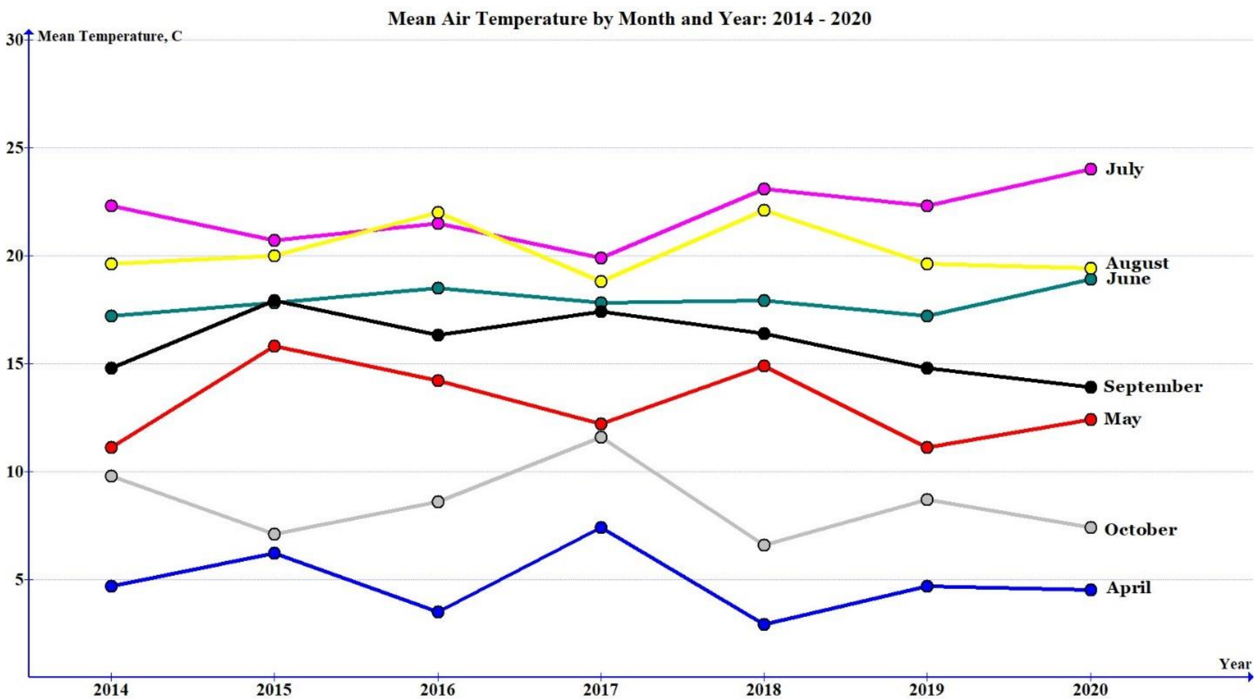
Monthly Meteorological Values – Environment Canada: *2020*

Ottawa Intl. Airport	Mean Temp., °C	Lowest Monthly Min. Temp	Highest Monthly Max. Temp.	Total Precip., mm	Number of Days with Precip. of 1mm or More
April	4.5	-6.5	16.8	68.5	7
May	12.4	-4.6	35.0	44.2	6
June	18.9	0.7	33.5	88.7	6
July	24.0	13.7	36.9	54.0	6
August	19.4	8.2	31.9	135.0	11
September	13.9	-0.4	27.0	52.0	8
October	7.4	-8.4	24.8	89.4	12
Total				**531.9**	**56**

The figure below shows the change in mean air temperature for individual months over the years spanning 2014 to 2020.

Although there is some variation from year to year in temperature, it is not possible to establish any trends. June and August appear to be two months with the least temperature variation from year to year.

It is important to take note of these temperatures because ambient air temperature will affect the temperature of lake water as well as that of sediments. This in turn could have an impact on aquatic plant growth, plankton succession over the summer as well as the timing of the zebra mussel reproduction cycle.



The actual weather on and just before lake water sampling dates is also very important. Heavy rains just prior to sampling could result in sharp changes in the concentrations of chemical species as well as the temperature of the lake. Just as important are dry hot spells which can result in warmer water and increased concentration levels of some parameters due to evaporation.

Below is a table showing the actual atmospheric conditions prevalent on our water sampling days. Information in this table was used to help interpret some of the chemical and physical parameters studied in this report.

10.1 Sampling Date Weather Conditions 2020

Date	Day of Year	Weather Conditions
May 16	137	Air temp: 13C; 24 mm rain fell day before sampling; Overcast to partial sun conditions, but bright; Wind approx. 5 km/hr.
May 30	151	Air Temp: 15C; Partly cloudy with sun patches; Very calm conditions, no wind. 4 mm rain fell day before sampling which broke a 3-day heat wave with air temperatures rising to 32C; Lake waters were heated during this period which is reflected in water temperatures.
June 14	166	Sunny clear day with no or little wind; Air temperature: 13C; 24 mm rain fell 2 and 4 days prior to sampling date. Very significant pollen storm particularly in the southern part of the lake. Surface pollen scum visible in many places.
July 2	184	Air temperature 27C; very little or no wind. Sunny for first four sampling sites (in order of presentation in this table); No rain preceding sampling by at least 5 days; Hot dry period.
July 18	200	Air temperature: 24 to 28C; very little or no wind; full sunshine. Four mm of rain fell during previous 48 hours. Heat wave continues.
August 1	214	Air temperature 23 to 24C; full sun with no wind. Five mm of rain fell about 30 hours previous to sampling date. Dry hot summer.
August 14	227	Air temperature 23 to 25C; Full sun with no wind. 16 mm rain four days prior to sampling.
August 30	243	Air temperature 13 to 15C' mostly sunny with some cloud; wind from 15 to 25 km/hr; 26 mm rain fell previous day.
September 12	256	Air temperature 13 to 16C; full sun; wind about 5 km/hr; 20mm rain fell 28 hours before sampling.
September 28	272	Air temperature 24C; mostly cloudy with some sun; wind from5 to 10 km/hr; no rain fell precious 10 days.
October 14	288	Air temperature 12C; fully sunny day; winds of less than 5 km/hr; 4 mm of rain fell day before sampling.

11.0 Water Levels – White Lake Dam: 2020

White Lake Dam is managed by the Ministry of Natural Resources and Forestry, Kemtpville District office. The operational plan is part of the Madawaska River Water Management Plan, 2009.

The White Lake Dam is a concrete structure, 29 m (98 ft.) long incorporating three log sluices: one central 2.44m (8 ft.) stoplog bay between two 4.27 m (14 ft.)

bays. Each bay contains six 12-inch by 12-inch stoplogs. Half logs and spacers are available to fine tune operations.

The table at right gives the target water levels for White Lake as read on the water level gauge at the dam. The water level gauge is calibrated in decimal feet.

The White Lake Dam Operating Regime is described on page 194 and 195 of the Madawaska River Management Plan and is quoted directly below:

The compliance framework for MNR facilities in the Madawaska River watershed does not require the use of mandatory level or flow limits. The level of White Lake is usually maintained between 3.5 and 5.2 feet. A minimum flow (baseflow) requirement for the White Lake Dam has been established. A flow of 0.14 m^3/s will be maintained at the dam at all times to ensure a sufficient flow is discharged into Waba Creek. This will provide a flow for the maintenance of fish habitat and address other ecological concerns during low flow conditions. A notch will be placed between the second and third log of the middle stop-log bay.

The annual variation of the operating band is given below. Water levels will decrease gradually from the spring flood peak in April to a constant level through the first half of May. In the middle of May, the summer drawdown will commence, which will bring the lake down to the winter holding level.

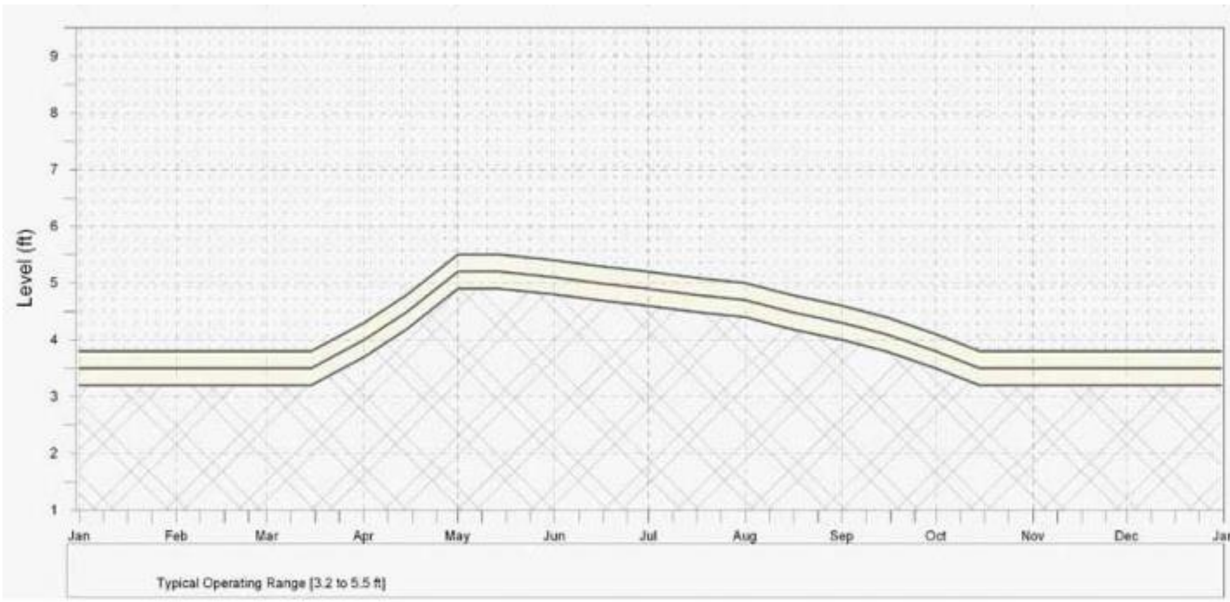
The typical annual mode of operation of White Lake Dam is summarized as:

Spring: The logs should be left at the winter setting until the water level rises above 3.5 feet on the gauge, at which point the logs should be replaced. By May 1, the water level should attain a target level of 5.2 feet. However, depending on the timing of the spring freshet (to avoid ice damage), all attempts should be made to attain the 5.2 feet level by April 15 to facilitate pike spawning. Stop logs should be manipulated through the remainder of the spring period so that water levels follow those prescribed by the operation plan. The drawdown is to begin May 15.

Summer: The target level for July 1 is a gauge reading of 4.9 feet, and the dam should be operated to reach this level. During the period from May 1 to September 1, water levels should be dropped gradually to reach 4.3 feet.

Dates	Target Levels	
	Decimal Feet	cm
January 1 to March 15	3.5	106.7
April 1	4.0	122.0
April 15	4.5	137.2
May 1	5.0	152.4
May 15	5.2	158.5
June 1	4.9	149.4
June 15	4.8	146.3
July 1	4.7	143.3
July 15	4.6	140.2
August 1	4.5	137.2
August 15	4.3	131.1
September 1	4.2	128.1
September 15	4.0	122.0
October 1	3.8	115.9
October 15 to December 31	3.5	106.7

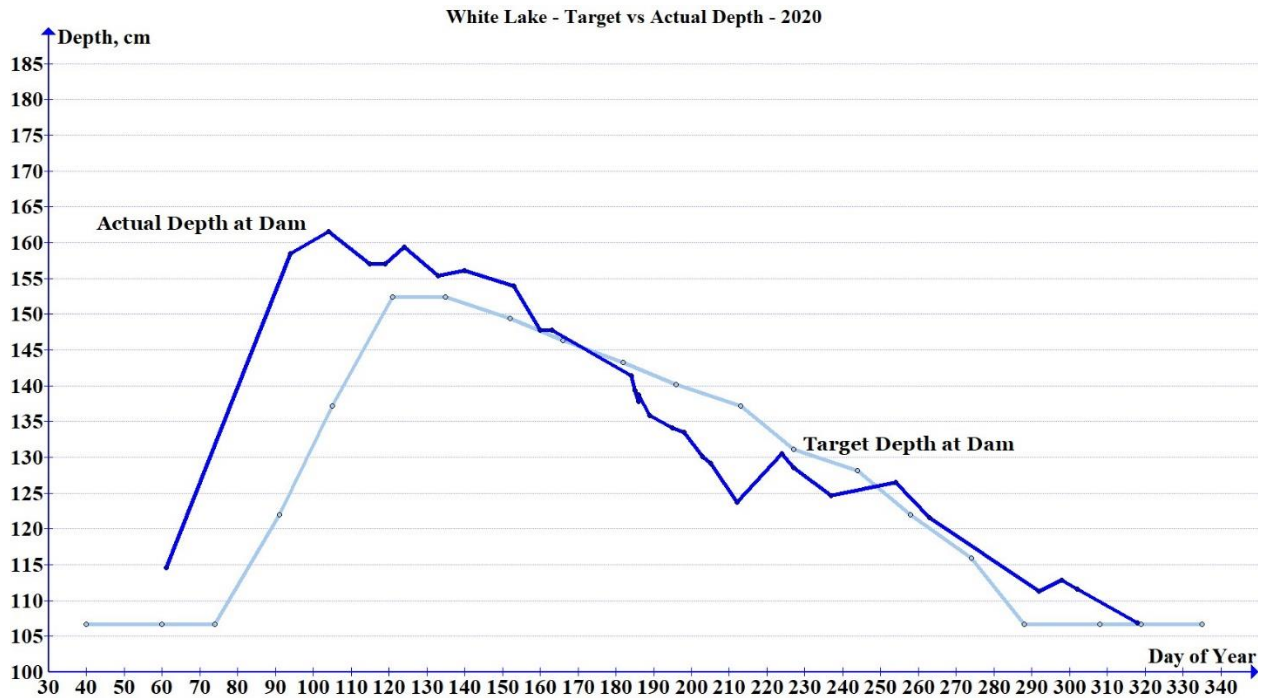
Fall & Winter: The fall/winter holding level is 3.5 feet which should be reached by October 15. If this level is not achieved by November 1, then that recorded level on this date will be considered the fall/winter holding level. Levels throughout the Fall and Winter should be maintained within ± 0.3 feet of the holding level. If the level should drop below 3.5 feet, it will be as a result of natural variation. Within the management plan the operating curve for water levels is shown in the graph below.



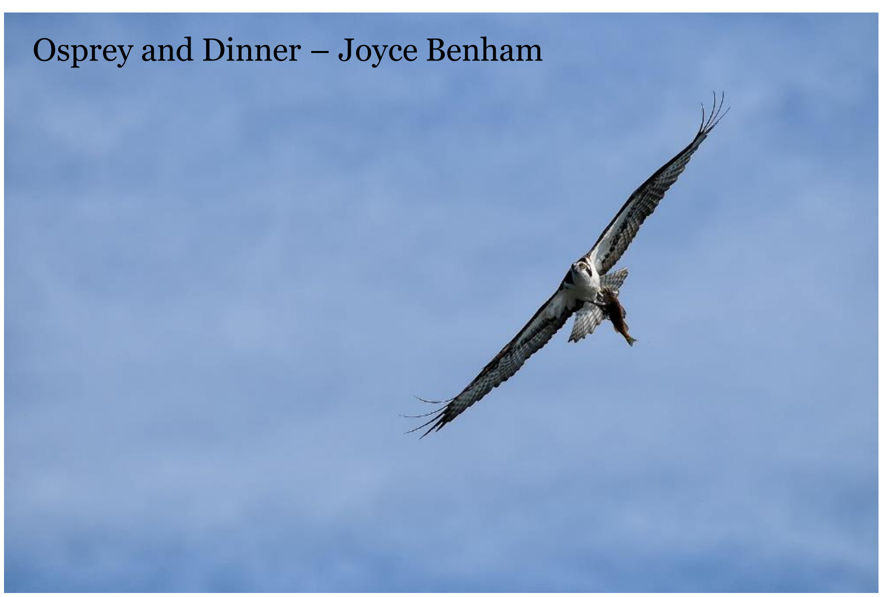
During dry years, such as 2016, the challenge is to balance water levels in the lake since a flow of .14 m^3/s must be maintained at the dam at all times to ensure a sufficient flow into Waba Creek.

In order to monitor water levels in White Lake we took regular and frequent readings of water levels at the White Lake Dam using the gauge fixed to the dam structure.

The figure below shows actual depth measurements read at the dam (blue line) plotted with the target water levels for the same time period (light blue line).



When comparing the line showing actual depth readings with that for target levels, it is evident that lake levels were high up to mid-May, and thereafter followed the water level plan until early August. Lower water levels at the beginning of August occurred after a period of hot dry weather. Beyond this point, water levels were as planned. At its highest level, the lake was briefly 25 cm deeper than its target depth. This maximum value was associated with the ice out date during which time water was entering the lake from all sources including melting ice, streams, surface runoff, and underground sources including springs.


Osprey and Dinner – Joyce Benham

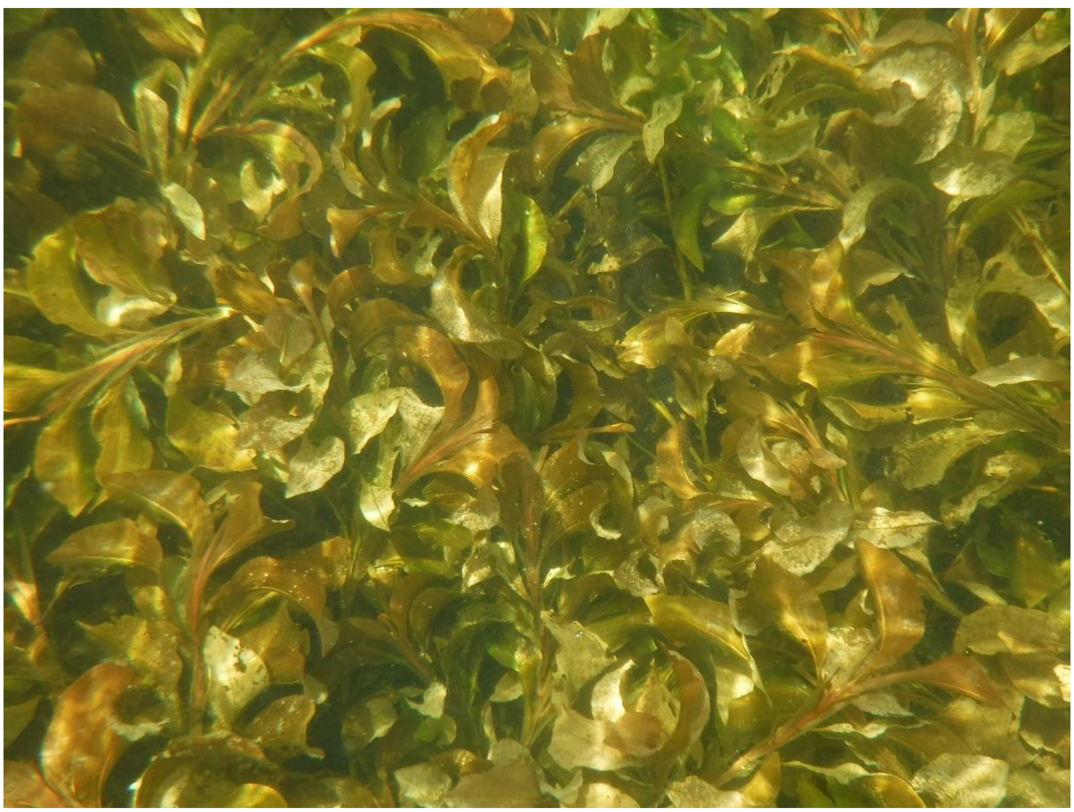
PART III
Research Activities and Environment Bulletins

12.0 Preliminary Report on White Lake Aquatic Plant Survey

The ability to study change over time in the assemblage of aquatic plants on White Lake was made possible by the efforts of L. J. Bond[28] when he published his findings on the observed occurrence and abundance of aquatic plants in the summer of 1976. A survey in the summer of 2020 was conducted to determine what changes have occurred within the White Lake aquatic plant community in the last 44 years. A total of 174 vegetated aquatic sites were visited. These sites were based upon the 98 stations in all parts of the lake, that Bond had used.

The table below summarizes some of the changes that were found in 2020. The table is based on the difference in relative frequency of occurrence of aquatic plants. It is evident but not too surprising to see that in 44 years some varieties have disappeared or are in decline, while other plant types have increased their occurrence in the lake. We were able to add 10 additional aquatic plants to the original Bond list.

A full report is currently in preparation and will be published in 2021 as a Special Report. As part of this study, a photographic and descriptive catalog of White Lake aquatic plants will also be created.



[28] L.J. Bond, *Ecological Study of White Lake, Renfrew and Lanark Counties 1976*, Lanark District, Ministry of Natural Resources, March, 1977

COMMON NAME	SPECIES NAME	STATUS & CHANGES SINCE 1976
Richardson's Pondweed	*Potamogeton richardsonii*	Currently the most dominant plant in 2020, major increase
Flat Stem Pondweed	*P. zosteriformnous*	new listing, the 2nd dominant type, not seen in 1976
Large Leaf Pondweed	*P. amplifolius*	new listing, low occurrence
Robbin's Pondweed	*P. robinsii*	new listing, low occurrence
Floating Pondweed	*P. natans*	no significant change
White Stem Pondweed	*P. praelongus*	new listing, low occurrence
Variable Pondweed	*P. gramineus*	new listing, low occurrence
Sago pondweed	*Stuckenia pectinata*	severe decline, now rare
Horned pondweed	*Zannichellia palustris*	severe decline, now absent was 2nd most dominant type in 1976
Slender Water	*Najas flexilis*	no significant change
Northen milfoil	*Muriophullum sibricum*	decreased occurrence, was most dominant type in 1976
Whorled Leaf	*M. verticallatum*	new listing, infrequent occurrence
Eurasian Water Milfoil	*M. spicatum*	new listing, invasive, widely distributed
Wild Celery, Tape Grass	*Vallisneria america*	no significant change
Water Star Grass	*Zosteralla dubia*	no significant change
Canada Waterweed	*Elodea canadensis*	no significant change
Coontail	*Ceratophyllum demersum*	no significant change
Common Bladderwort	*Utricularia vulgaris*	no significant change
Nitella	*Nitella*	new listing
aquatic moss	*Fontinalis*	new listing, in deep water
chara	*chara*	no significant change
White Water Lily	*Nymphaea ordorata*	increased occurrence
Yellow Water Lily	*Nuphar variegata*	no significant change
Star duckweed	*Lemna triscula*	no significant change
Water Marigold	*Megalodonta beckii*	new listing, common occurrence
frogbit	*Limnobium laevigatum*	new listing, rare occurrence
Arrowhead	*Sagittaria spp.*	no significant change
Pickerel Weed	*Pontederia cordata*	new listing
Common Bulrush	*Scirpus validus*	no significant change
Wild Rice	*Zizania aquatica*	increased occurrence

>5% increased occurrence	invasive	>5% decreased occurrence

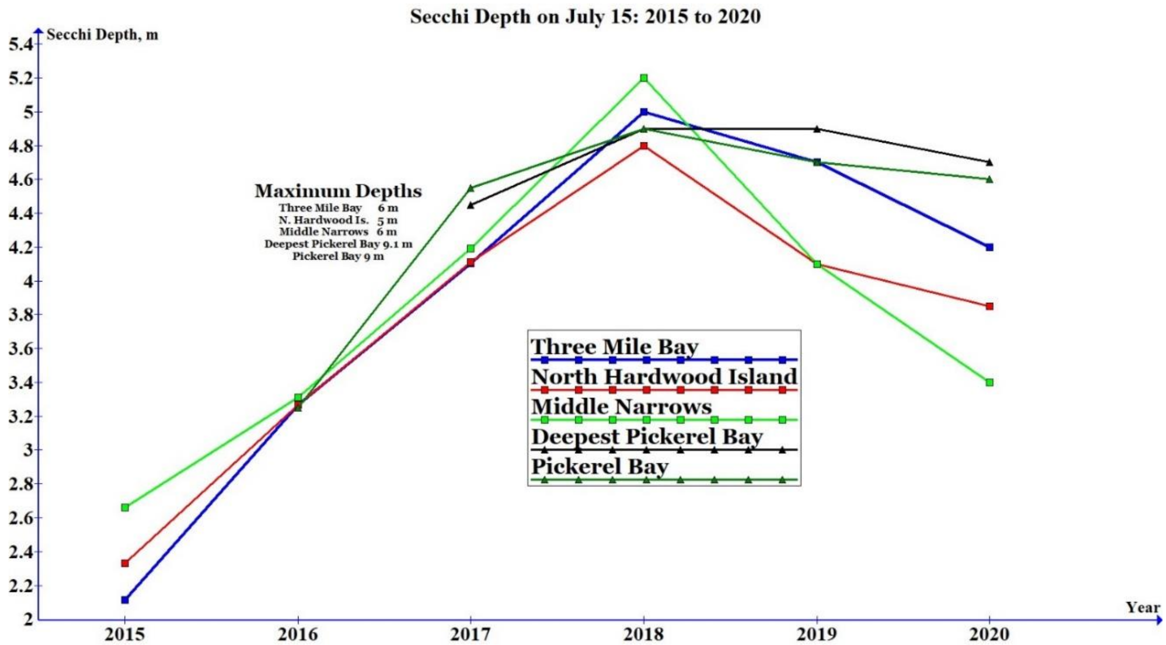
13.0 Zebra Mussel Update - 2020

In the 2019 Water Quality Monitoring Report (pages 81-95) an extensive article was published on the current status of the zebra mussel population in White Lake. In that report, it was noted that some of the zebra mussels which made up the explosive colonization of White Lake in 2016, had begun to die off. This generation of zebra mussels had few restraints on their growth and reproduction. Food, in the form of algae and plankton, was plentiful and there were no predators to limit their spread and well-being. Zebra mussels have a life span of from three to five years.

In 2020, the remainder of this 'first' generation of zebra mussels died off. As part of a study we were completing, members of the scientific team visited and snorkeled dozens of sites in all parts of the lake. It was apparent that there had been a significant die off of zebra mussels at many of the rocky sholes we visited. Pictured below is a common sight at many places on the lake.

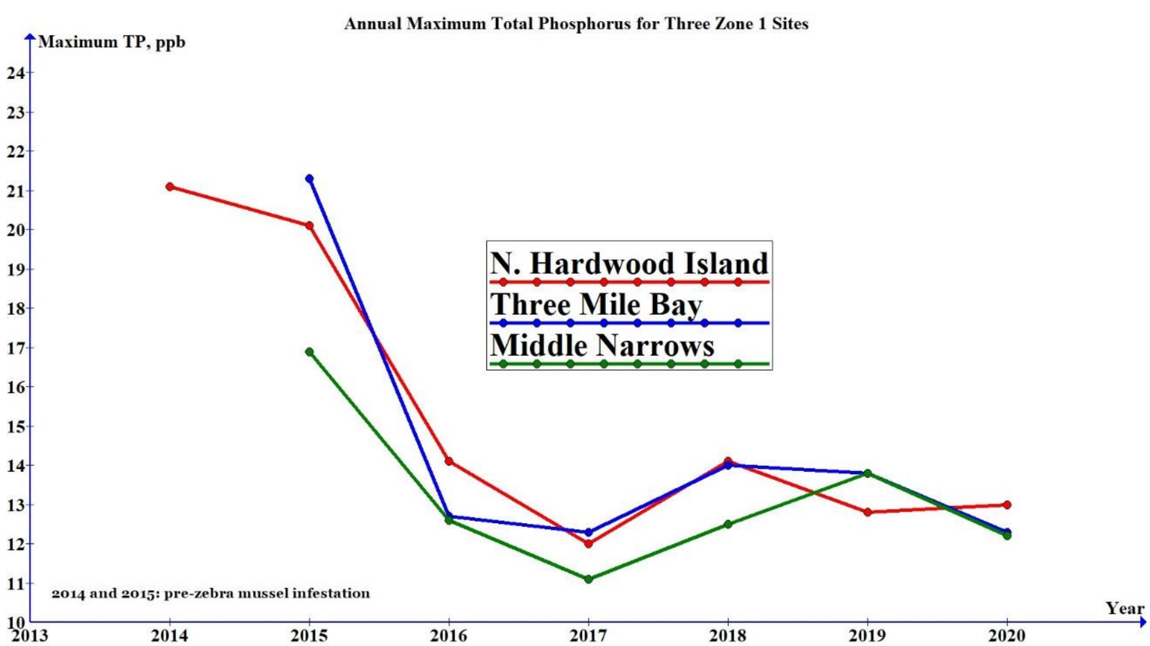
This photograph shows that virtually all of the large adult zebra mussels clinging to the rock had died. The shells were open and empty. Further, there were very few or no smaller zebra mussels, as would normally be observed.

Physical and chemical characteristics of the lake itself have also registered a change. Water clarity, as measured using a Secchi disk, has decreased during the past two years as compared to data collected in 2016 when the zebra mussel infestation was at its height.



This is shown in the above graph which indicates water clarity has been decreasing somewhat during the past two years.

In addition to a change in water clarity, there has also been a change in measured total phosphorus values for open (not shoreline) lake waters.



Zebra mussels are filter feeders and in a well-mixed lake, like White Lake, are capable of almost completely filtering out phosphorus-containing particles (plankton, algae, detritus, etc.) larger than about 0.5 micro-metres (microns).

Although the decrease in water clarity and increase in total phosphorus values are consistent with a zebra mussel population which is stressed and potentially decreasing, one cannot exclude that these effects may have also been partly caused by changes in weather or other factors unrelated to zebra mussel populations.

In most parts of the lake, we observed a marked increase in the extent and thickness of an algal mat, called periphyton, covering surfaces including rocks and other materials such as submerged trees and branches. It is important to note that this algal mat covered only the upper surfaces (facing the sun) and not the underside facing the lake bottom.

Periphyton is a complex mixture of algae, cyanobacteria (blue-green algae), microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems and has likely been present in White Lake for centuries. Its existence has been noted in other studies of White Lake[29].

Interestingly, the blue-green algae present in the algal mat is a calcareous blue-green algae which, in fact, excretes calcium carbonate[30]. These algae are responsible for creating marl deposits which can be transformed into limestone and even create reefs[31]. If one takes a sample of this algal mat from White Lake, and after drying add some vinegar or weak hydrochloric acid, it will ‘fizz’ releasing carbon dioxide bubbles.

Calcareous blue-green algae (L); with added vinegar (R)

[29] J.P. Ferris, *White Lake Integrated Resources Lake Plan*, Lanark and Renfrew Counties, Ministry of Natural Resources; December, 1985.
[30] A. Pentecost, *Blue-Green Algae and Freshwater Carbonate Deposits*; Proc. R. Soc. Lond. B 1978, p. 43-61, 1978.
[31] J. Schneider and T. Campion-Alsumard, *Construction and destruction of carbonates by marine and freshwater cyanobacteria,* Eur. J. Phycol, **34**: 417-426, 1999.

Below are photos of the algal mat (periphyton) found on rocky substrate with section lifted off to illustrate consistency and thickness.

Algal mat showing difference in thickness and consistency at two different locations

The presence of zebra mussels in a lake, like White Lake, is transformative and can result in major changes to the ecosystem. Nutrients, such as phosphorus, otherwise destined to remain evenly distributed in the bulk of lake water, are transferred to the near shore area. Phosphorus released from sediments (internal loading) is also shunted to the near shore area rather than returning, at the end of summer, to the sediment it originated from. Increased water clarity promotes the growth of aquatic plants and their spread to deeper waters. Fish species, such as pickerel, can be disadvantaged because of loss of spawning grounds and shaded areas in the lake.

There are other changes, however, which are more difficult to quantify. These are changes in water chemistry which occur in the area immediate to the zebra mussels. Zebra mussels are not efficient users of nutrients such as phosphorus and most of the phosphorus ingested is quickly excreted as feces. Mussels can also divert filtered material which contains toxins, like blue-green algae, via a separate mechanism producing pseudo-feces of undigested material. Also, nutrients such as ammonia and soluble phosphate are also released directly into the water immediately adjacent to the mussels. This in turn changes the nitrogen to phosphorus ratio in the water promoting the growth and proliferations of algal mats among other effects[32].

This could explain the significant increase of algal matting on submerged surfaces observed during the 2020 field season.

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[32] H.A. Vanderploeg et al, *Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes;* Can. J. Fish. Aquat. Sci., **59**, 1209-1228; 2002.

Below are photos of periphyton covering the surface of rocks. Shown are some zebra mussels completely covered by the matting.

Algal mat covering zebra mussels

It is possible that the presence of the algal mat covering the zebra mussels could have resulted in death for two reasons. Firstly, the algal mat could prevent the zebra mussel from effectively feeding by preventing particulate matter from reaching its feeding siphon. Secondly, the zebra mussel could perish from asphyxiation resulting from anoxic conditions (hypoxia) during periods of algal respiration[33].

Zebra mussels attach themselves to hard or plant substrates using byssal threads. There may be as many as thirty of these threads, the attachment strength of which can vary with light, temperature, water movements, the presence of other mussels, and predators. Zebra mussels are capable of detaching themselves, and moving to other locations which are more conducive to survival. Zebra mussels prefer surfaces which are hidden from view such as under rocks or logs and are not in direct sunlight (J. Kobak).

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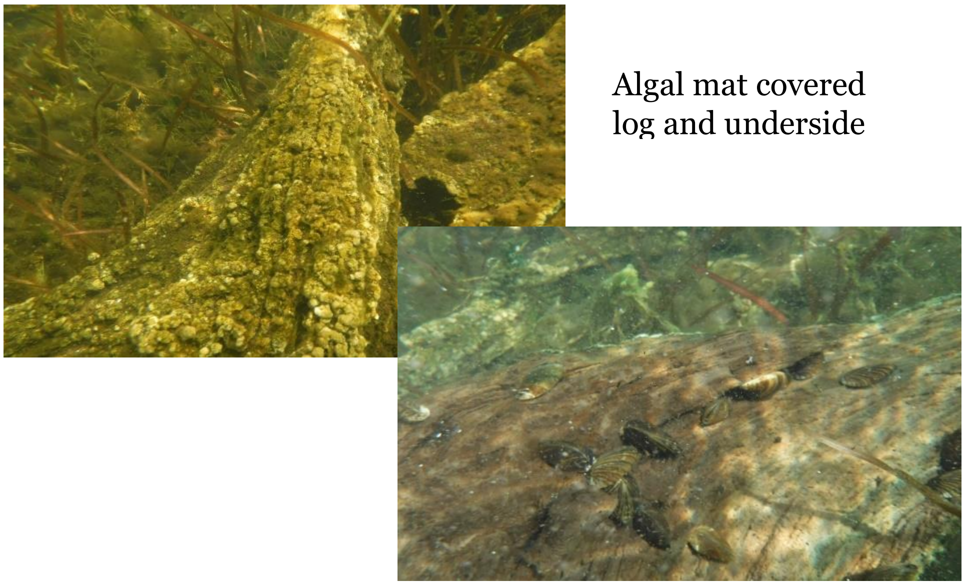
[33] J. Kobak, *Behaviour of Juvenile and Adult Zebra Mussels (Dreissena polymorpha)*, in *Quagga and Zebra Mussels, Biology, Impacts and Control*' T.F. Nalepa and D.W. Schloesser, Eds., CRC Press, Chapter 21, pp. 331-344, 2014.

As mentioned above, rocks found to be littered with dead adult mussels and also covered with an algal mat did not host many live adult or more juvenile mussels.

In White Lake, healthy adult and juvenile zebra mussels could be found on the underside of rocks and logs covered with an algal mat. The algal mat requires light and so does not colonize the underside of substrate materials. Below are photos illustrating the point made above:



Algal mat covered log and underside

The chemistry of White Lake is perfect for indefinitely maintaining healthy populations of zebra mussels. The observed decrease in zebra mussel numbers is likely temporary as conditions change over time.

It is clear from these observations that the number, or perhaps more accurately the biomass, of zebra mussels in White Lake will vary with time. Changes in population density of zebra mussels are linked to changes in lake chemistry and biology. The cyclical nature of zebra mussel populations in lakes has been reported in the scientific literature[34], and it is possible that cycles will vary with water body. Zebra mussels have been in White Lake since at least 2015 and it is reported that it takes from 7 to 12 years before populations become stable[35].

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[34] D.L. Strayer et al., *Long-term population dynamics of dreissenid mussels (Dreissena polymorpha and D. rostriformus): a cross-system analysis*; Ecosphere, *Vol 10(4), Aticle e02701, April 2019.*
[35] M. Millane et al, *Impact of the zebra mussel invasion on the ecological integrity of Lough Sheelin, Ireland: distribution, population characteristics and water quality changes in the lake;* Aquatic Invasions, Vol. 3, issue 3, pp. 271-281, 2008.

Healthy zebra mussels collected from the underside of one section of dock on Three Mile Bay – October 2020

The above photo is of 5 kg (11 lbs) of zebra mussels recovered from a single dock floatation billet. The dock, comprised of 6 billets therefore supported about 31.8 kg (70 lbs) of mussels or about 4.2 kg/m^2 (0.85 lbs/ft^2).

14.0 Relationship Between Secchi Depth and Total Phosphorus

We have been collecting water clarity (Secchi depth) and total phosphorus data for 7 years. We now have enough data to explore if there is a quantitative relationship between these two important water quality parameters. If there is, this would be helpful in determining approximate total phosphorus levels at sites using Secchi depth as a surrogate measurement. We are limited by the Lake Partner Program to a finite number of approved sample sites, but would like to have more information for other sites in addition to these.

Water clarity is governed by particulate matter, living or dead, suspended in the water column. For White Lake, we know that the presence of phytoplankton and zooplankton account for most if not all water turbidity.

The growth of plankton is limited by available nutrients and other factors such as sunlight and water temperature. The concentration of total phosphorus in lake water is generally the limiting factor governing plankton growth. If the concentration of phosphorus has overwhelming influence on growth, when compared to other factors, then we would expect that there would be a direct relationship between Secchi depth and total phosphorus data.

Total phosphorus refers to the total quantity of phosphorus present in lake water which has passed through an 80-micron (millionth of a metre) filter. The phosphorus in these samples can be divided into two parts; dissolved (like sugar in water), and particulate, such as plankton.

There are many sources of phosphorus which enter White Lake from the air, land (including human contributions), and released from sediments (internal loading). The contributions of all of these sources are dependent on other factors including climate and human activity and since 2016, the action of zebra mussels.

Prior to the arrival of zebra mussels, total phosphorus concentrations were low in the spring, tripled to a maximum value during the summer and returned to low values in the fall. Once zebra mussels infested the lake, the bivalves filtered out a sizable fraction of the total phosphorus present as particulate matter, leaving behind dissolved phosphorus.

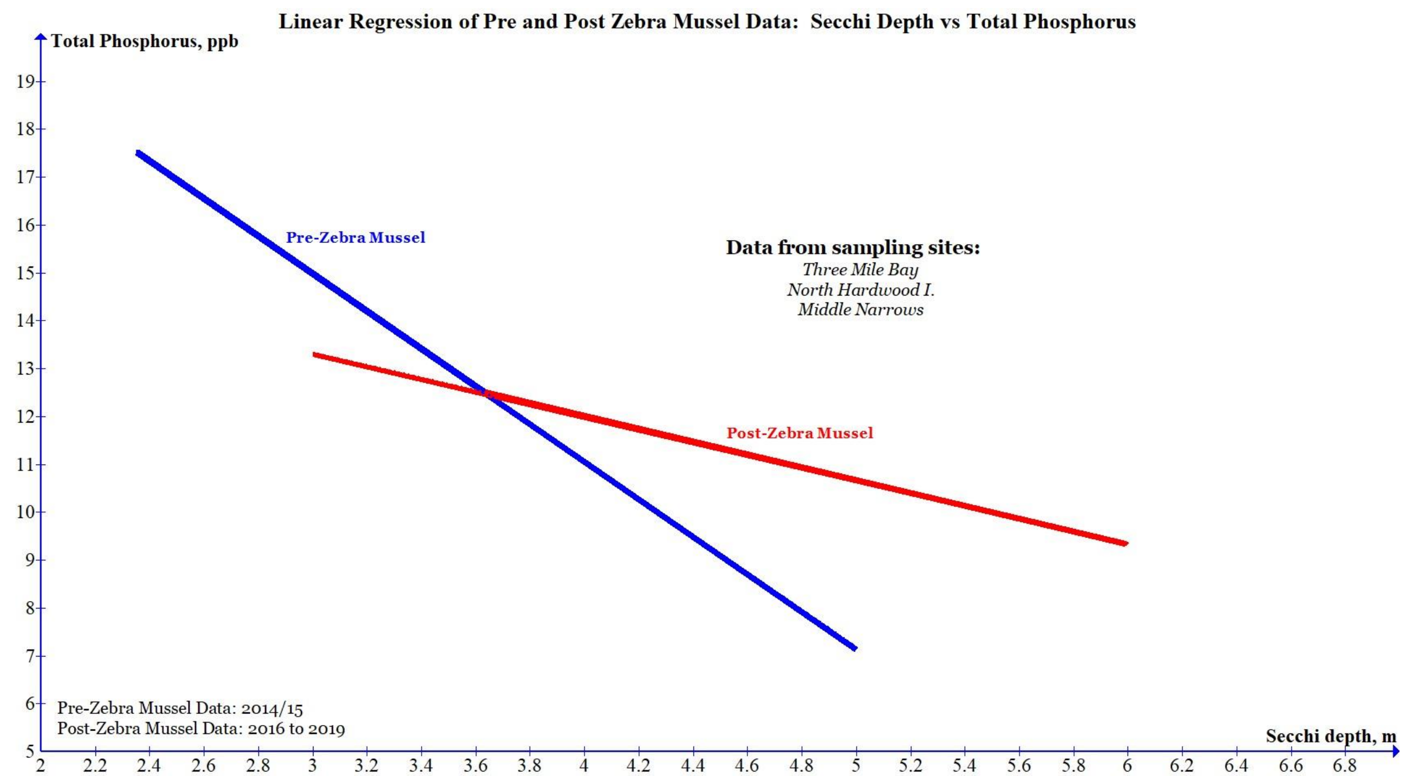
As a result of mussel filtration activity, total phosphorus values were still low in the spring and late fall, but rose to much lower (about half) peak values in mid-summer.

The measured concentration of total phosphorus at any given time reveals the balance between phosphorus inputs and phosphorus loss or removal. When the total phosphorus level reaches its maximum value, there exists at that time an equal balance between phosphorus input and removal rates.

We know from the scientific literature that zebra mussels, as part of their digestive functions, also release dissolved phosphorus into the water column adding to that being released from septic systems, internal loading from sediments and other sources. In terms of losses, these can occur from particle sedimentation, zebra mussel filtration, growth of aquatic plankton to sizes greater than 80 microns (these are filtered out of the TP water sample), to name only a few.

Below is a plot of the graphical relationship between Secchi depth and total phosphorus concentrations. The two lines on the graph are calculated using a linear regression function giving a ‘best fit” line for the data.

The blue line is drawn from data collected prior to the infestation of zebra mussels (2014 and 2015). The red line is for data collected after zebra mussels infested White Lake (2016 to 2019).



The most obvious observation is the different slopes of the two lines. The blue line (pre-z. mussels) is much steeper than the red line (post-z. mussels). This is because the range of Secchi depth measurements for the blue line is much smaller than that for the red line. As well, pre-zebra mussel total phosphorus concentrations have a greater range (4 to 10 ppb) than for the period following infestation (3 to 6 ppb). Note that these values are derived from the best fit line and do not represent individual data points. For the pre-zebra mussel period, total phosphorus values reached or exceeded 21 ppb by midsummer, with lowest values of 7 ppb in the spring. Once zebra mussels had invaded White Lake, total phosphorus values ranged from about 7 to 14 ppb for the equivalent time periods.

The range in Secchi depths is reversed for the two data sets. The calculated range for the pre-Zebra mussel data is from 2.4 to 5 m and for the post-zebra mussel data is from 3 to 6 m.

Note that this graph contains only data for three sites in Zone 1 (See appendix 1). Secchi depths (post-zebra mussel) in excess of 9 metres have been recorded for the deepest sampling sites, for which we do not have corresponding total phosphorus data. These Secchi disk readings are not part of the data base used to calculated the red line.

Of importance is the calculated correlation coefficient (R^2) for each of the regression lines in the above graph. A value for the correlation coefficient approaching 1 indicates that there is likely a linear relationship between the two parameters studied. Values closer to zero denote the opposite conclusion.

For the pre-zebra mussel data (blue line) the correlation coefficient is 0.7034, which is high and does indicate that one could (have) used one parameter as a surrogate for the other.

The correlation coefficient for the red line (post-zebra mussel) is only 0.2812, which is relatively low. This shows that Secchi depth has a relatively weak relationship to total phosphorus levels, and that these two parameters vary independently from one another. This may be because of other parameters contributing to measured Secchi depth and/or total phosphorus values. This is in agreement with the findings of researchers completing similar studies in a lake in Northern New York State[36].

The explanation for this behaviour may be linked to the fact that there are a number of factors each contributing significantly to total phosphorus levels, and each of these may be acting somewhat independently. After zebra mussels infested the lake, total phosphorus levels were reduced to less than half, and so any changes in one phosphorus source may have a disproportionate effect on the total amount. This may not have been the case prior to the presence of zebra mussels when total phosphorus values were much higher.

Because lake water samples are filtered through an 80-micron filter prior to analysis, any assemblage or algal colony forming particles larger than 80 microns are filtered out. An example of this is chrysophyte[37] algae which are present in White Lake and also form relatively large colonies which would be filtered out. Chrysophytes are also a primary food for zooplankton, which are often also larger than 80 microns. Combined, these two groups can result in a reduction in water clarity (smaller Secchi depths) which would not correlate with higher total phosphorus measurements in the water column.

Whatever the reason, now that the lake has zebra mussels, one cannot use either factor as a predictor or surrogate for the other. Secchi depths readings and total phosphorus levels both have to be determined separately.

15.0 Fisheries

The health of the White Lake fishery is important to the economic wellbeing of area merchants and service suppliers. In this section, we report on the work of the Ministry of Natural Resources Forestry monitoring the fishery of White Lake.

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[36] B. Zhu D. et al; *Alteration of Ecosystem Function by Zebra Mussels in Oneida Lake: Impacts on Submerged Macrophytes;* B. Zhu D. et al; Ecosystems (2006) 9: 1017–1028.

[37] D.C. Grégoire and D. Overholt; White Lake Water Quality Report, 2018, p 108. Full report available on the White Lake Science and Information website.

The Broad-scale Fisheries Monitoring program was created by MNRF to evaluate Ontario's fisheries on a broad level. Broad-scale monitoring includes the collection of detailed information about fish species and fish communities, physical and chemical water characteristics, aquatic invasive species, and fishing effort for each lake surveyed. Once every 5 years, information is collected from a representative number of lakes in each Fisheries Monitoring Zone in a standardized way. The number of lakes included in the program is sufficient for managing and reporting on fisheries in each zone, but represents a relatively small percentage of the total number of lakes in Ontario. For White Lake, the first sampling cycle of the program occurred in 2008 and was repeated in 2014 and more recently in 2019.

The Broad-scale Fisheries Monitoring program is designed to:

- describe the distribution, amount, and diversity of fishes in Ontario
- estimate the current state and changes over time of Ontario's fisheries
- identify natural and human-caused stresses affecting fisheries
- provide reports on the state of fisheries and aquatic environments in Ontario

The program provides MNRF biologists with additional benefits and opportunities to gather information on the biodiversity and health of aquatic environments. It includes monitoring the spread of aquatic invasive species, collecting genetic samples for researchers, gathering climate change data, sampling fish for contaminants for the Ministry of the Environment Conservation and Park's Guide to Eating Ontario Sport Fish, and collecting samples for the monitoring of water quality in surveyed lakes.

The last full report entitled *zone summary for Fisheries Management Zone 18; Cycle 1: 2008-2012* can be downloaded from the White Lake Science and Information website. This 150-page document contains a wealth of information about the fisheries in Zone 18 lakes including White Lake. A lake synopsis data sheet for White Lake is published as part of this effort and is reproduced in this report as Appendix 3.

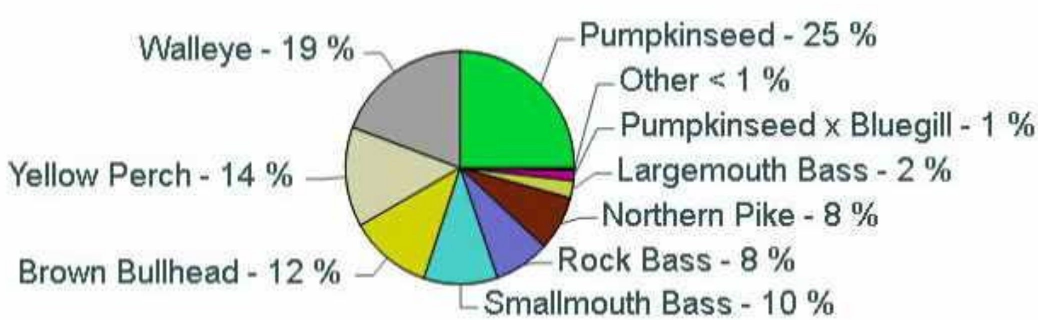
More information on the Broad scale Fisheries monitoring program can be obtained at the following website: https://www.ontario.ca/page/broad-scale-monitoring-program. Reports for each of the three study years can be obtained on the FishOnline website. In the search box on the site enter the White Lake waterbody ID 18-3808-50183.

The fish netting results for each of the three years, starting with 2019 are presented below. A cursory examination of the data clearly shows that the fishery is changing with time. We do not know what effect the infestation of White Lake with zebra mussels has had on individual species. Definitive results may take several more 5-year measurement cycles as White Lake reaches its new equilibrium as a result of the effects of invasive species and other factors such as climate change and lake overuse.

Fish Netting Results: August 26 to September 5, 2019

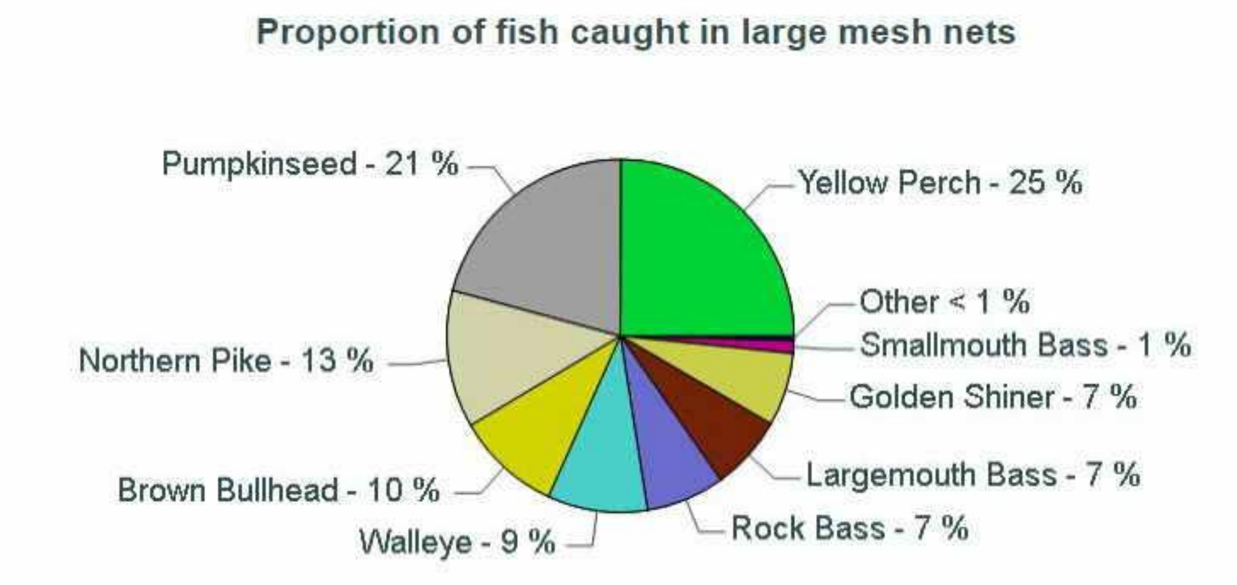
Fish species	Total catch %	Maximum length (cm)	Minimum length (cm)	Average length (cm)
Pumpkinseed	25	34.1	1.2	20.7
Walleye	19	63.8	24.1	40.7
Yellow Perch	14	34.9	13.3	22.0
Brown Bullhead	12	37.8	23.5	33.1
Smallmouth Bass	10	46.2	12.6	33.3
Rock Bass	8	23.1	9.8	15.4
Northern Pike	8	66.5	33.6	51.2
Largemouth Bass	2	38.9	11.4	27.5
Pumpkinseed x Bluegill	1	22.4	20.4	21.3
Golden Shiner	< 1	15.9	15.9	15.9
White Sucker	< 1	49.8	49.8	49.8

Proportion of fish caught in large mesh nets



Fish Netting Results: July 2 to July 10, 2014

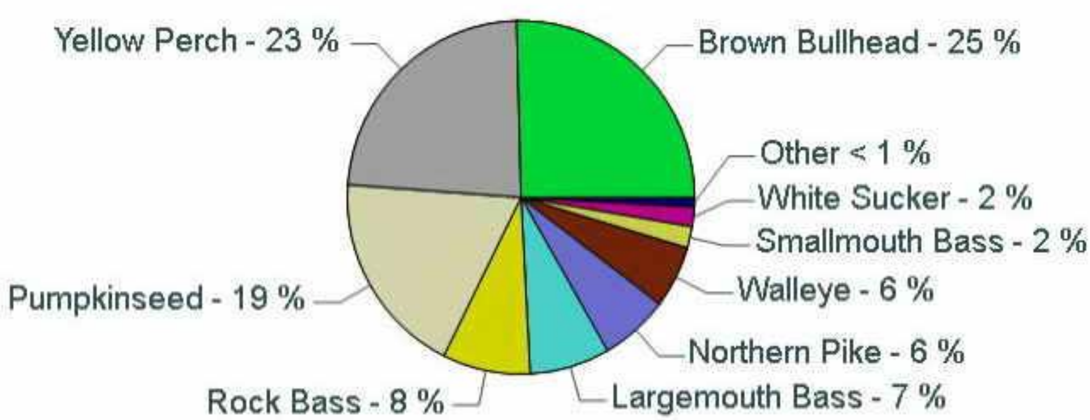
Fish species	Total catch %	Maximum length (cm)	Minimum length (cm)	Average length (cm)
Yellow Perch	25	31.1	12.6	22.4
Pumpkinseed	21	24.6	9.1	20.2
Northern Pike	13	80.8	25.9	48.8
Brown Bullhead	10	40.1	18.6	31.4
Walleye	9	62.5	25.4	47.6
Rock Bass	7	25.1	9.4	15.4
Largemouth Bass	7	45.3	13.5	30.5
Golden Shiner	7	18.9	11.6	15.8
Smallmouth Bass	1	43.9	25.0	36.3
White Sucker	< 1	46.5	44.5	45.5
Bluegill	< 1	18.1	18.1	18.1



Fish Netting Results: July 28 to August 7, 2008

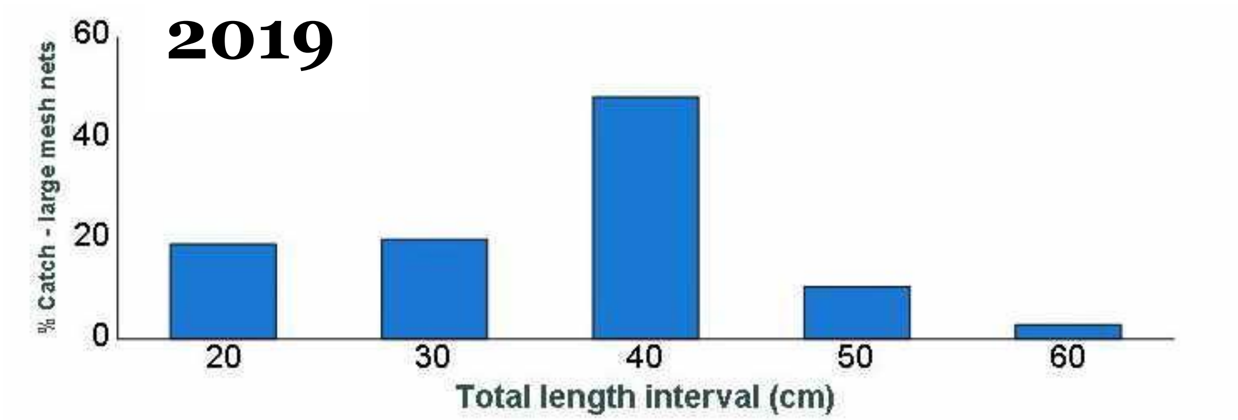
Fish species	Total catch %	Maximum length (cm)	Minimum length (cm)	Average length (cm)
Brown Bullhead	25	40.0	14.0	29.9
Yellow Perch	23	29.0	13.0	19.8
Pumpkinseed	19	23.0	7.0	19.3
Rock Bass	8	22.0	6.0	15.2
Largemouth Bass	7	45.0	15.0	28.3
Northern Pike	6	67.0	17.0	45.9
Walleye	6	67.0	16.0	41.4
Smallmouth Bass	2	45.0	15.0	31.7
White Sucker	2	59.0	16.0	46.2
Bluegill	< 1	23.0	22.0	22.3
Golden Shiner	< 1	16.0	16.0	16.0

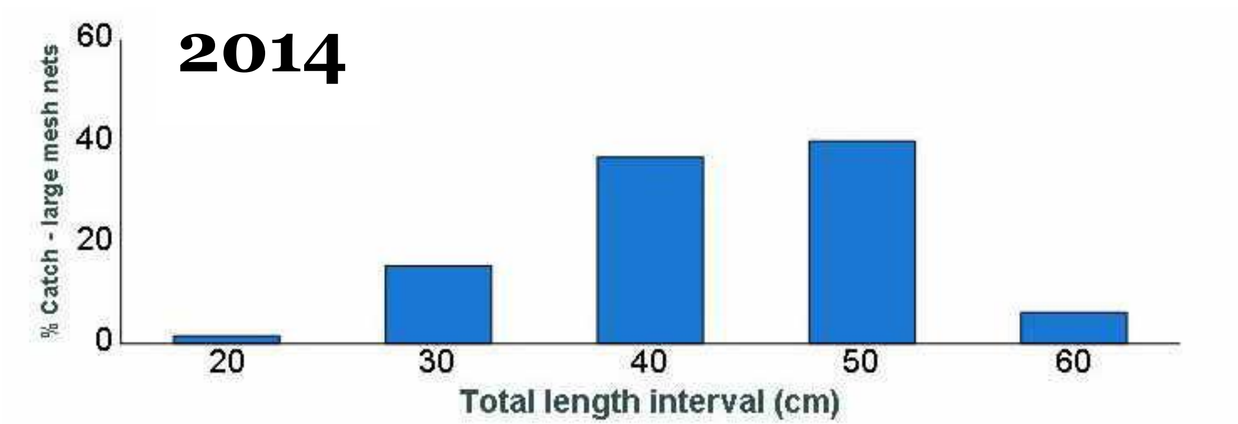
Proportion of fish caught in large mesh nets

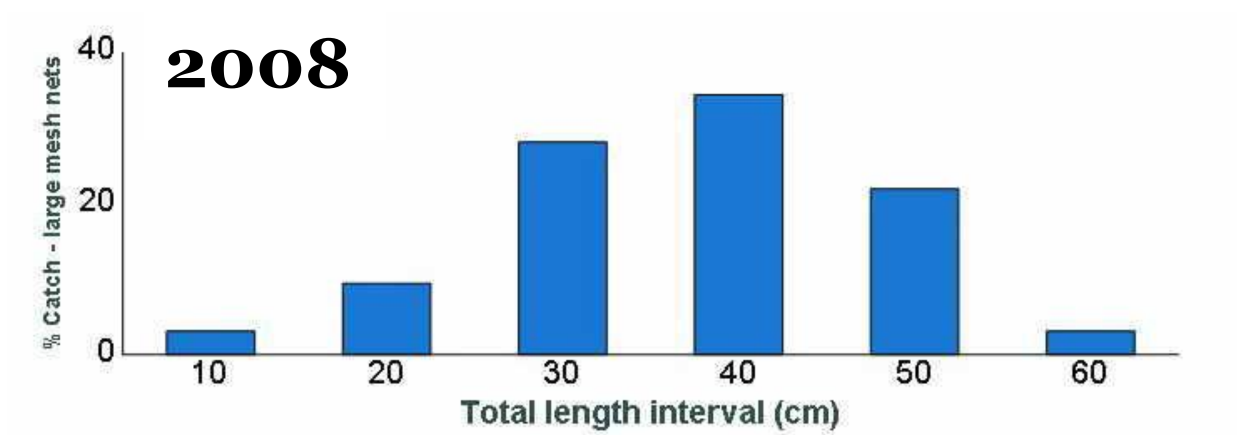


The figure below compares the length distribution of walleye (pickerel) for the three Broad-scale Fisheries Monitoring studies completed between 2008 and 2019. It is clear that the populations of pickerel are changing with time, likely in concert with changes occurring in White Lake itself as time passes.

Pickerel

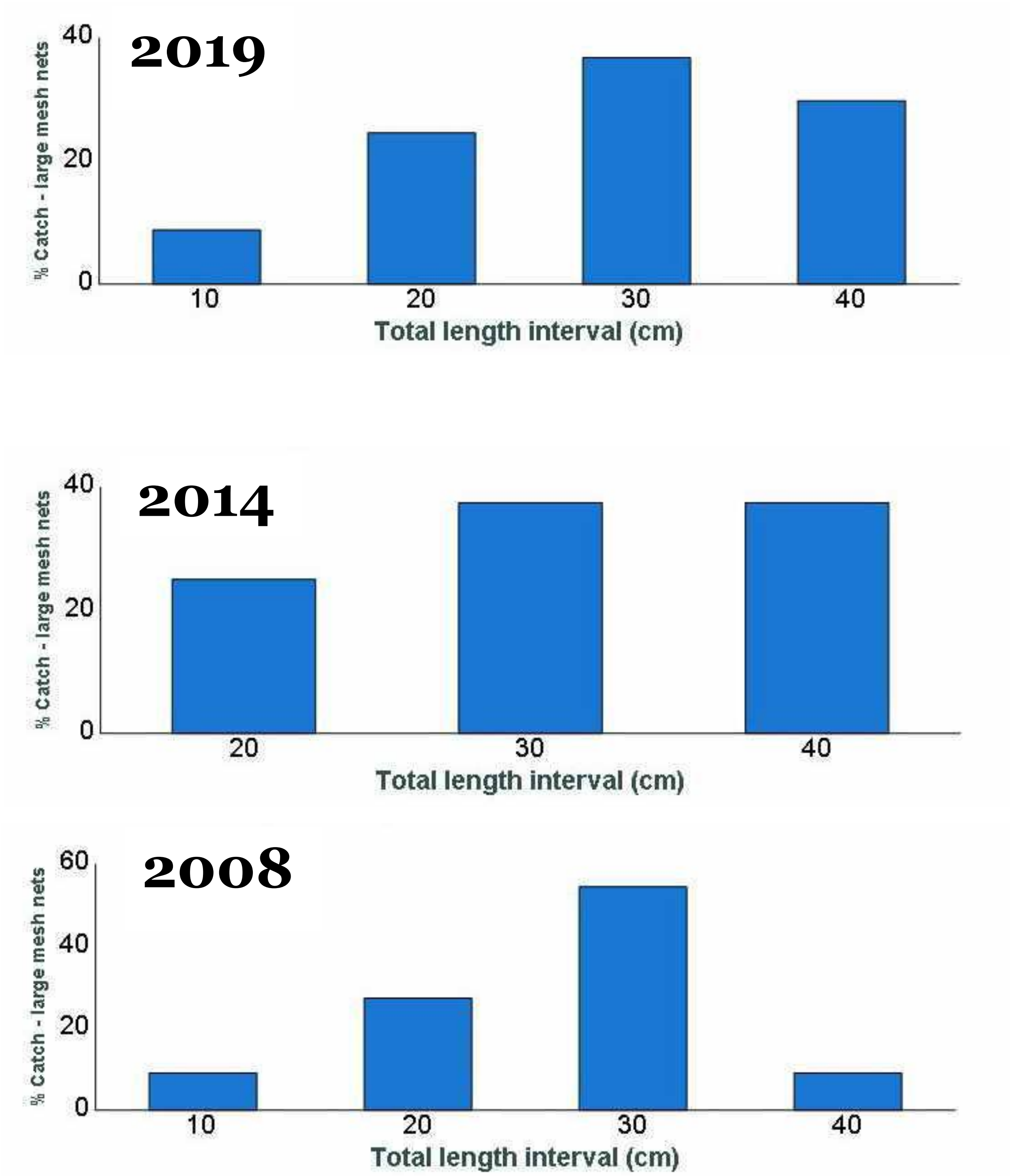






The figure below compares the length distribution of smallmouth bass for the three Broad-scale Fisheries Monitoring studies completed between 2008 and 2019. It is clear that bass populations are also changing with time.

Smallmouth Bass



16.0 White Lake Loon Survey and Wildlife Observations June 27 to July 4th, 2020

Joyce Benham and Bob Carrière

Because of the ongoing Covid-19 pandemic, boat traffic was relatively light on White Lake. The weather was pleasant all week long and so we had ample time to complete our observations. This year, it was not only humans who were facing an existential threat. The loons on White Lake were on their own dealing with a very serious issue.

Photo credit: Joyce Benham

On our first outing on the lake, it quickly became evident that 2020 was a difficult year for loons. There were fewer adult looms to be seen and very few chicks.

An article appearing in the Ottawa Citizen reported that the issue which resulted in poor loon reproduction was an infestation of a species of black fly (Simulium annulus) which only attacks loons and not humans. In the article, Dr. Piper, a loon researcher from California said that these black flies are “active in May, when the adult fly needs a meal of blood in order to reproduce. And clouds of the tiny flies (smaller than the kind that go for humans) swarm around each loon, just as they are sitting on eggs. In years when fly numbers are low, the loons put up with it. But in years with many flies, loons can be driven off their nests and the eggs don’t hatch. It has been a dreadful first round of nests for most breeding pairs”. The article further states: “Typical pairs in the study area abandoned their first nesting attempt in early May because of the clouds of flies that descended upon them and have only just begun to re-nest or think about doing so.

“Based on what we have seen, it appears that 70 to 80 per cent of all pairs could not stand to incubate the first clutch of eggs they laid in early to mid-May, making 2020 even slightly more devastating a black fly year than 2014, the previous worst year on record.

The only way to escape black flies is to dive and stay underwater. Loons can leave their eggs uncovered for a couple of hours, but if they completely abandon the nest, then the eggs are finished".

We also observed that water clarity was high and that there were abundant green filamentous algae in many places as well as dense beds of aquatic plants throughout shallow areas of the lake.

The observation number is correlated to a numbered location on the map below. These sites are those which have in the past hosted loon nests or fishing locations of adult loons. Any site numbers omitted was because of inactivity.

Site specific observations:

I*n each of sites 12 and 19, there was one nesting pair of loons each with two chicks. Unfortunately, there are the only two sites on the lake which produced offspring. By early fall and before loons migrated, we observed that three of the four chicks had survived. It is well known that less that 50% of chicks survive their first year.*

Site 1:	Single adult loon.
Site 4:	Two adult loons.
Site 5:	On southeast point of Hardwood I., active osprey nest with two chicks. Two adult loons were observed along with an empty nest.
Site 7:	Single adult loon.
Site 8:	Six adult loons.
Site 9:	1 adult loon.
Site 12:	Two adult loons plus two chicks.
Site 13:	Three adult loons.
Site 16:	One adult loon.
Site 17:	Three adult loons in the immediate area.
Site 18:	Two blue herons.
Site 19:	Two adult loons plus two chicks.
Site 20:	Several blue herons.
Site 28:	Two adult loons.

For more information on loons and their struggle with black flies, please click here.

Summary of Loon observations for 2020:

Total number of adult loons:	25
Number of nesting pairs:	2
Total number of chicks:	4

The table below summarized the results of loon surveys for seven years starting in 2013. It is clear that 2020 was a difficult year for loons. When compared to 2019, the total adult loon population has declined by 34% and the number of chicks produced by 83%.

OBSERVATION	2013	2015	2016	2017	2018	2019	2020
Number of Adults	23	40	32	45	44	38	25
Number of Nesting Pairs	7	10	11	19	10	12	2
Number of Chicks	16	17	16	21	18	23	4

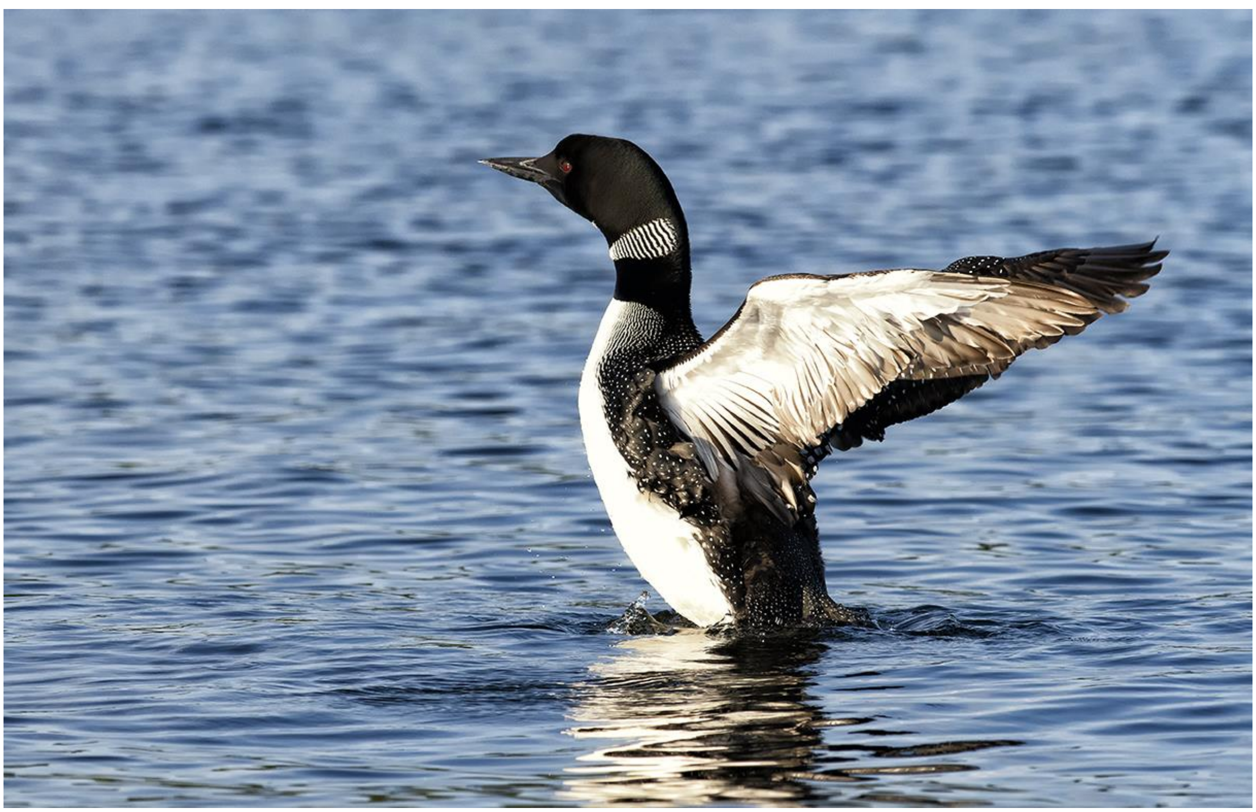
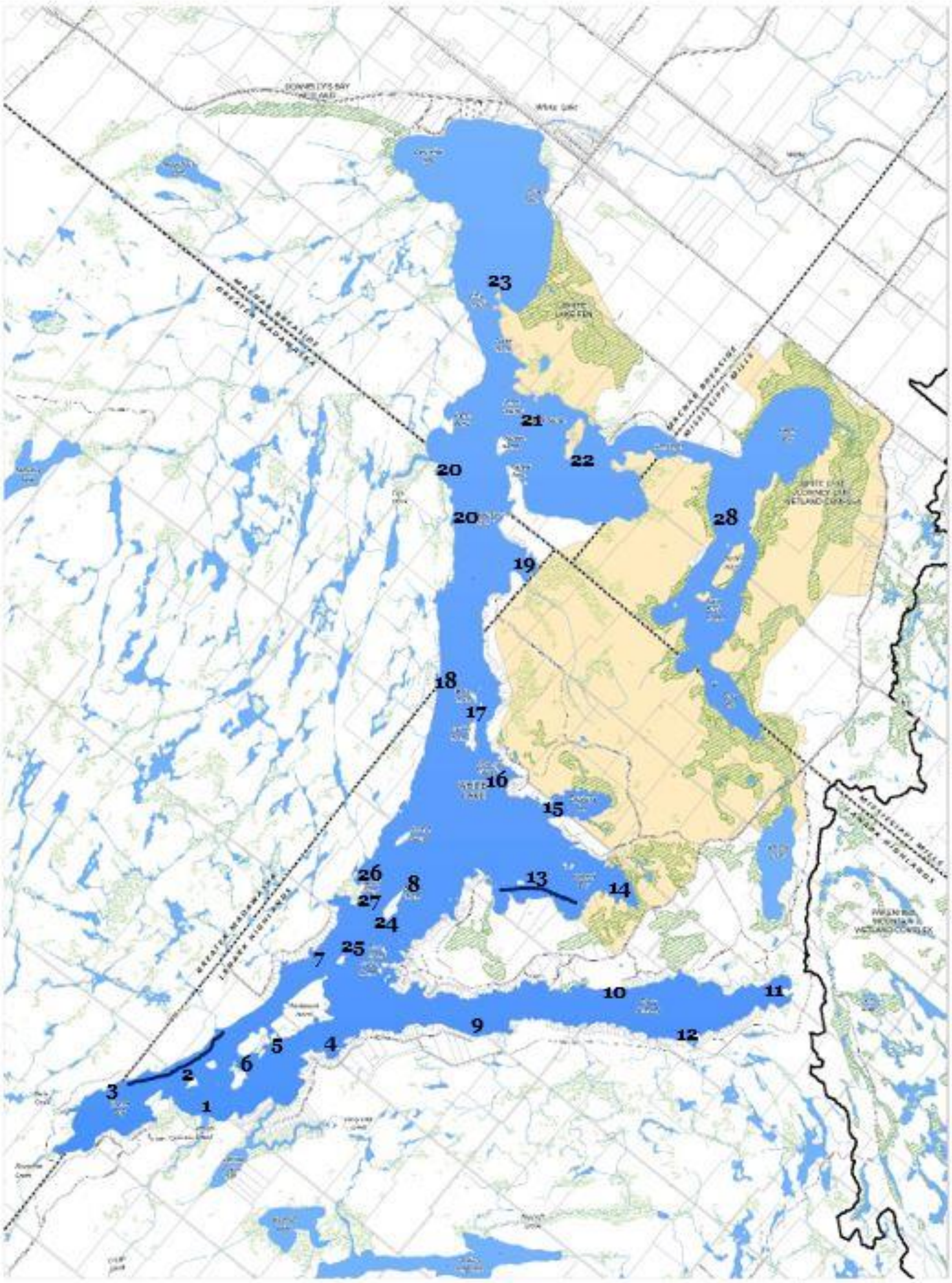


Photo credit: Joyce Benham

Loon Observation Sites

June 27 – July 4, 2020



17.0 Double-Crested Cormorant Survey - 2020

The **double-crested cormorant** (*Phalacrocorax auritus*) is a member of the cormorant family of seabirds. Its habitat is near rivers and lakes as well as in coastal areas, and is widely distributed across North America, from the Aleutian Islands in Alaska down to Florida and Mexico. They are a native species in Ontario including White Lake.

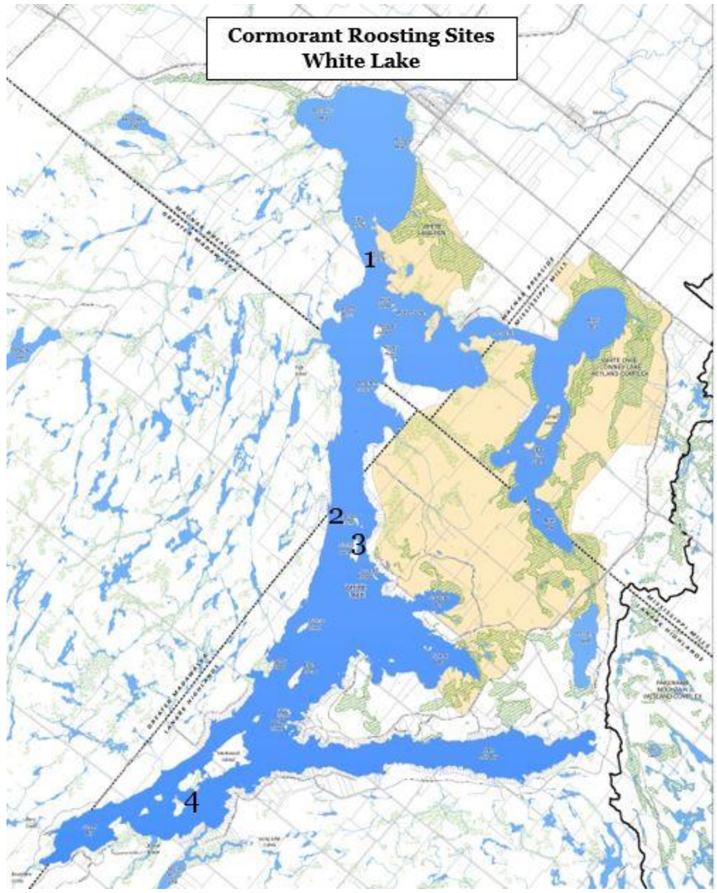
Measuring 70–90 cm (28–35 in) in length, it is an all-black bird which gains a small double crest of black and white feathers in breeding season. It has a bare patch of orange-yellow facial skin. Five subspecies are recognized. It mainly eats fish and catches its prey by swimming and diving. Its feathers, like those of all cormorants, are not waterproof and it must spend time drying them out after spending time in the water. Once threatened by the use of DDT, the numbers of this bird have increased markedly in recent years (Wikipedia).

When large numbers of cormorants congregate in a roosting or nesting area, their droppings can kill trees and other vegetation. They also compete with loons and other fish-feeding birds for food. For this reason, the cormorant has been vilified, even though exactly the same can be said of the Great Blue Heron, which also roost communally, and destroy patches of forest or even entire islands where their nests are located. The authors do not support the killing of cormorants because they are a natural species to White Lake and are not present in numbers warranting action.

Cormorants have been using White Lake for many years. However, their numbers have always remained small. In recent years, we have noticed that the White Lake population of cormorants may be increasing. As part of our water quality monitoring program, we decided to start monitoring cormorant numbers on White Lake. Every two weeks we patrol and sample 9 sites in all parts of the lake. Samples for total phosphorus are collected as are plankton samples, water temperature and Secchi depth measurements.

During this two-hour period, we collect data on the location and numbers of cormorants at 4 specific sites, where they have been observed to roost. Also included are any cormorants we spot in flight or fishing in open water. We do not know the location of the nesting sites at this time. Sites 1,2 and 4 (see map) are exposed rocks where local gulls also roost. Sites 2 and 4 are submerged until late summer whereas site 1 is available during the entire summer. Site 3 is a small islet on the north end of the Stanley Island group. Cormorants were observed there roosting in the tall pines as well as on the rocks along the shoreline.

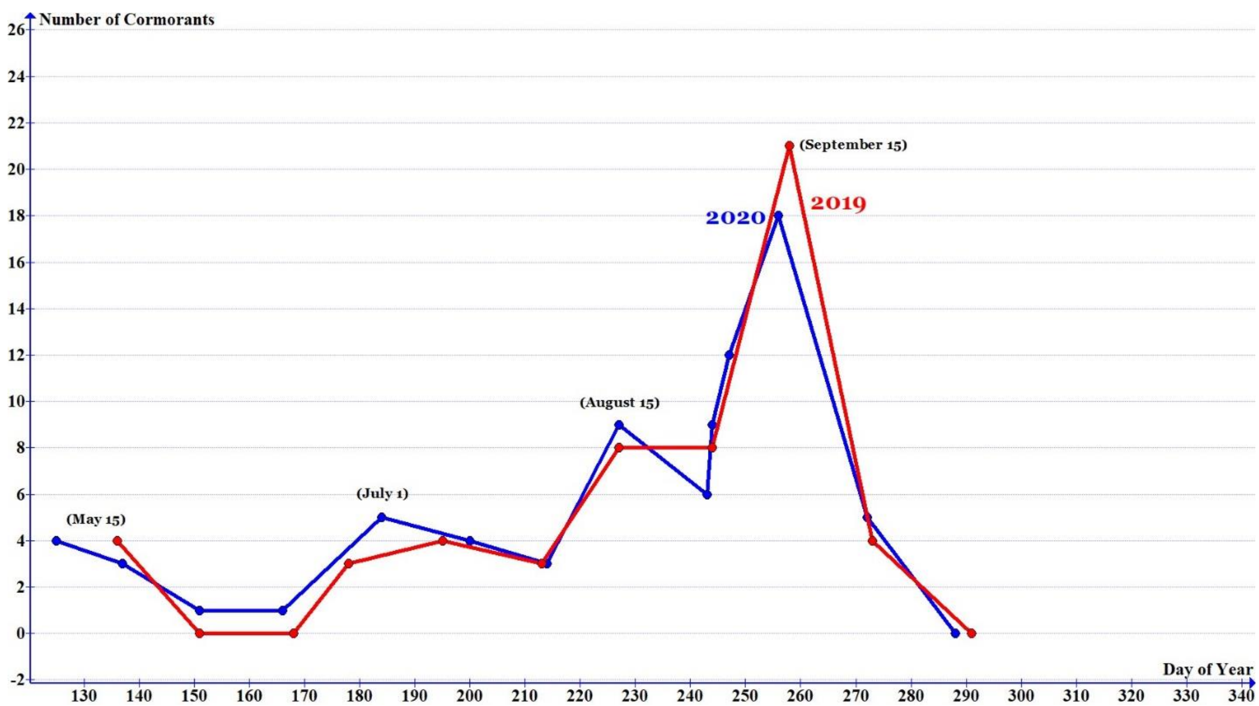
The number of cormorants observed for each date in the tables below can be taken as a minimum number of cormorants, since it is possible that birds in flight or feeding were missed. However, cormorants are communal birds and tend to aggregate in groups rather than be spread out over the entire lake.



Cormorant Count on White Lake – 2020						
Date	**Map Location**					**Total #**
	1	**2**	**3**	**4**	**other**	
May 4	-*	-	-	-	4-McLaughlin's I	4
May 16	-	-	3	-	-	3
May 30	1	-	-	-	-	1
June 14	-	-	-	-	1-Barry's I	1
July 2	3	-	-	1	1-Village Basin	5
July 18	3	-	2	-	-	4
August 1	1	-	2	-		3
August 14	2	1	5	-	1-Curley's I	9
August 30	1	5	-	-		6
August 31	-	9	-	-		9
September 3	-	12	-	-	-	12
September 12	9	7	-	-	2-Village Basin	18
September 28	4	-	1	-		5
October 14	-	-	-	-		-
*none observed						

Cormorant Count on White Lake – 2019						
Date	**Map Location**					**Total #**
	1	**2**	**3**	**4**	**other**	
May 16	-*	-	-		4 in flight	4
May 31	-	-	-		-	-
June 17	-	-	-		-	-
June 27	3	-	-		-	3
July 14	3	-			1 Village Basin	4
August 1	-	-	3		-	3
August 15	6	-	1		1 in flight	8
September 1	4	-	3		1 in flight	8
September 15	10	5	1	3	2 in flight	21
September 30	3	-	-		1 in flight	4
October 18	-	-	-		-	-
*none observed						

The cormorant count for 2019 is included for comparison purposes. When the data for 2019 and 2020 (the only two years for which we have data) are plotted as separate lines on a graph, the following is obtained:



It is interesting that the data curves for both years are virtually the same, with populations peaking in mid-May, July 1, mid-August and mid-September. It is tempting to suggest interpretations for these points, but any further analysis is not justified by the data we have at present.

What we can say is that the mid-August cormorant population numbers probably reflects the permanent resident population of cormorants on White Lake. This data suggests that it is likely that there are from 8 to 10 cormorants making White Lake their home.

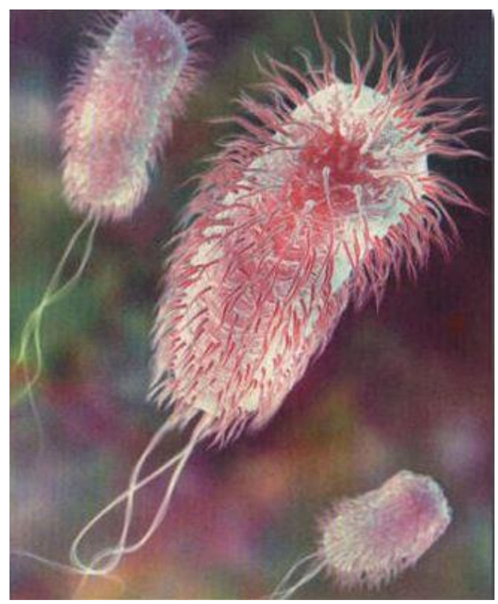
The very large population numbers recorded in mid-September are more than likely seasonal visitors from other lakes migrating south. These birds arrive late, spend about 10 to 15 days feeding and resting and then leave.

Our objective in monitoring cormorant species is to gather facts so that we can accurately report on changes in population numbers and impacts on the lake. Should White Lake become threatened in the future by exploding numbers of cormorants, we will be in a position to recommend and support any control measured warranted.

We will continue monitoring cormorant populations on White Lake and attempt to find the specific nesting site(s) if possible.

18.0 E-coli

What is *E. coli*?



Escherichia coli, commonly called *E. coli*, is one of the most common species of fecal coliform bacteria. It is a normal component of the large intestines in human and other warm-blooded animals including birds, beavers, otters, muskrats, racoons, and other mammals. There are many different strains of *E. coli*, most of which are harmless or even beneficial. Some strains, however, can make you sick. We all carry about one million *E. coli* cells per gram of feces in our guts, and if you are healthy, none of these are capable of causing gastrointestinal illness.

Why do we test for *E. coli*?

When *E. coli* is found in water, it is evidence of sewage or animal waste contamination. Although, on its own, *E. coli* is not likely to cause illness, it is very easy to culture in the lab, making it a useful indicator for other accompanying pathogens or toxins which are much more difficult to detect and quantify.

How and when does *E. coli* get into a lake?

Even in isolated lakes, it is common to find very low levels of *E. coli* in the water. The source of this *E. coli* can be from birds using or overflying the lake, from wild animals and *E. coli* surviving in soils near the lakeshore. When there is a rain event, some of this ‘ambient’ E. coli is washed into the lake.

Much larger and potentially dangerous levels of E. coli can enter a lake from upstream lakes or rivers which are used by farm animals, or by discharge from, for example, sewage treatment plants. An additional source is from faulty septic systems.

What about White Lake?

White Lake is a headwater lake, which means that there are no significant water sources upstream from the lake, and hence no significant sources of *E. coli*. There are no active farms on White Lake or large point sources such as sewage plants, so it is expected that *E. coli* values would be low for lake waters sampled distant from the shoreline.

Has White Lake been tested for *E. coli* and what were the results?

In 1973, the White Lake Water Quality Committee (which later merged with the WLPOA) measured the *E. coli* concentration at 375 separate locations over a three-day period. Shoreline samples were collected in front of most of the 414 cottages on the lake and at other locations including resorts and marinas. It was a monumental effort requiring dozens of people and a Provincial Government willing to pay the considerable costs associated with the survey. As a result of their work, the Committee found about 30 locations with elevated *E. coli* concentrations. Remedial action was left up to the property owners.

More recently, the WLPOA has also sampled White Lake for *E. coli*. The WLPOA website and documents on file show that samples were collected from 2009 to 2012, 2015, 2016 and again in 2018. These samples were collected in open waters away from the shoreline. Reported *E. coli* concentrations were very low as expected for a headwater lake.

Because the beach at White Lake village is a public beach, the local Health Unit samples beach-water at this site on a regular basis. If high *E. coli* levels are detected, the beach is closed until further testing shows that it is safe to use.

Should the lake associations be testing for *E. coli* as part of its Water Quality Monitoring Program?

We believe that, for White Lake, testing of open waters away from the shoreline is not required unless there is a reason, such as the appearance of a new large point source, which could affect water quality. Any open water measurement giving high results would have to be followed up by a more detailed testing plan in order to identify the source of contamination. At a cost of about $20 per sample, it would be prohibitively expensive for the lake associations to test the waterfronts of every or even a significant number of cottages on White Lake.

It is recommended that individual cottagers, residents, resort owners, etc. take responsibility for their own *E. coli* contributions to the lake as a personal health matter. Cottages or residences on the lake which have large lawns, which attract geese during the summer, or anyone who is unsure about the efficacy of their septic systems may wish to conduct private tests. Private cottage or resort beaches should also be tested especially because it is known that *E. coli* can survive in beach sand and be re-suspended by wave action. Samples should be taken where the water is less than 1 metre deep, and after a significant rain event in order to detect *E. coli* washed into the lake.

Sources of Information:

More can be learned about *E. coli* by visiting the websites of the two Health Units serving White Lake:

Leeds Grenville & Lanark District Health Unit

Renfrew County and District Health Unit

If you would like to test your shoreline or beach for *E. coli*, sample bottles and sampling instructions can be obtained from commercial laboratories such as:

Eurofins Ottawa located at 146 Colonnade Road S., Nepean, ON; 613-727-5692

Great Blue Heron – Joyce Benham

19.0 <u>Lake Foam</u>

Every year in late summer and early fall we can see lines of white foam streaming in the wind across the lake. Sometimes there are relatively large accumulations of foam along the shoreline.

Although it is possible that it is pollution, for White Lake that turns out to be very unlikely. We know this because pollution from detergents produce a foam which dissipates quickly and often smells fragrant. Foam from detergents would also be observed throughout the year and not exclusively at the end of summer.

Natural lake foam is long-lasting and even when there is no wind, often emits a fishy smell. This is the kind of foam we have on White Lake which is good news!

What is lake foam and where does it come from?

Lake foam is a natural phenomenon that occurs on many lakes. Foam is produced when organic matter from decaying plants and plankton in the water and sediments decomposes releasing compounds such as fatty acids. These compounds readily dissolve in water and act to reduce the surface tension of lake water in much the same way soap does, hence the foam.

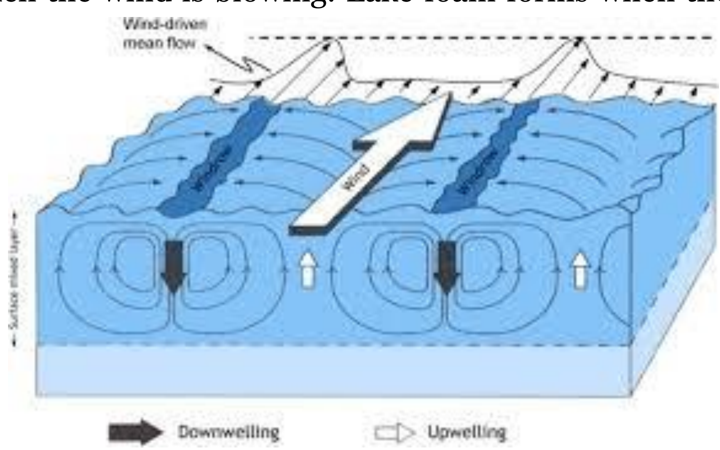
Chemists call this class of compounds surfactants (short for surface active agents). Like soap, these compounds are soluble in both water and oil and can concentrate on the surface of the lake because they are lighter (less dense) than water.

It takes only a very small amount of fatty acids or other foaming agents to produce a large amount of foam. The foam itself is only about 1% foaming agent and 99% water. There is no hazard or danger associated with lake foam.

Why do we see lines of foam forming in the same direction as the wind is blowing?

The lines or streaks of foam visible on the lake in the fall are the natural consequence of how water at the surface of the lake interacts with the wind. These lines are called Langmuir lines, so named after the physicist who first described them mathematically.

The photo on the right shows Langmuir lines on the surface of the lake. The diagram below shows how water circulates and mixes when the wind is blowing. Lake foam forms when the wind causes two streams of rising water to meet and rise to meet the wind.



Lake foam along shoreline, Western shore, October 12, 2020

PART IV
Acknowledgements and Author Profiles

20.0 Acknowledgements

We are grateful to the Lake Partner Program of the Ontario Ministry of the Environment Conservation and Parks for providing us with sampling equipment and the analysis of water samples for total phosphorus, calcium, dissolved organic carbon, and chloride. Costs and time related to lake sampling and all other activities were self-funded by Dr. Conrad Grégoire and David Overholt.

21.0 Author Profiles

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 Science and Information 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.

Joyce Benham is an accomplished nature photographer and along with husband **Robert Carrière**, spends one week in July of each year photographing and documenting wildlife sightings on White Lake. The naturalist couple from Hammond, Ontario documents the number and location of adult loons and chicks and from file photos can recognize individual loons. Monitored annually, loon populations can be used to measure habitat health as well as threats from wave action, boat traffic and other factors contributing to changing loon populations.

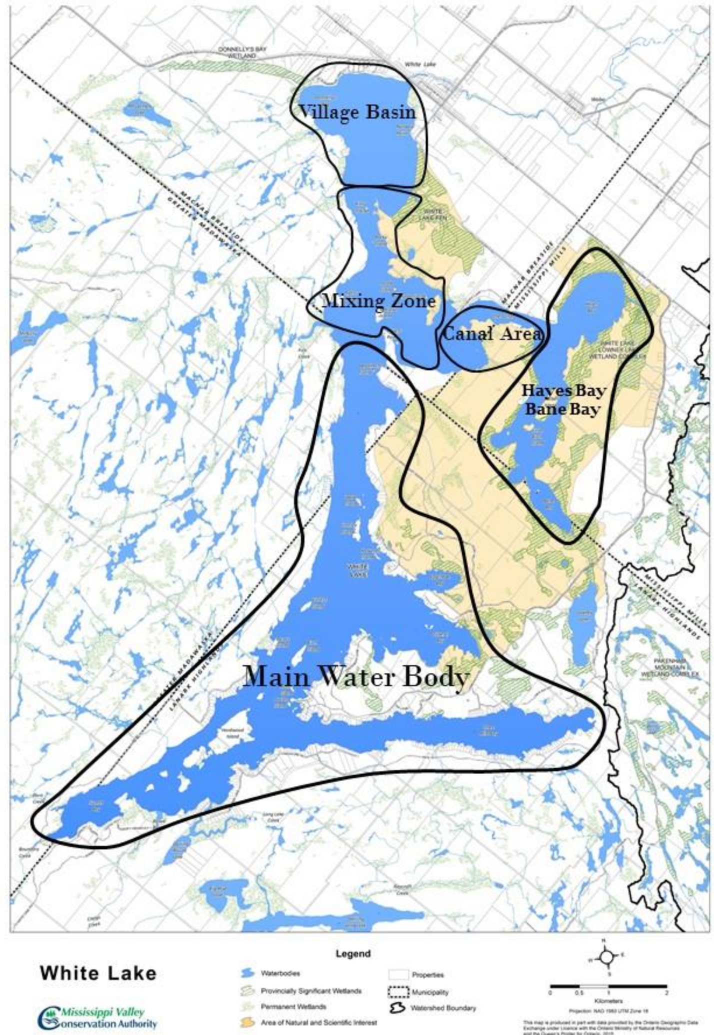
PART V
Appendices

Appendix 1: 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 0f 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.

Appendix 2:

Chemical and Physical Data – 2020

Three Mile Bay N. 45° 15.767'; W. 076° 32.521 Depth: 6.0 M

Date	Time	Day of Year	Secchi Depth, M	Temp, °C	Total P, ppb	Ca,ppm	Cl, ppm
May 16	10:01	137	>depth	10.4	7.8,9.4 (8.6)	31.2	3.2
May 30	10:54	151	5.1	19.0	-	-	-
June 14	10:05	166	4.2	19.0	12.0,10.4 (11.2)	32.0	3.4
July 2	9:07	184	4.8	24.8	-	-	-
July 18	9:13	200	4.2	25.7	12.4,12.2 (12.3)	31.2	3.4
August 1	9:12	214	4.8	25.7	-	-	-
August 14	9:00	227	4.9	25.0	12.0,10.4 (11.2)	30.9	3.4
August 30	10:04	243	>depth	20.8	-	-	-
September 12	10:01	256	5.5	18.0	10.2,10.4 (10.3)	28.4	3.5
September 28	13:15	272	>depth	17.7	-	-	-
October 14	10:12	288	>depth	12.2	8.4,8.3 (8.4)	29.7	3.5

North Hardwood Island N. 45º 16.162'; W. 076º 33.203' Depth: 5.0 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	10:15	137	4.9	10.6	8.2,7.8 (8.0)	31.9	3.1
May 30	11:05	151	>depth	19.8	-	-	-
June 14	10:21	166	4.7	19.0	10.0,9.0 (9.5)	32.6	3.3
July 2	9:17	184	4.4	24.8	-	-	-
July 18	9:31	200	3.4	25.7	13.0,13.0 (13.0)	31.6	3.4
August 1	9:18	214	4.9	25.7	-	-	-
August 14	9:12	227	4.9	25.2	10.6,10.6 (10.6)	30.9	3.5
August 30	10:16	243	5.2	21.2	-	-	-
September 12	10:17	256	5.7	18.7	10.4,11.0 (10.7)	28.8	3.5
September 28	13:26	272	>depth	17.7	-	-	--
October 14	10:24	288	>depth	12.3	9.2,8.3 (8.8)	29.0	3.4

Deepest Pickerel Bay N. 45º 16.81'; W. 076º 31.63 Depth: 9.0 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	10:27	137	5.6	10.2	-	-	-
May 30	11:20	151	7.0	20.4	-	-	-
June 14	10:42	166	5.7	19.2	-	-	-
July 2	9:29	184	4.9	24.2	-	-	-
July 18	9:44	200	4.7	25.8	-	-	-
August 1	9:31	214	5.2	25.7	-	-	-
August 14	9:27	227	5.4	25.2	-	-	-
August 30	10:31	243	5.0	21.3	-	-	-
September 12	10:31	256	5.6	18.5	-	-	-
September 28	13:38	272	6.3	17.7	-	-	-
October 14	10:36	288	8.4	12.6	-	-	-

Pickerel Bay N. 45º 16.33'; W. 076º 31.03 Depth: 7.5 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	10:35	137	5.7	10.2	-	-	-
May 30	11:40	151	7.6	20.6	-	-	-
June 14	10:50	166	6.0	19.0	-	-	-
July 2	9:40	184	5.5	24.3	-	-	-
July 18	9:55	200	4.6	25.9	-	-	-
August 1	9:45	214	6.4	25.8	-	-	-
August 14	9:39	227	6.5	25.2	-	-	-
August 30	10:43	243	5.2	21.2	-	-	-
September 12	10:42	256	5.7	18.5	-	-	-
September 28	13:50	272	6.0	17.7	-	-	-
October 14	10:45	288	8.4	12.6	-	-	-

Middle Narrows N. 45º 18.548'; W. 076º 31.271' Depth: 6.0 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	10:45	137	4.7	10.1	8.0,8.4 (8.2)	31.6	3.5
May 30	11:55	151	>depth	20.9	-	-	-
June 14	11:00	166	4.2	19.8	11.2,9.6 (10.4)	33.1	3.4
July 2	9:50	184	4.8	24.0	-	-	-
July 18	10:05	200	3.4	25.6	12.2,12.2 (12.2)	31.4	3.7
August 1	9:50	214	4.8	25.6	-	-	-
August 14	9:52	227	4.4	25.3	11.0,10.8 (10.9)	30.6	3.6
August 30	10:53	243	5.7	21.3	-	-	-
September 12	10:54	256	4.4	18.6	10.1,7.0 (10.1)*	29.6	3.4
September 28	14:00	272	5.8	17.7	-	-	--
October 14	10:58	288	>depth	12.3	8.2,7.9 (8.1)	30.6	3.6

*broken sample bottle, leak. 7.0 value rejected

The Canal N. 45º 19.267'; W. 076º 30.013' Depth: 2.4 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	11:00	137	>depth	11.8	8.0, 7.6 (7.8)	32.0	4.8
May 30	12:16	151	>depth	21.8	-	-	-
June 14	11:19	166	>depth	18.7	7.8,7.2 (7.5)	32.4	4.4
July 2	10:04	184	>depth	25.6	-	-	-
July 18	10:18	200	>depth	25.0	9.4,9.0 (9.2)	31.2	4.5
August 1	10:02	214	>depth	25.8	-	-	-
August 14	10:07	227	>depth	25.9	9.0,8.8 (8.9)	27.9	4.9
August 30	11:07	243	>depth	18.1	-	-	-
September 12	11:10	256	>depth	15.8	7.6,6.4 (7.0)	29.2	4.7
September 28	14:14	272	>depth	18.8	-	-	-
October 14	11:13	288	>depth	11.0	7.1,6.9 (7.0)	31.5	4.8

Temperatures taken 1 m from bottom.

Hayes Bay N. 45º 19.037'; W. 076º 28.424' Depth: 1.6 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	11:11	137	>depth	12.1	6.4,7.0 (6.7)	34.5	8.5
May 30	12:18	151	>depth	22.3	-	-	-
June 14	11:28	166	>depth	18.5	9.6,8.8 (9.2)	33.8	8.7
July 2	10:13	184	>depth	26.1	-	-	-
July 18	10:29	200	>depth	25.8	9.2,9.6 (9.4)	34.0	9.6
August 1	10:12	214	>depth	26.0	-	-	-
August 14	10:15	227	>depth	26.0	9.2,10.4 (9.7)	31.1	9.2
August 30	11:18	243	>depth	18.2	-	-	-
September 12	11:22	256	>depth	15.9	7.6,7.8 (7.7)	29.4	9.0
September 28	14:23	272	>depth	19.9	-	-	-
October 14	11:21	288	>depth	10.7	6.7,6.9 (6.8)	32.5	9.0

Temperatures taken 1 m from bottom.

Jacob's Island N. 45º 19.989; W. 076º 30.622' Depth: 4.0 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	11:27	137	>depth	10.0	9.6,8.8 (9.2)	31.6	3.6
May 30	12:33	151	>depth	22.0	-	-	-
June 14	11:41	166	>depth	19.0	10.8,10,8 (10.8)	32.4	3.6
July 2	10:25	184	>depth	24.0	-	-	-
July 18	10:50	200	>depth	25.9	12.0,11.8 (11.9)	31.1	3.6
August 1	10:23	214	>depth	25.6	-	-	-
August 14	10:29	227	>depth	25.4	11.2,11.4 (11.3)	30.4	3.6
August 30	12:25	243	>depth	20.6	-	-	-
September 12	11:35	256	>depth	18.6	10.2,9.4 (9.8)	28.8	3.8
September 28	14:34	272	>depth	18.3	-	-	-
October 14	11:34	288	>depth	11.8	9.2,9.3 (9.3)	29.0	4.0

Village Basin N. 45º 21.233'; W. 076º 30.303' Depth: 1.65 M

Date	Time	Day of Year	Secchi Depth, M	Temp, ºC	Total P, ppb	Ca, ppm	Cl, ppm
May 16	11:41	137	>depth	11.8	7.6,8.2 (7.9)	29.4	3.7
May 30	12:43	151	>depth	22.1	-	-	-
June 14	12:05	166	>depth	18.3	7.4,8.2 (7.8)	32.4	3.8
July 2	10:40	184	>depth	25.3	-	-	-
July 18	11:00	200	>depth	25.7	8.6,8.2 (8.4)	31.7	4.1
August 1	10:43	214	>depth	25.8	-	-	-
August 14	10:41	227	>depth	26.0	10.0,9.4 (9.7)	28.9	4.0
August 30	12:39	243	>depth	18.2	-	-	-
September 12	11:51	256	>depth	16.0	7.4,7.0 (7.2)	28.4	4.0
September 28	14:45	272	>depth	19.4	-	-	-
October 14	11:47	288	>depth	10.4	6.6,7.1 (6.9)	29.0	4.1

Temperatures taken 1 m from bottom. B= bottom temperature

Weather Conditions 2020

Date	Day of Year	Weather Conditions
May 16	137	Air temp: 13C; 24 mm rain fell day before sampling; Overcast to partial sun conditions, but bright; Wind approx. 5 km/hr.
May 30	151	Air Temp: 15C; Partly cloudy with sun patches; Very calm conditions, no wind. 4 mm rain fell day before sampling which broke a 3-day heat wave with air temperatures rising to 32C; Lake waters were heated during this period which is reflected in water temperatures.
June 14	166	Sunny clear day with no or little wind; Air temperature: 13C; 24 mm rain fell 2 and 4 days prior to sampling date. Very significant pollen storm particularly in the southern part of the lake. Surface pollen scum visible in many places.
July 2	184	Air temperature 27C; very little or no wind. Sunny for first four sampling sites (in order of presentation in this table); No rain preceding sampling by at least 5 days; Hot dry period.
July 18	200	Air temperature: 24 to 28C; very little or no wind; full sunshine. Four mm of rain fell during previous 48 hours. Heat wave continues.
August 1	214	Air temperature 23 to 24C; full sun with no wind. Five mm of rain fell about 30 hours previous to sampling date. Dry hot summer.
August 14	227	Air temperature 23 to 25C; Full sun with no wind. 16 mm rain four days prior to sampling.
August 30	243	Air temperature 13 to 15C’ mostly sunny with some cloud; wind from 15 to 25 km/hr; 26 mm rain fell previous day.
September 12	256	Air temperature 13 to 16C; full sun; wind about 5 km/hr; 20mm rain fell 28 hours before sampling.
September 28	272	Air temperature 24C; mostly cloudy with some sun; wind from5 to 10 km/hr; no rain fell precious 10 days.
October 14	288	Air temperature 12C; fully sunny day; winds of less than 5 km/hr; 4 mm of rain fell day before sampling.

Notes:

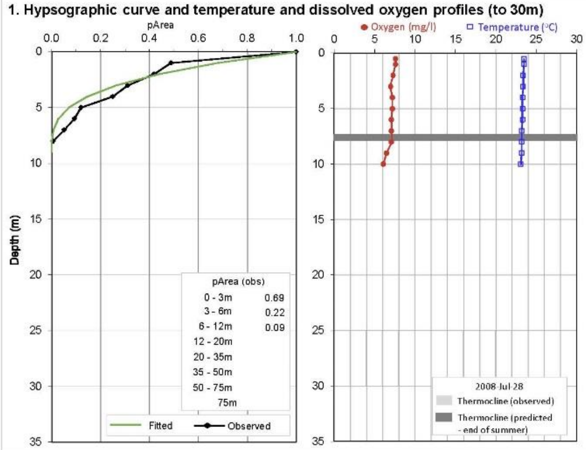
1. Temperatures were taken at Secchi Depth. When sampling site depth was less than Secchi depth, temperatures were taken 1 M from bottom.
2. Water samples for total phosphorous were taken at Secchi Depth or when sampling site depth was less than Secchi depth, samples were taken 1 M from bottom.
3. All water samples were filtered through 80-micron filter prior to determination of total phosphorous.
4. Sampling dates were ideally the first of the month for temperature and Secchi depth and the 15^{th} of the month for Secchi depth, temperature and total phosphorus. Some adjustments in timing had to be done to accommodate inclement weather and availability of personnel.
5. Total phosphorous water samples were not taken at the Pickerel Bay or Deepest Pickerel Bay locations as these locations were not part of the Lake Partner Program for.

Appendix 3 : Broad Scale Fish Monitoring Lake Synopsis October 21,2016

White Lake (18-3808-50183)

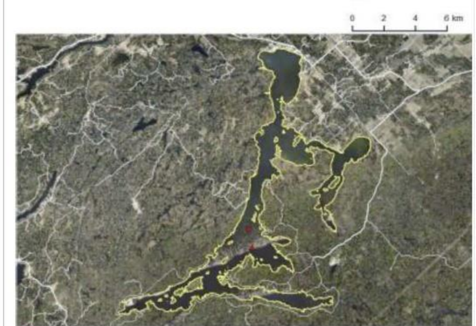
Area (ha):	2,365	**Lake class (n) :**	4:1,500-5,000 ha (8)	**FMZ:**	18
Depth max/mn (m):	9.1 / 2.1	**TDS / TP:**	152.5 / 14.7	**Survey date:**	2008-Jul (Cycle 1)
Secchi spr/sum (m):	4.2 / 3.8	**DD5 / MAT:**	2,024 / 6.1	**Selection:**	Trend & State / Walleye

1. Hypsographic curve and temperature and dissolved oxygen profiles (to 30m)



5. Lake map and angling activity

SDF = 7.0



▲ chem. site
● T / DO site

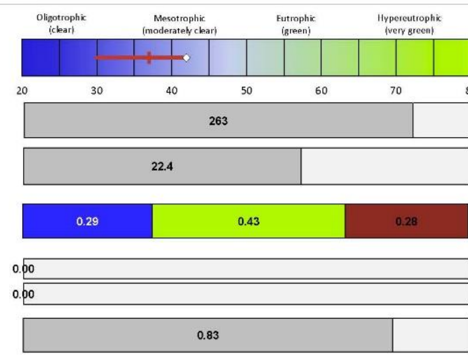
Mean angling activity (number / km^2)

	Lake	Lake class	Date
Summer - vessels	0.750	0.448	2012/05/20 — 2012/08/26
Summer - shore anglers		0.000	
Winter - huts	0.036	0.072	2012/01/10 — 2012/03/18
Winter - open ice anglers		0.054	

2. Habitat statistics

Trophic state index	
TSI - Phosphorus	43
TSI - Secchi	41
Average	42
Predicted	
No. ice-free days	263
Max. surface temp (°C)	22.4
Proportion of days	
Cold (8-12°C)	0.29
Cool (16-20°C)	0.43
Warm (22-26°C)	0.28
Observed thermocline depth (m)	-
Predicted thermocline depth (m)	7.6 (end of summer)
Hypolimnetic space	
Area observed (prop)	-
Area predicted (prop)	< 0.01
Volume observed (prop)	-
Volume predicted (prop)	< 0.01
Littoral area (prop ≤ 4.6m)	0.83

6. Habitat graphs

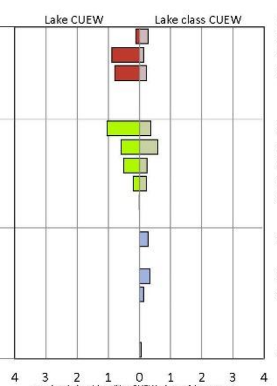


3. Water chemistry statistics

	Lake (pctl)	Lake class Min	Lake class Max
True colour (TCU)	15.0 (38)	9.6	28.0
pH	8.0 (100)	7.2	8.0
Conductivity (uS/cm/s)	229.0 (100)	62.4	229.0
Alkalinity (mg/L CaCO3)	108.0 (100)	19.8	108.0
Calcium (mg/L)	31.4 (100)	9.2	31.4
Magnesium (mg/L)	8.4 (86)	1.6	9.0
Sodium (mg/L)	2.5 (43)	1.1	6.1
Potassium (mg/L)	0.8 (29)	0.5	1.4
Chloride (mg/L)	3.9 (38)	1.7	9.5
Sulphate (mg/L)	6.6 (63)	3.5	8.4
Silicate (mg/L)	2.3 (100)	0.6	2.3
Iron	97.0 (75)	44.0	99.0
DIC (mg/L)	26.5 (100)	5.3	26.5
DOC (mg/L)	5.3 (63)	2.3	6.8
Ammonia/Ammonium (mg/L)	56.0 (100)	6.0	56.0
Nitrate/Nitrite (ug/L)	6.0 (38)	2.0	194.0
TKN (ug/L)	412.0 (100)	210.0	412.0
Total Phosphorus (ug/L)	14.7 (100)	4.8	14.7

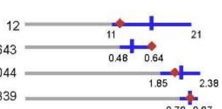
7. Fish community (large mesh catch)

	Species	CUE	TLEN_Mn	CUEW	n
	Smallmouth bass	0.26	317	0.13	8
	Sunfish	4.71	211	0.88	8
Warm	Catfish	2.22	300	0.79	8
	Minnows				
	Other				
	Walleye	1.01	417	1.04	6
	Northern pike	1.01	456	0.59	6
Cool	Yellow perch	5.27	198	0.52	8
	Suckers	0.19	449	0.20	8
	Minnows	0.02	154	0.00	3
	Other				
	Lake trout				5
	Brook trout				
	Whitefishes				2
Cold	Ciscoes				5
	Rainbow smelt				
	Minnows				
	Other				4
	All species	14.69	313	4.14	



4. Biodiversity

nTaxa (S)	12
Evenness	0.643
Shannon	2.044
Simpson (1-D)	0.839



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