Science and Monitoring Synthesis for South-Eastern Georgian Bay

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Executive Summary

This report synthesizes science and monitoring information for south-eastern Georgian Bay with particular emphasis on phosphorus, causes of cyanobacteria and harmful algae blooms and the general condition of aquatic resources within this region. The region includes the nearshore waters and coastal areas west of Hwy 69 extending from the French River to Port Severn, the watersheds and open waters of Severn Sound, eastern Nottawasaga Bay and the watersheds of the Penetang Peninsula and Nottawasaga Valley. The region is notable for its natural beauty, ecological significance, recreational potential and tourism investment. The prevailing environmental concerns of the public and resource management agencies are elevated nutrient concentrations in the nearshore, nuisance and harmful algal blooms, loss and degradation of aquatic habitat, unsustainable shoreline development, sustained low water levels, invasive species and severe outbreaks of avian botulism.

Summary of Current Water Quality and Habitat Conditions

Significant long-term declines in open water nutrient levels have occurred and the recent distribution of total phosphorus concentrations across Georgian Bay represent oligotrophic or nutrient poor conditions. The downward trend in phosphorus concentrations is due in part to reductions in loadings; however, the prevailing theory is that a change in nutrient cycling and a redirection of nutrient and energy flow in the direction of the nearshore has occurred. Several nearshore areas, embayments and tributaries are of most concern due to high phosphorus concentrations, blooms of cyanobacteria and harmful algae and degraded aquatic habitat conditions. A general summary of water quality conditions within this geographic scope are as follows:

- Phosphorus concentrations at the mouth of the French River are within provincial limits; however, much higher concentrations and cyanobacteria blooms are reported up stream;
- Sturgeon Bay (Township of the Archipelago) has the most intense cyanobacteria blooms and deeper water areas have low levels of dissolved oxygen critical for fish survival;
- While the water quality in Parry Sound is excellent, some inland bays connected to the Sound by narrow channels experience algal blooms (e.g., Deep Bay);
- Go-Home Bay, Twelve Mile Bay, Cognashene Lake, Honey Harbour, North Bay, South Bay, Church Bay, the Severn River and Port Severn experience one or more of the following conditions: high phosphorus concentrations; increased filamentous algae and aquatic plant growth; low dissolved oxygen concentrations impacting fish habitat; declines in water clarity, and shifts in aquatic invertebrate and phytoplankton community structure;
- Lake Simcoe and Lake Couchiching do not appear to contribute excessive phosphorus concentrations to Georgian Bay. Yet, by the time the Severn River enters Georgian Bay at Port Severn higher than expected concentrations are observed;
- The open waters of Severn Sound show a marked decrease in total phosphorus concentrations over time; however, the presence of cyanobacteria blooms indicate that nutrient loads should be monitored and controlled;
- The Nottawasaga River discharges approximately 47 tonnes of phosphorus annually to Nottawasaga Bay. The Lower and Middle Nottawasaga River Reaches and the Innisfil

Creek subwatershed have the lowest stream health ranks with high phosphorus concentrations and turbidity;

- *Escherichia coli (E. coli*) bacteria levels within south-eastern Georgian Bay are generally low with a few exceptions;
- Record low water levels were recorded in the winter of 2013. Coastal wetlands have become stranded decreasing the amount of available spawning, nursery and forage habitat for fish and wildlife. Low lake levels also contribute to the spread and establishment of invasive plants such as Phragmites at beaches and other shoreline areas. Botulism is associated with low lake levels, invasive species and nutrient dynamics in the nearshore zone.

Causes and Contributing Factors

The source water of the French River is the mesotrophic Lake Nipissing. The most significant concerns over water quality and cyanobacteria blooms are associated with a sewage lagoon; however, agriculture activity and a golf course may contribute as well. The cause(s) of high phosphorus concentrations east of Hwy 69 are not well understood.

Enclosed embayments and long narrow channels with limited hydrologic connection to Georgian Bay develop water quality conditions of their own depending on the basin morphometry, degree of water circulation/flushing, watershed geology, input from land runoff and tributaries and shoreline development. Many of these bays are deep enough to stratify resulting in low dissolved oxygen levels and phosphorus enrichment of hypolimnion water impacting cold water fish habitat.

Tributaries may represent one of the largest external sources of phosphorus. Low tributary flow also results in low flushing rates of water in isolated embayments. Late summer oxygen depletion in the hypolimnetic waters is coincident with the release of soluble phosphorus from the sediment into the water column. Cyanobacteria blooms are a recurrent problem in Sturgeon Bay despite moderate phosphorus concentrations in surface waters. Cyanobacteria out compete other algal species due to their ability to vertically migrate in the water column, scavenge and respond to low iron concentrations.

The lower Nottawasaga River is considered impaired by the effects of high turbidity during the growing season, high loads of suspended solids and flow reductions from water taking. Treated sewage from three waste water treatment plants discharge into the lower river. Major constraints to stream health are municipal drains, rural and urban non-point pollution sources. Storm events cause erosion and high pulses of suspended solids to Nottawasaga Bay. A high degree of agricultural activity, deforestation plus farm drains contribute to rapid drainage with high flow velocities. Treated sewage and agricultural fertilizers increase the nutrient content so algae can grow in quiet reaches. The causes of the turbidity can be both suspended sediment and algae especially at low flow times. These events are highly visible where the river discharges to Georgian Bay at Wasaga Beach. The plume may also contain higher levels of *E coli* with potential impact to adjacent beaches. In many respects the lower Nottawasaga River is typical of the lower reaches of many rivers in an agricultural landscape.

Cottages and resorts may be a contributing factor to water quality problems due to decades of imported nutrients in the form of human waste stored in septic beds along lake shores and tributaries. These nutrients are thought to slowly enter the water and contribute to phosphorus concentrations and *E. coli* bacteria. High density residential and cottage communities, especially in enclosed embayments and channels and in areas with underlying fractured rock or porous soils are of particular concern.

Conditions Leading to Increasing Trends of Degradation

The situation in Sturgeon Bay may foreshadow events in other enclosed embayments in south-eastern Georgian Bay. Climate related influences such as decreased precipitation, increased air and water temperature, lack of ice cover and evaporative loss and sustained low water levels may exacerbate already degraded water quality and aquatic habitat conditions. Increases in population growth and unsustainable development and alteration to the shoreline may not only threaten the quality of the Georgian Bay as a drinking water source, it may impair residential, commercial and recreational uses for future generations.

In addition to the external phosphorus loads in land runoff, atmospheric deposition as dust fall, wetland drainage, and septic tank effluent, some embayments may release phosphorus and iron from the sediment into the water column under low oxygen conditions. These soluble forms of micronutrients are capable of stimulating cyanobacteria and harmful algal blooms.

Without a basic understanding of the impacts of future water levels to coastal wetlands resource agencies and municipalities will be unable to put in place the necessary wetland protection mechanisms to ensure ecosystem resiliency.

Priority Areas for Science and Monitoring

Sturgeon Bay appears to have the worst water quality problems in eastern Georgian Bay and requires more study. Go-Home Bay, Twelve Mile Bay, Cognashene Lake, Honey Harbour, North Bay, South Bay, Church Bay, the Severn River and Port Severn are other areas experiencing water quality problems that deserve elucidation. Embayments with limited circulation and flushing with Georgian Bay water and deep enough to stratify and produce oxygen depletion and phosphorus enrichment of hypolimnion water require additional science and monitoring. There are insufficient data in most cases to determine the condition of major tributaries within the south-eastern Georgian Bay region and long-term trends are lacking.

Severn Sound has the most extensive water quality data set that captures historic and current environmental conditions. However, much information remains to be extracted from the patterns of variability to discern anthropogenic causes. Information on tributary loading, basin flushing, circulation and temperature regime, shoreline development and alterations, invasive species, fish communities and their habitat, and coastal wetland health and conservation are key areas of research.

Within the Nottawasaga Bay, there are 23 beaches with numerous feeder creeks within Tiny Township. Several beaches form the world's largest freshwater beach at Wasaga

Beach Provincial Park. The nearshore system of Nottawasaga Bay is understudied and little scientific literature exists. Systematic measurements of natural physical processes (e.g., bathymetry, water circulation, residence time, surface meteorology) are not conducted in this region. It is important to fill this information gap so that management actions can be determined. A large region between Penetanguishene and Wasaga Beach is not managed by a Conservation Authority making this a priority area for science, monitoring and conservation action. The Lower and Middle Nottawasaga River reaches and the Innisfil subwatersheds are priority areas due to their degraded water quality and habitat conditions and increasing land use pressures.

Summary of Information Needs and Unanswered Management Questions

The ability to manage the water resources and aquatic habitats and species of this area is generally compromised by a lack of monitoring and science. Many studies are conducted at irregular intervals or are so far apart in time that detecting and reporting ecosystem changes and causes is exceedingly difficult. This impedes environmental management decision making because action triggers are unclear. The environmental effects of record low water levels are unclear because of the lack of studies. This is particularly true of eastern Georgian Bay and Nottawasaga Bay and in areas without conservation authorities to conduct watershed-wide studies. A more complete summary of recommendations is available in the body of this report; however, the following represents the major information needs and unanswered management questions:

- Study the various watershed, ground water, tributary, septic and wetland phosphorus sources and contributions to Sturgeon Bay and other isolated embayments and river mouths with water quality problems;
- Determine the internal loads and fate of regenerated phosphorus in Sturgeon Bay and other enclosed embayments;
- Study the trends and factors responsible for low dissolved oxygen depletion and cyanobacteria and harmful algal blooms. Determine the role of iron in blooms formation;
- Study the natural physical process information (e.g., remote sensing and volumetric measures of bottom sediment, bathymetry and circulation);
- Determine the source(s) of elevated phosphorus at Port Severn and maintain monitoring, synthesis and reporting of tributaries and the open waters of Severn Sound:
- Perform synoptic surveys of eastern Nottawasaga Bay to understand nearshore phosphorus concentrations and sources, fish communities, aquatic and terrestrial invasive species, and shoreline alteration impacts;
- Determine the composition of the Nottawasaga River plume and investigate sources of suspended sediments, all forms of phosphorus and *E. Coli*, to determine management actions;
- Examine the sources of high phosphorus concentrations and turbidity levels in the Nottawasaga River system to guide implementation of phosphorus control and implementation of best management practices;
- Investigate the input and sources of phosphorus from groundwater discharge to Nottawasaga Bay from the Nottawasaga River, local streams and beaches;

- Study the contribution of septic systems and effects on water quality in selected embayments, beaches, tributaries and the Nottawasaga River;
- Monitor coastal wetlands water quality and function in relation to phosphorus and habitat provision;
- Consider microbial and chemical source tracking techniques to identify sources of phosphorus and fecal pollution at beaches, rivers, and nearshore waters around South Eastern Georgian Bay;
- Study the current and future impacts of sustained low water levels on water quality, beach health and aquatic habitats and species and synthesize data for management action;

Recent concern over lakewide changes in nutrient cycling and redirection of energy to the nearshore system, invasive species interactions, and trophic status as well as the recurrence of local and regional water-quality problems should be ample justification for enhanced monitoring efforts. Furthermore, the 2012 amended Great Lakes Water Quality Agreement (GLWQA) commits the government of Canada to undertake monitoring, surveillance, science and modeling to assess and report on phosphorus concentrations with the objective to minimize the extent of low oxygen conditions and maintain levels of algal biomass and cyanobacteria consistent with a healthy Great Lakes aquatic ecosystem.

Science and monitoring that improves our understanding of the causes and consequences of nutrient input and associated water quality issues will benefit the scientific community and resource management agencies working regions experiencing similar challenges.

1.0 Overview

In amending the Great Lake Water Quality Agreement (GLWQA) in 2012, the Governments of Canada and the United States have committed to a shared vision of a healthy and prosperous Great Lakes region. Recognizing these commitments, Environment Canada seeks to improve the understanding of Georgian Bay water quality and habitat conditions to guide future decisions around science and monitoring needs and to guide the development and implementation of measures to reduce phosphorus/nutrient inputs, low oxygen conditions, toxic/nuisance algae growth and promote aquatic habitat conservation.

The citizens of Georgian Bay are also concerned about water quality, human health, and aquatic habitat conditions. Reducing the occurrence of toxic and nuisance algal blooms that degrade drinking water quality, impair fish spawning, and adversely impact commercial and recreational fishing, swimming, tourism and overall enjoyment of the Great Lakes is of particular importance.

In an effort to address these issues in Georgian Bay, Environment Canada renewed the 2007-2012 Lake Simcoe Clean-Up Fund an expanded its geographic scope to include south-eastern Georgian Bay (Fig.1). The purpose of the 2013-2017 Lake Simcoe/South-Eastern Georgian Bay Clean-Up Fund is to enhance research and monitoring to improve environmental information for decision making, conserve aquatic habitat and species, and reduce rural and urban non-point sources of phosphorous and nutrients, and reduce discharge of phosphorus from point sources.

The Fund provides an opportunity for government and non-government scientists to enhance research and monitoring to improve information on the aquatic environment for management decision making. The following key science and monitoring deliverables associated with this key objective are:

- Conduct monitoring to measure phosphorus in south-eastern Georgian Bay;
- Conduct research and monitoring to assess conditions contributing to increased phosphorus inputs into south-eastern Georgian Bay and nuisance and toxic algae growth to fill information gaps and aid in restoration and protection efforts; and,
- Conduct and support other research and monitoring necessary to guide the development and implementation of measures to reduce phosphorus/nutrient inputs and address low oxygen conditions and toxic/nuisance algae growth.

The output of science and monitoring activities will include science based reports describing current water quality conditions, phosphorus sources and causes of nuisance and toxic algal blooms, and the conditions which may lead to increasing trends of degradation. Priority areas for phosphorus load reductions are to be identified, and scientific information will be compiled and distributed to decision makers and the public. The outcome of such work will lead to increased understanding of the phosphorus reduction measures required to restore and protect water quality and ecosystem health.

Numerous research and monitoring programs have been conducted over the years in south-eastern Georgian Bay. Yet, despite the geographic size, complexity of environmental issues, and the many jurisdictions involved in resource management, no synthesis exists that summarizes science and monitoring program activities and results for the aquatic environment. A gap analysis has also not been completed to determine key information needs and to prioritize future research, phosphorus reduction, monitoring, and restoration activities in south-eastern Georgian Bay. The purpose of this report is to synthesize research and monitoring activities and results, and identify information gaps and priority areas for focused science and monitoring for the southern and eastern regions of Georgian Bay.

The Study Area

The geographic area for this synthesis consists of the coastal ecosystem west of Highway 400/69 north to the French River, the watersheds draining into Severn Sound and the Nottawasaga Valley watershed draining to Nottawasaga Bay (Fig. 1).

Figure 1 Geographic scope of the Clean-Up Fund

The enormous recreational potential of this region was recognized early as shown by establishment of resorts in the 1880s and publication of a vacation guide in 1896 (Sly and Munawar, 1988). Its iconic natural setting continues to be highly valued for recreation by Canadian and U.S. citizens: this represents an important economic input to the area.

There may be a romantic notion that the Georgian Bay area is a pristine wilderness. However, there is increasing uneasiness that the area is threatened by changes in the quality of this water resource. Much of the shoreline is made accessible by roads and is now dotted by cottages, resorts, marinas, fishing camps and towns. The shoreline is highly altered in places and the cumulative impacts are to a large part unknown. Many of the inflowing rivers are controlled by dams and hydroelectric plants with potentially deleterious impacts to fish populations. The remaining natural qualities, however, are well worth preserving and improving.

The ***eastern Georgian Bay coast*** (Fig. 1) is an ecologically diverse landscape renowned for its rugged bedrock shorelines and profound beauty. It is a mosaic of vast gneissic rock lands, forested moraines and sand plains, thousands of islands, beaver ponds, marshes and peat lands. The 36,000 islands form the largest freshwater archipelago in the world. In 2004, the United Nations Educational, Science, and Cultural Organization designated the coast as the "Georgian Bay Littoral World Biosphere Reserve" in recognition of its significance. Major tributaries include the French River draining Lake Nipissing, the Musquash and Moon Rivers draining Lake Muskoka, and the Magnetawan River. Soil cover of the Precambrian bedrock by the thin acidic soil is sparse and variable (Sly and Munawar, 1988) and the local runoff water is yellow/brown and generally nutrient poor with low dissolved solids (salts) (Scheifer and Scheifer, 2010. Some of the bays such as Parry Sound are large enough to contain many smaller sheltered bays and finger lakes. Some bays are long and narrow with restricted water exchange with Georgian Bay. The area is characterized by a low human population but extensive cottage development. The largest population centre is the town of Parry Sound.

The ***Severn Sound watershed*** covers an area of approximately 1000 km2. The Severn Sound basin is a complex of sheltered and exposed bays ranging from two to four m deep in the eastern end to a 43 m deep basin off the northern end of Beausoleil Island where the Sound meets Georgian Bay (SSRAP, 2002). The nearshore zone consists of many embayments, submerged reefs and a variety of substrates with areas of dense aquatic vegetation that provide habitat for shorebirds, waterfowl, and fish. The shallow, relatively nutrient rich waters, combined with geological transition zones from sedimentary to Precambrian, create ideal conditions for fringing wetlands and a diverse fish community. The headwater streams are of fair to good water quality, and forest cover and wetlands are generally of good quality (NVCA, 2007). The main water source to Severn Sound is the Severn River. Several smaller rivers and creeks drain the remaining subwatersheds (e.g., Coldwater River, Sturgeon River, Wye River, North River, and Hogg Creek) (Fig. 2).

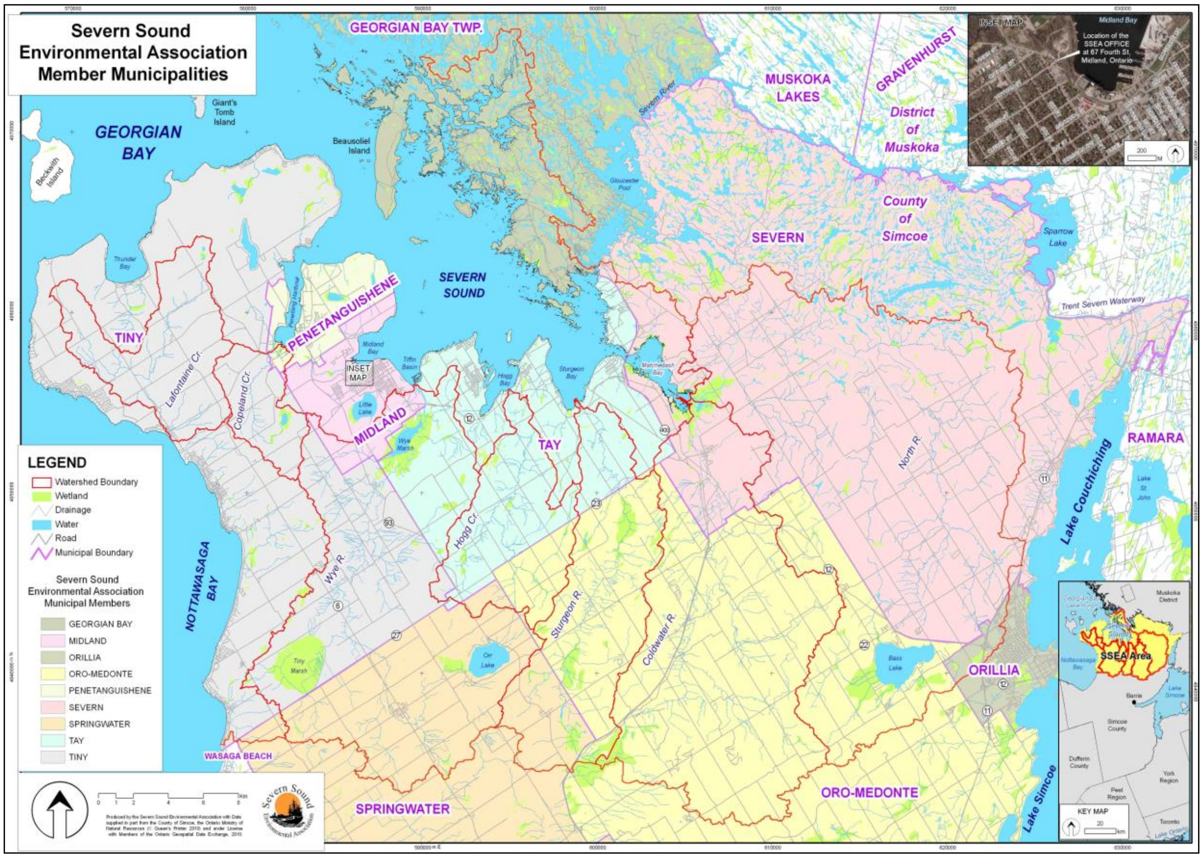


Figure 2 Severn Sound subwatersheds and major tributaries.

Severn Sound was one of the 17 Canadian Areas of Concern (AOCs) in the Great Lakes. Remediation was considered complete in 2002 with the provision that monitoring continue. Severn Sound was de-listed as an AOC in 2003.

Nottawasaga Bay and its watersheds (Fig. 3) lie at the southern end of Georgian Bay where Precambrian geology gives way to glacial till and large sand beaches (Sly and Munawar, 1988) and the Niagara Escarpment begins (Scheifer and Scheifer, 2010). The nearshore margins of Nottawasaga Bay are characterized by the widespread presence of sand sheets that account for approximately 90% of the total area mapped. Existing coarse substrates suitable for lake trout and whitefish occur as narrow discontinuous shore parallel zones and shoals throughout the nearshore region (Eyles and Mohr, 2006). The Nottawasaga Valley watershed is mostly rural with several growing urban centres such as Alliston, Wasaga Beach, Shelburne, Midhurst and Collingwood. Agriculture dominates land use but natural areas of forest and wetlands are a significant portion where land is not suited for agriculture. Wetland and forest condition is generally good.

Figure 3 Jurisdiction of the Nottawasaga Valley Conservation Authority.

Water quality is good in much of the watershed but is impacted by agriculture and urban loads of nutrients and sediment in three of the 10 sub-watersheds. The Nottawasaga River is the largest river draining the watershed (drainage area of 3,361 sq. km) with 6 primary tributaries: the Boyne River the Mad River, the Pine River, Innisfil Creek, Bear Creek, and Willow Creek (NVCA, 2005).The main branch of the river's source is in the till moraines of Amaranth Township.

1.2 Science and Monitoring Coordination

Various government agencies and non-government organizations conduct monitoring and research in Georgian Bay.

Environment Canada conducts open lake cruises to provide information on water quality in the Great Lakes. The main objectives of the Great Lakes Surveillance Program are to ensure compliance with water quality objectives, evaluate water quality trends and identify emerging issues. The Surveillance Program is delivered as part of Canada's commitment to the Canada-United States Great Lakes Water Quality Agreement. The Program also responds to the needs of the binational Cooperative Science and Monitoring Initiative, the Lakewide Management Plans, the Binational Toxics Strategy and the Integrated Atmospheric Deposition Network. The Great Lakes Surveillance Program has monitored water quality in the Great Lakes for over 40 years. Environment Canada (EC) also conducts research and modeling on water movements, beach contamination, algae ecology, and nutrient processing.

Department of Fisheries and Oceans (DFO) conducts surveys of fish habitat and fish populations to calculate biotic integrity indices as a way of assessing fish response to management.

The **Ontario Ministry of Environment (MOE)** periodically collects water quality information over the coastline of Eastern Georgian Bay as part of the Ontario Ministry of the Environment's Great Lakes Monitoring program. Surveys of nearshore sites in eastern Georgina Bay are conducted on a six year cycle as part of the Great Lakes Nearshore Index/Reference network. Ten nearshore sites are monitored periodically for a wide range of environmental features including water quality, sediment quality, benthic invertebrates, and limnological and habitat features as part of a suite of ~70 stations throughout the Great Lakes. Question-focused and needs-driven studies are conducted periodically. From 2003 to 2005, approximately 135 locations distributed over the whole of Eastern Georgian Bay were surveyed for nutrients and other water quality features as part of synoptic survey to characterize the range of water quality conditions. Sites based on key geographic features resulted in a dataset representative of the diverse physiographic conditions of the land-water-human interface of Georgian Bay. During 2006 and 2007, sites in Sturgeon Bay (North part of eastern Georgian Bay near Pointe au Baril), an embayment subject to deleterious cyanobacteria (blue-green algae) blooms, were surveyed in a joint MOE and EC study. The purpose of the study was to document the characteristics of the phytoplankton in this embayment to help better understand the conditions that lead to cyanobacteria blooms.

The **Ontario Ministry of Natural Resources (OMNR)** conducts research and monitoring on fish populations and fish habitat. OMNR sets fish harvest quotas serving both commercial and recreational fisheries.

The **Severn Sound Environmental Association** (SSEA) is a Joint Service Board under the Municipal Act (Section 202). It was originally founded in 1997 as a partnership between federal, provincial and municipal partners to support the completion of the Severn Sound Remedial Action Plan and to provide a local, community-based environmental office in the Severn Sound area. The SSEA provides continuing support to the federal and provincial agencies, but particularly to the local municipalities, to sustain environmental quality and to ensure continued protection through wise stewardship of Severn Sound and its tributaries.

The Nottawasaga Valley Conservation Authority (NVCA) provides a complete range of water shed health monitoring for the entire Nottawasaga Valley system and the 10 sub-watersheds throughout the area of jurisdiction. The NVCA conducts regular spring-fall monitoring of water quality, benthic populations, *E.coli*, ground water, endangered species (e.g. lake sturgeon) fisheries population and habitat at 18 stations throughout the watershed. Hundreds of stewardship initiatives are carried out to restore and protect water quality, habitat, and fisheries. NVCA continues to update coastal wetland mapping and work with partners on a variety of related initiatives such as natural heritage system planning and invasive species monitoring.

Georgian Bay Forever (GBF), formerly the GBA Foundation, is a registered Canadian charity. The GBF provides a community response to the growing need for scientific research and public education on Georgian Bay's aquatic ecosystem and the environmentally sustainable quality of life its communities and visitors enjoy**.** Through conferences, newsletters and other communications GBF is educating communities and the responsible government bodies about the threats—and their solutions—facing Georgian Bay. By teaming up with other non-profit organizations, universities, colleges, government departments and agencies GBF advances the reach of their research and strengthen its credibility.

Dr. Pat Chow-Fraser of **McMaster University** has a long history working in Georgian Bay. She and her students have developed ecological indicators for wetland water quality, fish communities, and macrophytes. Many of the coastal wetlands have been delineated to estimate aerial extent using remote sensing and geospatial tools and over 100 coastal wetlands have been assessed using a suite of indicators.

2.0 Summary of Research and Monitoring

2.1 Offshore Water Quality Monitoring

There are two sources of water to the south-eastern Georgian Bay nearshore and its embayments; the open water system (offshore) of the Bay and the tributaries that act as conduits of nutrients and sediment from inland watersheds. Fundamental differences between the two sources depend on local geology. While Georgian Bay water tends to have a higher dissolved solids concentration (salts) as shown by, for example, electrical conductivity, the tributary waters tend to have lower dissolved solids, lower pH, conductivity and somewhat higher nutrient concentrations.

The deeper offshore area develops a thermocline that divides the water vertically into the warm surface water (epilimnion) and cold bottom water (hypolimnion). During the summer period the water is said to be “thermally stratified” and the density difference between the two thermal layers inhibits mixing. Many smaller bays are deep enough to stratify. During the summer stratification period the biota in the hypolimnion consume oxygen which is not replaced by contact with the atmosphere through surface mixing. The oxygen consumption rate is determined by the supply of organic carbon from external (watershed) and internal sources (lake productivity or trophic state), the water temperature and the depth. The properties of nearshore and bay water are determined by the degree of input from tributary and alongshore sources and mixing between the offshore and nearshore waters. With vigorous mixing during windy conditions, nearshore water may be indistinguishable from offshore water. During quiescent conditions a gradient may develop at the shoreline. The latter is aided in some places by extensive shallow areas or shoreline alterations such as groynes that impede water movement. Embayments may or may not have much water exchange with open water. These isolated embayments can develop properties quite different from the open water.

The offshore waters of Georgian Bay is not a contributing factor to water quality problems (e.g.: nutrients) in the nearshore or embayments. The distribution of total phosphorus concentrations in Georgian Bay (2009) represents oligotrophic or nutrient poor water (Fig. 4). Parry Sound and the tip of the Penetanguishene Peninsula show the highest concentrations which are still low in the oligotrophic range. Moreover, there has been a decline in the concentration of this important nutrient in the open waters of Georgian Bay (Fig. 5). Phosphorus load reduction measures initiated in the mid-1970s as part of the Great Lakes Water Quality Agreement have led to significant reductions of total phosphorus concentration throughout the Great Lakes system (Dolan and Chapra, 2012). Of course, in the 1970s, we never anticipated the entry and impact of invasive zebra mussels on the system. The phosphorus decline in more recent years may be less influenced by a nutrient loading reduction; rather it is thought to relate to a change in biological processing of phosphorus (Barbiero et al. 2009, Nalepa et al. 2009).

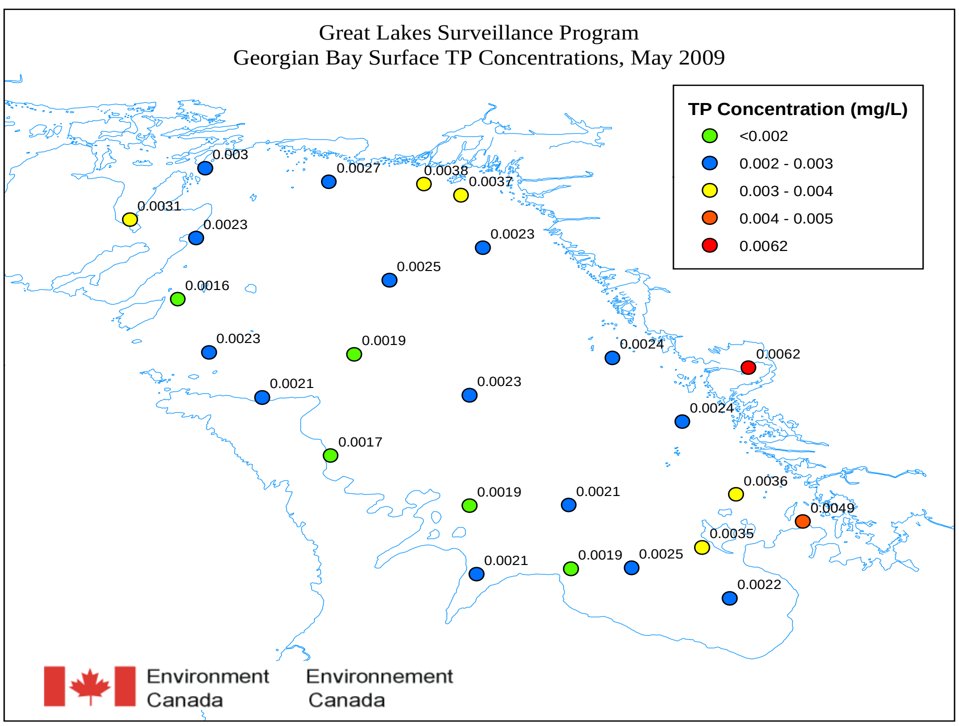


Figure 4 Georgian Bay spatial trend of phosphorus concentrations.

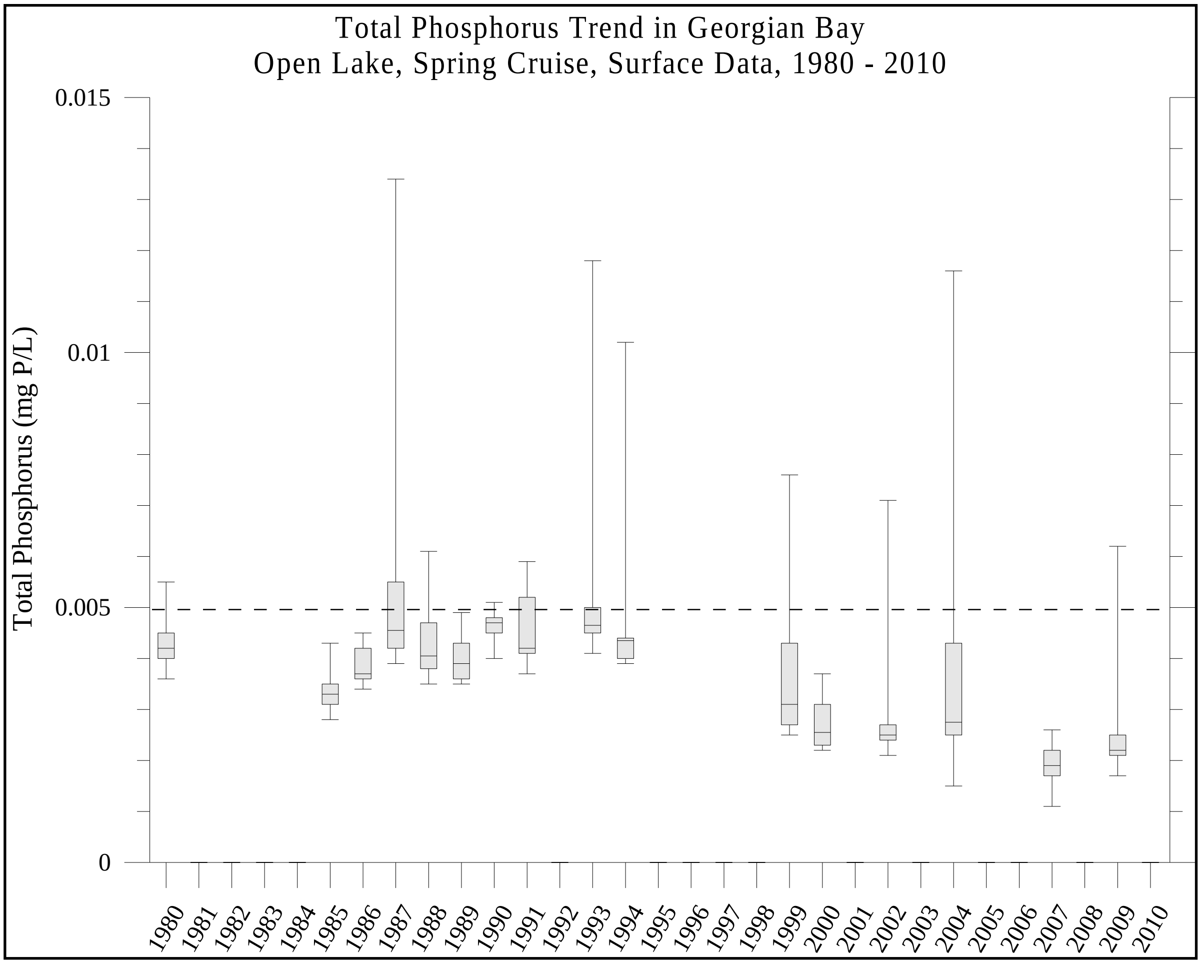


Figure 5 Georgian Bay temporal trend of phosphorus concentration. Data are represented by the maximum, third quartile, median, first quartile and the minimum.

2.2 Nearshore Water Quality Monitoring

2.2.1 French River Water Quality

There are concerns about high phosphorus concentrations and cyanobacteria blooms in the French River. This River, with its channels and islands, extends from Lake Nipissing to Georgian Bay and is usually thought of as a pristine wilderness. The source water in Lake Nipissing is mesotrophic with average phosphorus concentrations of 11µg/L in the period 1988 to 1990 and 16 µg/L in 2003-2004 (OME, 2012). Somewhat lower concentrations are sometimes found in the outlet area (Neary and Clark, 1992).

An algal bloom occurred in the Wolseley Bay area in 2007 (French River Watch and French River Stewardship Council web sites). Phosphorus data from OMOE's Lake Partners Program are provided by the French River Watch. Scattered throughout the data are several concentrations higher than 15 µg/L, a few exceed 20 µg/L, and fewer exceeded 30 µg/L. The highest concentration (37 µg/L) was recorded in Wolseley Bay (Sturgeon Bay portion) 33 Km east of Hwy 69. Apparently, a sewage lagoon system at the town of Noelville drains into a tributary of Wolseley Bay. The French River Watch website coordinator seems most concerned about the sewage lagoon; however, agriculture activity and a golf course may contribute phosphorus as well. It is difficult to be certain if any change in the river occurs at Wolseley Bay from the data, but the frequency of elevated concentrations seems higher in this area than upstream locations. At an upstream station three of 18 water samples exceeded 15 µg/L of phosphorus while one of those was higher than 30µg/L. In Wolseley Bay, 18 of 36 samples were higher than 20 µg/L, and three exceeded 30 µg P/L. Sporadic high concentrations occur as far downstream as 17 Km west of Hwy 69. There, 10 out of 24 samples were greater than 15 µg P/L and three were higher than 20 µg P/L. The data suggest sporadic pollution or flow events that warrant synoptic surveys and, if verified, an investigation of the cause(s).

2.2.2 Eastern Georgian Bay Water Quality

Differences between the offshore, nearshore and embayments were well characterized in an extensive eastern Georgian Bay water quality survey by the MOE from 2003 to 2005 (Diep et al. 2007). The survey included 135 stations with each station visited once in spring, summer and fall beginning from Killarney to Honey Harbour. Water samples were analyzed for a suite of nutrients, ions, conductivity, pH, turbidity, and chlorophyll *a* and it was determined whether stations were stratified. The survey allowed a spatial comparison of offshore, nearshore and embayment water quality as it progressed from north to south along the shore.

Inshore-offshore gradients were found with lower conductivity, alkalinity, pH and higher nutrients and chlorophyll *a* in the inland embayments. Locations close to watersheds had water with lower ion concentrations. With a median total phosphorus concentration of 5.4 µg/L and annual averaged total phosphorus level ranging between 2.0 and 22.0 µg/L, locations sampled for this study ranged from oligotrophic to meso-eutrophic, with the majority of locations in the oligotrophic range. Locations that are considered meso-eutrophic and exceed the Provincial Water Quality Objective (PWQO) of 20 µg/L, set for the prevention of nuisance concentrations of algae in lakes, are located within the Sturgeon Bay area (Fig.6). Epilimnetic total phosphorus concentrations exceeded 10 µg/L in one or more of the three samples at 34 of the 135 stations. Seasonal differences between samples were also noted. There was a gradient between open water stations and enclosed embayments that indicates increasing hydrological isolation of embayments the further they extend from open water. Thus, embayments develop conditions of their own depending on the watershed inputs, morphometry, shoreline development and the extent of exchange with open water.

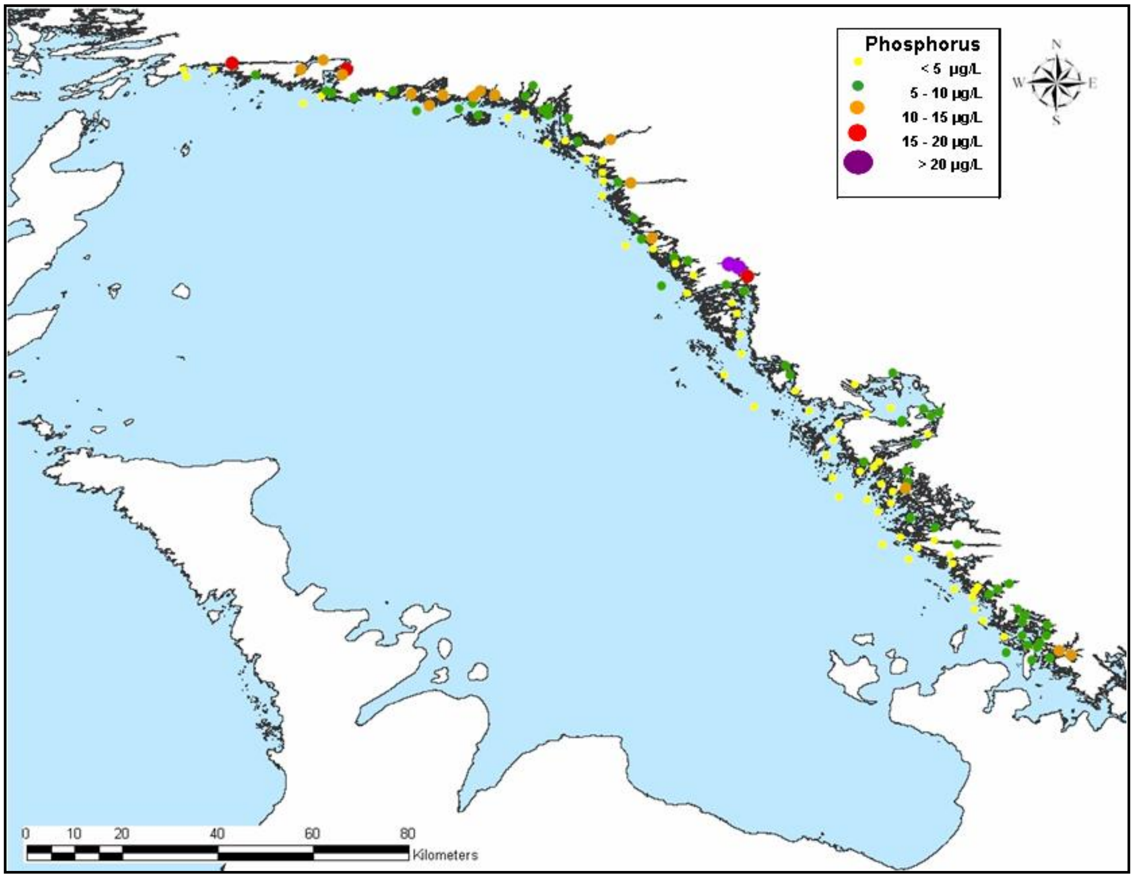


Figure 6 Spatial map of annual total phosphorus (TP) concentration for all locations sampled for the Georgian Bay Water Quality Study (2003 – 2005).

2.2.3 Township of Georgian Bay Water Quality

A variety of water quality monitoring programs has taken place over the years by the Township of the Archipelago, the Township of Georgian Bay, and the District Municipality of Muskoka (DMM). For the most part the programs extend from the late 1990s or early 2000s and focus on perceived or known trouble areas as well as other areas of interest to recreational users. Most of the data show oligotrophic water with little evidence of bacterial contamination. A good deal of the data are summarized in a water quality monitoring summary report (WQMSR) for the period 2001 to 2009 (Schiefer and Schiefer, 2010). As well, there is a report on benthos indicators of water quality (Griffiths and Muter, 2003) and a report from SSEA on water quality in the North and South bays of Honey Harbour (Chiandet and Sherman, 2010).

Areas with water quality problems were also highlighted in a study that compiled the problems and examined causes (HESL, 2010) (Table 1). The problematic embayments are relatively isolated from open Georgian Bay and are deep enough to stratify and produce oxygen depletion and phosphorus enrichment of hypolimnetic water. There are insufficient data in most cases to determine long-term trends that would show conditions worsening over time from stresses such as shoreline development. For example, no data exists to determine whether or not oxygen depletion in some of the deeper and more isolated bays is a recent phenomenon or something that has occurred since pre-settlement times. At present, water quality doesn't seem to be changing rapidly. The causation study pointed out that direct links between water quality problems and putative causes are often not available. This is an important finding that indicates that more information is required to manage the problematic areas. Some light may be shed on the issues by paleolimnological studies and by back casting nutrient conditions with the Lakeshore Capacity Model (Patterson et al. 2006).

Table 1. Summary of observed conditions perceived as being deteriorated or unacceptable. Water Quality Monitoring Summary Report 2001 to 2009 indicated by WQMSR and Report on Water Quality in the Honey Harbour Area of Georgian Bay indicated by WQHH (from HESL 2011).

AREA	SOURCE	OBSERVATION	LINKED TO CAUSE
Honey Harbour (HH), North Bay (NB), Honey Harbour South Bay (SB), Go-Home Bay (GHB), Twelve Mile Bay (TMB), Cognashene Lake (CL), Severn River, Port Severn, and Church Bay of Honey Harbour			
All	WQMSR	1. Water quality addressed as the number 1 concern in opinion surveys.	na
HH,NB,SB,GHB ,TMB	WQMSR	2. Lakeshore development has caused TP levels characteristic of more advanced eutrophication (3.8).	no
SB	WQMSR	3. Filamentous algal growth on nearshore rocks as a result of eutrophication (3.8, 4.24).	no
HH	WQMSR	4. Water clarity declines from 8m in Geo Bay to 3m in Honey Harbour (3.8)	no
NB,SB,TMB,CL	WQMSR	5. Dissolved oxygen depletion as symptom of eutrophication (levels severe in NB,SB due to eutrophication)	no
NB,SB,	WQMSR	6. Cold water fish scarce in areas with degraded water quality. Habitat suitability described but cause not identified	yes/no
ALL	WQMSR	7. low water levels are aggravating water quality conditions (3.8)	no
Severn River	WQMSR	8. Higher TP at Port Severn due to Lakeshore development in Little Lake and Port Severn	no
Port Severn	WQMSR	9. Increased Aquatic Plant growth due to higher nutrient loadings	no
TMB	WQMSR	10. Higher TP levels in east indicative of development. 11. Declines in clarity from mouth to east end	no
CL	WQMSR	12. P sediment release in Cognashene linked to many decades of lakeshore development	no
HH(south)	WQMSR	13. High bacteria counts due to human activity	no
Church Bay	Griffiths	14. Indications of degraded water quality by invertebrate community structure in some area including Church Bay. Abundant aquatic vegetation and periphyton indicated with rapid accumulation of material.	Yes?
All	SSEA*	15. **These areas should be considered sensitive to significant inputs of phosphorus**	no
HH	SSEA	16.Declines in water clarity in recent years (25) – no explanation	na
ALL	SSEA	17. Phytoplankton shift to dominance by Chrysophytes with an increase in diversity between 1998 and 2008.	na

The WQMSR summarized nutrient data from several stations over 2001 to 2009 for problem prone Twelve Mile Bay, Go-Home Lake, Cognashene Lake, North and South Bays of Honey Harbour. In addition to the chemistry sites bacteria data were gathered from Wah

Wah Taysee, Gibson Lake, Six Mile Lake, Gloucester Pool, and Severn River. Information on oxygen and temperature profiles and sonar information on fish abundance was included.

Twelve Mile Bay results indicated that water clarity decreases and phosphorus increases from 4 to 6 μg/L to 11-16 μg/L with distance from the mouth at Georgian Bay. Oxygen depletion occurred in the hypolimnion of the east end, furthest from the mouth, to the extent that fish were excluded and phosphorus was regenerated from sediment. Data were available beginning in 2002.

Go-Home Bay is flushed by the Go-Home River and Georgian Bay. Water clarity declined from 7m in Georgian Bay to just over 3m in the "inner bay". Phosphorus concentrations were generally low but one of the seven stations had a multi-year mean of 13.6 μg/L. Go-Home Bay is too shallow to stratify.

Cognashene Lake is another isolated bay with a connection to Georgian Bay. Conductivity decreases from the connection to the north and east bays consistent with less and less influence from Georgian Bay. That influence, however, is substantial because the overall conductivity is not different from that of Georgian Bay. Phosphorus was generally low with many values a few μg/L higher than Georgian Bay, increasing to 5 to 10 μg/L at some stations and 14 to 16 μg/L depending on water levels and degree of flushing. Oxygen depletion in the hypolimnion occurs with exclusion of cold water fish and release of sediment phosphorus.

North and South Bays of Honey Harbour have small watersheds; South Bay receives some water from Baxter Lake fed from the Severn River system. Conductivity is similar to that of Georgian Bay. Phosphorus concentrations, however, are higher than both Georgian Bay and Baxter Lake. Growths of filamentous algae have been observed. Oxygen depletion in the hypolimnion occurs with exclusion of coldwater fish and sediment phosphorus regeneration. The latter phenomenon occurs when iron-phosphorus compounds in sediment break down due to very low oxygen concentrations. The phosphorus is released in a soluble form that is capable of stimulating algae if it mixes into surface water.

Lake Simcoe and Lake Couchiching are not sources of excessive phosphorus concentrations to Georgian Bay; however, by the time the Severn River enters Georgian Bay at Port Severn, the surface water may have acquired much more phosphorus than one would expect. Several monitoring attempts have yielded inconsistent results over the years. In 2003, the outlet concentrations of Lake Couchiching ranged from 9 to 10.4 μg/L (SSEA 2005). In 2011 the phosphorus concentration in the Severn River averaged 12.6 μg/L and in Gloucester Pool was 11.7 μg/L in 2005-2010 and 9.4 μg (Lin, 2011,Wianko, 2011). The WQMSR, however, shows a phosphorus concentration in the Severn River at Port Severn of 21 μg/L averaged over 2001 to 2009. Other data collected in September of 2002 (39 μg/L), May 2003 (8 μg/L), October 2003 (8 μg/L) were noted in the 2003 report (Schiefer, 2003). The high September 2002 phosphorus concentration of 39 μg/L was repeated in the 2005, 2006, and 2007 reports; concentrations of 13 to 15 μg/L were found at Port Severn in September 2007. The difference between high and low values was attributed to change in residents' activities. More regular monthly sampling by SSEA in the period 2002 to 2009 resulted in an average summer phosphorus concentration of 12 μg/L (K. Sherman, SSEA, personal communication). The higher concentrations and the apparent increase in phosphorus over a short stretch of waterway should be investigated to determine whether they can be confirmed. If so the cause should be determined.

2.2.5 2009 Volunteer Bacterial Water Quality Monitoring Program (in WQMSR)

The program pertains to recreational water only and uses an indicator bacteria Escherichia coli (*E. coli)* selected by the Ministry of Health to assess the risk that swimming areas may harbor waterborne pathogens of fecal origin.. Water samples were collected bi-monthly at several sites in each region with some additional sampling after significant rainfall events. The Provincial standard for recreational water is 100 colony forming units (cfu) of *E. coli* per 100 mL of water. The background in the general area is less than 5cfu *E. coli* / 100mL. The Georgian Bay Association (now Georgian Bay Forever) and scientists working on these reports feel the Provincial standard is not restrictive enough for high quality water and have therefore chosen 10cfu *E. coli* / 100mL as their water quality objective. Most of the samples met the local objective and few exceed the Provincial standard.

Eleven sites were sampled six times in Honey Harbour South. Four of the 66 samples exceeded the Provincial standard while 26 samples were less than the local objective. Eight stations were sampled once in Honey Harbour North; all results were below the local objective. The Cognashene area was sampled five times at eight stations; one sample exceeded the Provincial standard and most were below or close to the local objective. Of particular note are results for a bay at Bone Island frequented by boats (Vanderhoof, 2001). All 5 five samples were below the local objective. The Go-Home Bay area was sampled six times at 14 stations. Three samples exceeded the Provincial standard; two of these were in a bay frequented by large live-aboard boats. The other four samples in that bay were zero or close to zero. All samples in the Wah Wah Taysee area were below the local objective. Samples at eight sites on two dates in Twelve Mile Bay were all below the Provincial objective. The Go-Home Lake area was exemplary with only one sample out of 42 exceeding the local objective. The 48 Gibson lake samples were mostly below the local guideline and all were below the Provincial guideline. Most of the 70 - Six Mile Lake samples were below the local guideline. Many of the Gloucester Pool samples were below the local objective and all were below the Provincial objective. Most of the Severn River samples were below the local objective and all were below the Provincial standard. Around Honey Harbour one of 30 samples exceeded the Provincial standard with several samples above the local objective.

Sampling surface waters for the presence of *E. coli* to determine the risk that recreational use of the water may result in waterborne illness is important. The methods used to date did not, however, distinguish between *E.coli* from wildlife and *E. coli* from humans which might indicate the possibility of human pathogens. While the bacterial results are within provincial and regional limits, the current programs do not pin point sources, their zone of influence (due to circulation or mixing) or detect temporal changes. Modeling may be of use in this regard.

2.2.5 District Municipality of Muskoka (DMM)

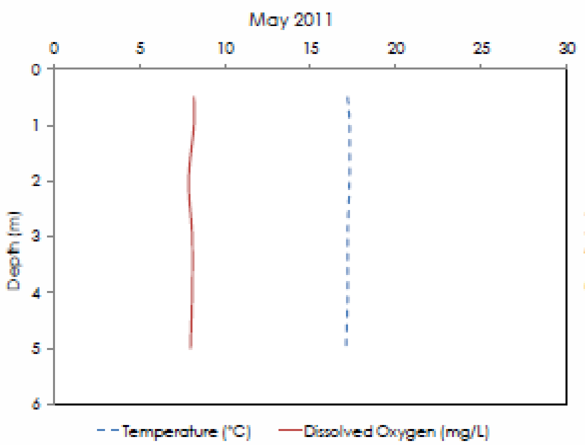
The DMM has conducted a water quality monitoring program since 1980. A suite of nutrients and ions as well as Secchi depth and oxygen are monitored at 193 sites in 164 lakes on a rotational basis during spring. Shoreline land use surveys are conducted in June and July and benthic macro-invertebrates are sampled from May to August. Some lakes are sampled in late summer for oxygen depletion. In 2011, the DMM program visited 12 lakes or bays in the Township of Georgian Bay including Cognashene Bay, Little Go-Home Bay, North Bay, South Bay and Wah Wah Taysee (DMM 2012).

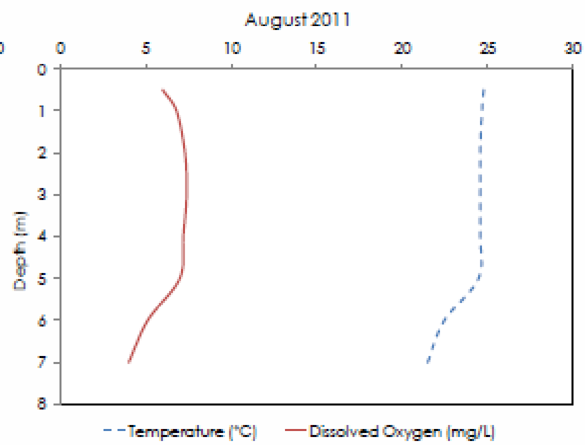
The DMM program publishes "Lake Data Sheets" (http://www.muskokawaterweb.ca/lake-data/muskoka-data/lake-data-sheets) which highlight recent and historic oxygen and temperature data, total phosphorus, depth, Secchi depth, an estimate of "sensitivity" and the area of the watershed and the water body. DMM models background concentrations of phosphorus and calculates a threshold which is the background plus 50%. Examples of Lake Data Sheets are shown for Little Go-Home Bay in 2010 (Fig. 7) and Baxter Lake in 2010 (Fig. 8). Little Go-Home Bay receives water from Gloucester pool (Severn River) and passes the water on to Baxter Lake eventually draining to South Bay of Honey Harbour. The DMM program revealed that phosphorus concentration more than doubled in Little Go-Home Bay between 2004 and 2012. The deeper Baxter Lake had somewhat higher phosphorus concentrations initially but has also increased in the last two sampling years. The August oxygen profile is interesting because it shows that considerable oxygen depletion can occur even at moderate to low phosphorus concentrations. In May, however, the oxygen concentration was already depleted by about 50% and this seems to be unusual. *This and similar bodies of water should be checked at ice out and monitored in the spring to determine whether they actually mix and that the water is equilibrated with the air.* If the lakes do not mix sufficiently in spring to cause oxygen equilibration they will begin the stratified summer season with decreased oxygen concentrations that confuse the meaning of the end of summer measurements. *This situation could be clarified by several oxygen profiles during the summer so that oxygen depletion rates could be calculated and compared with other lakes in the area taking into account morphometric and temperature data (Charlton, 1980).*

The DMM has a significant data set. Each sampling location should be examined for trends and the results summarized if this has not already been done. The causes of the low dissolved oxygen and increasing phosphorus in Little Go-Home Bay and Baxter Lake should be investigated.

Little Go-Home Bay

Municipality:	Georgian Bay	Watershed:	West
Surface Area:	1.1 km²	Watershed Area (excluding lake):	4.3 km²
Maximum Depth:	12 m	Lake Trout Lake?	No
Wetland Area:	10.56 %	Secchi Depth (10-year average):	4.6 m
Phosphorus (10-year average):	11.0 µg/L	Sensitivity:	Moderate





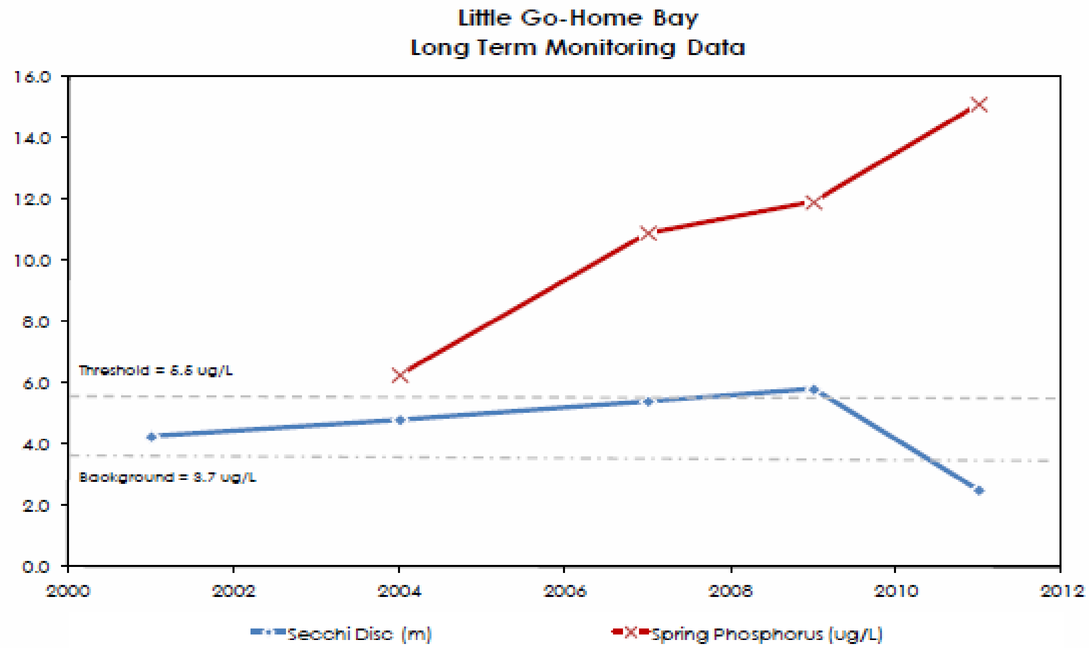
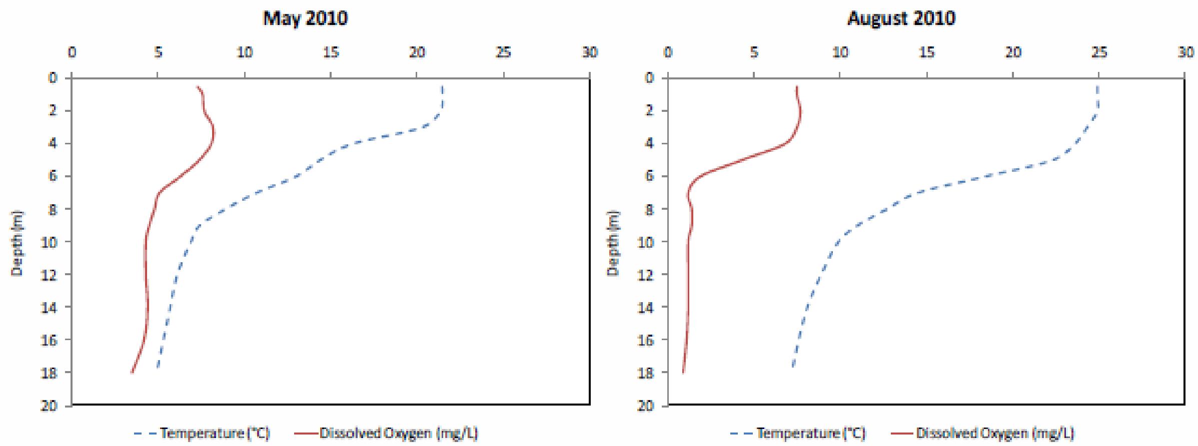


Figure 7. Example of data sheet for Little Go-Home Bay.

Baxter Lake

Municipality:	Georgian Bay	Watershed:	West
Surface Area:	0.45 km^2	Watershed Area (excluding lake):	2.3 km^2
Maximum Depth:	16 m	Lake Trout Lake?	No
Wetland Area:	4.13 %	Secchi Depth (10-year average):	4.5 m
Phosphorus (10-year average):	10.2 µg/L	Sensitivity:	Moderate (OT)



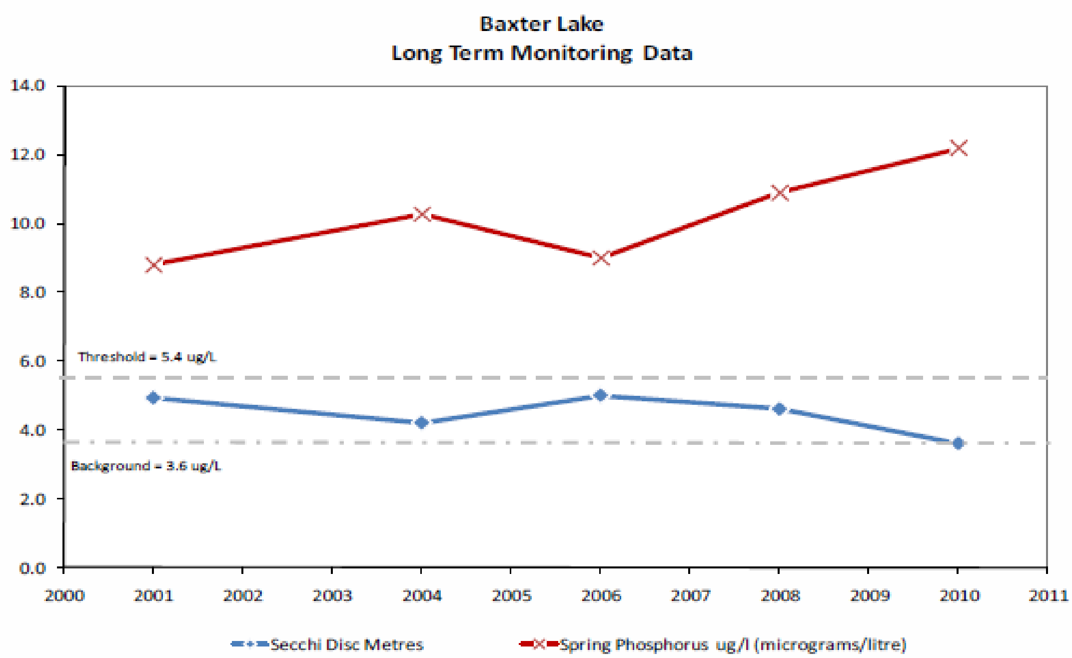


Figure 8. Example of data sheet for Baxter Lake.

2.2.6 Township of the Archipelago

A volunteer water quality monitoring program has been in place since 1999 (Township of the Archipelago, 2012 a,b) for several sites in each of Sturgeon Bay, Woods Bay, South Channel area, Skerryvore area, Pointe au Baril Islands, Bayfield Inlet, and the Sans Souci area. This program has chosen a bacteria local objective of 10 cfu/100mL.

Water clarity was relatively poor at 1 to 3.5 m in Sturgeon Bay due to cyanobacteria blooms. Wood Bay clarity was 3 to 4 m while South Channel clarity ranged from 2.9 to 6.5 m. Clarity in the Pointe au Baril Islands area ranged from 3 to 8.5 m and clarity in the Sans Souci area ranged from 4.9m in some enclosed bays to 12.5 m in more open areas (Township of the Archipelago, 2012b).

Bacterial results for *E. coli* were generally good with a mean for seven sites on four dates of 5.5 cfu/100mL in the Sans Souci and the mean for seven sites and seven dates was 4.7 cfu/100mL in the Woods Bay area. The average for 14 stations on five dates in the South Channel area was 8.4 cfu/100 mL with two samples higher than the Provincial standard. In Sturgeon Bay samples at 14 stations for five dates averaged 12.0 cfu/100mL with none over the Provincial standard. *E. coli* in the Skerryvore area averaged 20.7 cfu/100 mL with two samples higher than the Provincial standard at a “lagoon” site. In the Pointe au Baril area most of the 55 samples at 11 sites were below the local objective, one sample was higher than the Provincial standard and the mean was 9.9 cfu/100mL. Finally, in Bayfield and Nares Inlets the mean of 24 samples was 2.6 cfu/100mL with most samples at or below the local objective (Township of the Archipelago, 2012a).

Sturgeon Bay

Sturgeon Bay (Pointe au Baril area, Township of The Archipelago) appears to have the worst water quality problems in eastern Georgian Bay. Cyanobacteria blooms occur in the north basin, where phosphorus concentrations are regionally high and a deep water portion develops anoxia which excludes fish and causes phosphorus release from the sediment. This phosphorus may nourish vertically migrating cyanobacteria and increase the phosphorus concentration in the epilimnion. Blooms are also seen in other areas of the bay, and it is unclear if they originate from the deeper basin or develop locally. Sturgeon Bay is connected to Georgian Bay by a 15 km channel that largely isolates the north basin and to a lesser extent the south basin. The south basin also has cyanobacteria blooms but to a lesser extent perhaps consistent with lower phosphorus concentrations (Gartner Lee, 2007 and Township of the Archipelago, 2003).

Tributaries feeding the north basin have low summer flow but, overall, the water residency time is 1.4 years which is equivalent to a flushing rate of 0.7 times per year. (This is actually a rapid water replacement compared to some larger lakes. The faster the water replacement the more the lake will resemble the chemical qualities of the sources.) Unfortunately, the phosphorus concentrations of the tributaries are higher than those in the bay and thus represent a pollution source given the data available. Indeed, not only are phosphorus concentrations higher than regional expectations but even conductivity is higher in several of the creeks than would be expected generally in the area (Township of the Archipelago, 2003).

Higher than regionally expected phosphorus concentrations in the north basin of Sturgeon Bay are not a new phenomenon. The data, however, are insufficient to shed light on whether a particular event such as the beginning of development had any effect. A summary of the phosphorus concentrations in the north basin shows that, although the consensus seems to be that the intense algae blooms began around 2000, the phosphorus conditions seemed high enough to stimulate blooms before then (Table 2).

Table 2. Total phosphorus history in the north basin of Sturgeon Bay (Pointe au Baril). Sources: a OME in Township of the Archipelago, (2003), b Township of the Archipelago (2003), c Gartner Lee (2007), d Diep et al. (2007), e Schiefer (2008), f S. Watson, Environment Canada personal communication.

Year	Total Phosphorus μg/L
1978[a]	16.3 avg, max 21
1983[a]	15.7 avg, max 20
1998[b]	16 avg
2001[b]	25 avg
2003[b]	24 avg
2003[c]	20.5 ice-free
2004[c]	20.2 ice-free
2004[d]	22.0 avg, 24.3 max
2005[c]	18.1 ice free
2006[c]	17.6 ice-free
2008[e]	30
2009[f]	15.9

Data for the period 2003 to 2011 suggests that phosphorus concentration declined in recent years for the north bay, the bay at the Provincial Park, and in the Pointe au Baril Channel(Figs. 9, 10, and 11). Initial slopes determined for the north basin and Point au Baril Channel would have reached concentrations of zero by about 2016 and about 2014 respectively (Gartner Lee, 2007). Additional data from the Lake Partners Program of OME in Fig. 11 shows the concentrations may be still declining at a reduced rate.

The decline early in this data set was consistent with a regional phenomenon of phosphorus loss from lakes and watersheds (Yan et al 2008, Eimers et al. 2009, and Palmer et al. 2011). The phosphorus decline is thought to relate to acid rain and raises these questions:

- Did export from water sheds increase and cause the eutrophication concerns?
- Did the export then decrease and cause the present decline in phosphorus concentrations?
- What are the implications for future management of Sturgeon Bay and other isolated bays?

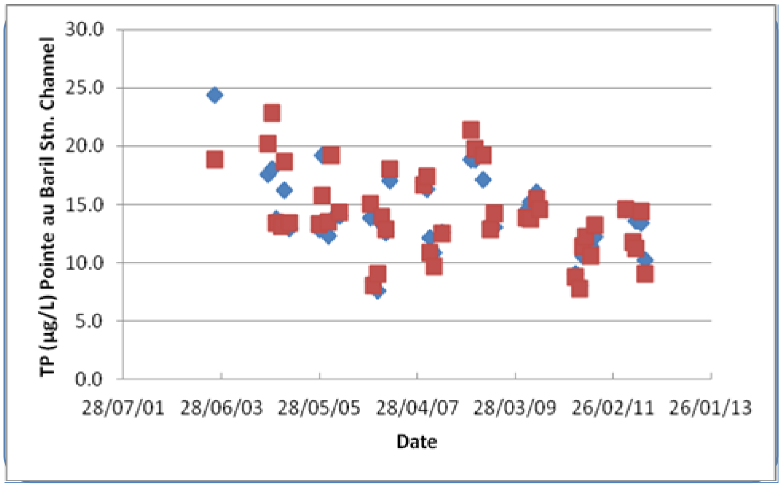


Figure 9. Total phosphorus trend within the north basin Sturgeon Bay 2003 to 2011.

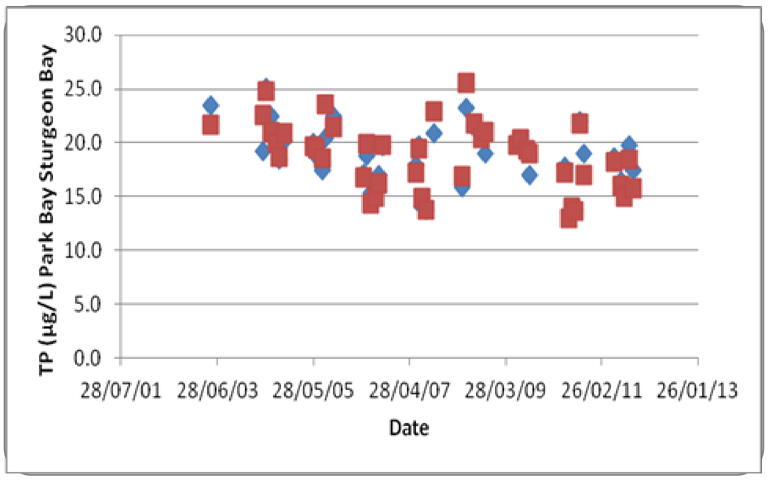


Figure 10. Total phosphorus trend within the Sturgeon Bay Provincial Park (2003-2012).

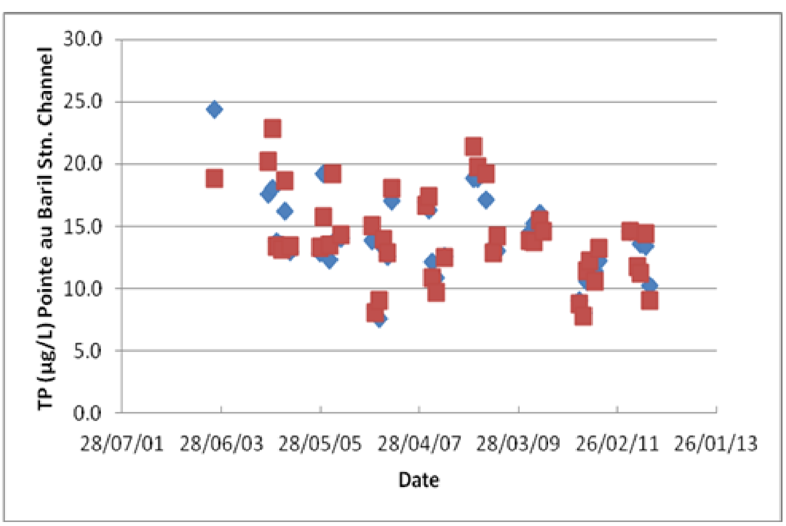


Figure 11. Total phosphorus trend at Pointe au Baril Station Channel 2003 to 2011.

The lowest phosphorus concentrations (< 15 ug/L) are in the Pointe au Baril Station Channel (south-east portion of the south bay). It is therefore tempting to assume that there would be low risk of water quality problems. The North Bay-Parry Sound District Health Unit, however, noted a cyanobacteria bloom in the Channel on October 19, 2012. Unfortunately, phosphorus concentrations for that time are not yet available but the incident illustrates two points: Blooms can occur at lower P concentrations than are present in the north basin and blooms can occur far removed from the north bay which is thought to be influenced by the internal loading or phosphorus regeneration from sediment.

Figures 9, 10, and 11 also show that there is an increasing phosphorus gradient between the south portion to the north basin and to the Provincial Park bay which is further north. One hypothesis to explain the gradient could be less exchange with low phosphorus water from Georgian Bay as Sturgeon Bay extends further north. Another hypothesis is that there is a nutrient source in the far north end of Sturgeon Bay. Both hypotheses should be tested.

Tributary Phosphorus

The few data available for tributary phosphorus are shown in Table 3. Most of the concentrations are at or above those that would be desirable in the bay water. Thus, tributary input does little to help reduce the trophic status of the bay. Indeed, tributaries are thought to be one of the largest external sources of phosphorus to Sturgeon Bay (Gartner Lee, 2008). The data are quite disparate, and it is clearly important to quantify the inputs of total and dissolved portions of the phosphorus load with a new sampling program.

Table 3. Tributary phosphorus data for the north basin of Sturgeon Bay.

Creek	Joy (2003) July, Aug 2002 TP µg/L	Joy (2004) July, Aug 2003 TP µg/L	**No index entries found.**Township of the Archipelago (2003) Spring, Early Summer Mid-Summer, Lake Summer TP µg/L	S. Watson, Environment Canada, (2009) personal communication Mar, June, Sept TP µg/L
Cranberry Lake Cr.	N/A, 800	110, 140	20, 42, 30, 24	14, 44, 51
Sucker Cr.	N/A, 200	0, 170	18, 24, 23, 18	15, 23, 29
South Tributary			20, 86, 36, 36	
Sturgeon Bay Provincial Park	0, 450	50, 170	20, 110, 59, 28	18, 93, 37
Creek B	N/A, 500	10, 140		
Bird Lake Cr.				26

Internal Loading

In addition to the external phosphorus loads in land runoff, precipitation and dust fall, wetland drainage, and septic tank effluent, Sturgeon Bay's north basin experiences "internal loading" of phosphorus. This is a release into the water of phosphorus stored in sediment. The release, or regeneration, occurs under conditions of low oxygen which is common in the bottom water of small lakes that stratify. The low oxygen develops following summer stratification into two layers, the epilimnion and the hypolimnion. A transition zone called the thermocline occurs between the two layers. Density differences restrict the mixing of the layers and this allows the biota in the hypolimnion to consume all the oxygen. When the oxygen is low enough the weak iron-phosphate bonds of the sediment material break down and the phosphorus and iron dissolve into the hypolimnion water. Phosphorus concentrations can reach 100's of µg/L. The movement of the upper layer erodes the lower layers so that the position of the thermocline deepens as summer progresses. At the same time, heat is transferred downward and the water can even gain heat from the lake bottom. Finally, the inter-layer density difference is insufficient to maintain the stratification and fall mixing occurs.

Algal blooms (usually composed of cyanobacteria) begin mid to late summer as the hypolimnion layer is eroded and the upper layers are incorporating the phosphorus in the bottom layer which stimulates and causes the blooms. While the factors that influence this mechanism are not well resolved, it is a common cause of fall blooms in many stratified, productive lakes. This seemingly straightforward process is difficult to accept because the phosphorus from the bottom water doesn't appear to cause a pronounced concentration increase in the epilimnion (see graphs in Gartner Lee, 2007).

At the height of the 2006 summer the north basin hypolimnion contained 386 µg/L of phosphorus (Gartner-Lee, 2007). If a functional concentration of 250 µg/L is used to smooth out the variability it can be calculated from the hypsometric curve (Gartner-Lee, 2008) that there was as much phosphorus in the small hypolimnion as there was in the epilimnion of the north basin. Depending on assumptions made about the phosphorus content of the thermocline and assuming the epilimnion began with 20 µg/L, there was enough phosphorus in the bottom water to raise the entire water column to near 40 µg/L but this was not observed. It seems difficult to discern how much of the regenerated phosphorus actually entered the surface water and whether that was enough to cause a bloom. This may simply indicate the difficulty in sampling when much of the cyanobacteria may be formed into a surface scum.

The fate of the regenerated phosphorus has not yet been explained. For example, the concentration decrease in hypolimnion phosphorus during September and October 2006 has not been examined in terms of causative processes. One possible cause may have been re-precipitation of the phosphorus back to the sediments. The thermocline is not a barrier to diffusion so downward diffusing oxygen would enter a shrinking hypolimnion and maybe this could cause re-precipitation and sinking out of the phosphorus. Some phosphorus could diffuse upwards as well. Clearly, this is speculation until the chemical reactions are examined.

Methods to decipher the fate of regenerated hypolimnion phosphorus were outlined in the Mesolimnion Exchange Model by Burns, (1976). The model was developed so the transfer of materials between the layers could be estimated during the stratified season. By accounting for heat accumulation in the bottom layer as driven by conduction, temperature and volume changes between surveys the exchange of water between layers could be estimated. Later it was realized diffusion processes could be included. Use of a model system like that of Burns could give a scientific analysis of the fate of the regenerated phosphorus or "internal load". So far, this has not been done for Sturgeon Bay.

Is the "internal load" actually a load? We think of the runoff, septic leakage, and, precipitation coming in from outside the lake as net loads. For the "internal load", however, we see increasing, then decreasing phosphorus in the bottom layer of the bay with little evidence that it actually gets into the upper layer to cause algal blooms. How then is it a load like the others? Certainly, it is a recycling process. Fish excretion and macrophyte decomposition are also recycled but are not usually considered loads. The Lakeshore Capacity Model mimics Sturgeon Bay surface water phosphorus better if a term for anoxic phosphorus is included (Gartner-Lee, 2008). We cannot discern whether there is a deficiency in data used, assumptions in the model or a real need to include regenerated phosphorus without corroborating knowledge of the fate of that phosphorus.

Modeling is used to help estimate the relative phosphorus loads from septic systems, runoff, precipitation etc. Generic export figures are used for forested and non-forested areas along with generic relationships between lake depth, flushing and retention to indicate an ice free phosphorus concentration under various scenarios of human development. The Lakeshore Capacity Model can be used to estimate the amount of development that would eventually harm a lake based on phosphorus concentrations.

Sturgeon Bay is different in that it is already in a phase of coping and management of a degraded state. Therefore additional, more detailed methods may be needed. For example, septic systems seem to represent a minor load when lumped into an annual phosphorus budget derived from the Lakeshore Capacity Model (Gartner-Lee, 2008). Clearly, that is a very important finding. It would seem advisable then to examine the situation in more detail. For example, the flow from tributaries decreases markedly during summer (Township of the Archipelago, 2003) so their loads are likely to decrease then. At the same time cottage septic systems become fully utilized for the same season. A detailed investigation of phosphorus sources during summer should be conducted in order to confirm their ability to stimulate algal blooms.

Finally, there is the matter of what phosphorus concentrations are required for algal blooms. In the west basin of Lake Erie there is usually no hypolimnion but there are dreissenid mussels on the bottom that can recycle some phosphorus. In the mid-1990s cyanobacteria blooms began to re-occur. At that time the summer phosphorus concentrations offshore were between 15 and 20 µg/L (Lake Erie LaMP, 2010). Whether this observation is transferrable to other situations is unknown. The point is that ambient phosphorus concentrations such as have been seen in surface waters of Sturgeon Bay may have been high enough to support cyanobacteria blooms without invoking the unknown fate of "internal loading"; the recent bloom in the Pointe au Baril Stn Channel is consistent with this notion.

The situation, however, may be even more complicated than thought. Iron is released from sediment as part of the phosphorus regeneration process. Some of the iron in solution is an essential nutrient for cyanobacteria, which can access this iron by migrating down to assimilate it and then migrating back up to depths where there is more light. It is thought that the blooms do not occur until recycling of the iron during bottom water anoxia allows them to grow and dominate the algal population. This "phosphorus-ferrous eutrophication model" is being tested in Sturgeon Bay (Molot et al. 2012) and may result in new information on the extent of nutrient control required.

In general terms, the principal areas for future investigation to better understand the problem in Sturgeon Bay and other sheltered embayments consist of bathymetric mapping, characterizing and quantifying bottom sediment volume, source tracking of phosphorus (tributaries, wetlands, septic discharge), understanding the significance of organic matter on hypolimnetic oxygen depletion, the role of hypolimnetic dissolved oxygen and internal phosphorus loading, the interaction of iron on the structure and biomass of cyanobacteria populations and integrative modeling .

Aquaculture and Parry Sound

Parry Sound is home to Aquacage Fisheries Ltd which rears rainbow trout in cages for market. Concerns with fish farms are accumulations of waste on the lake bottom, nutrient pollution of water, and escapes of the caged fish. An early report (OME 1993) found no effects of the fish farm. In 2002, Environment Canada completed some water and bottom sampling near the fish farm. Very few data were collected but the results suggest that the majority of phosphorus concentrations in water samples close to the farm during the growing season ranged from 3 to 7 μg/L. A few higher concentrations of 12 and 15 μg/L were found in nearby Depot Harbour where the farm and stock are located during winter. The summer location is 50 to 70 m deep (45°19'14.29"N, 80°06'35.39"W). There were some indications of low level enrichment of sediment beneath the farm. Overall, the water quality near the fish farm was similar to that nearby in Georgian Bay at the time (J. Milne Environment Canada, personal communication). More recently Diep et al. (2007) found average phosphorus concentrations at six stations of 6.3 and 7.0 μg/L in Depot Harbour, 7.6, near the Seguin River, 9.7 at Seguin, 4.6 at a deep water site, and 4.3 at semi isolated Loon Bay. The Environment Canada data indicates 6μg/L of phosphorus at an open water site in 2009. Thus, the data on hand indicate the open waters are of good quality but there are influences towards higher phosphorus concentrations in some places. Parry Sound perhaps needs more investigation to establish baseline conditions in its bays and more populated areas than has been done in the past.

2.2.5 Severn Sound

Improved sewage treatment was key to de-listing Severn Sound as a Great Lakes Area of Concern in 2003. Monitoring of the open waters of Severn Sound began in 1973 by the Ontario Ministry of Environment. Five stations were regularly sampled, one in each bay of Severn Sound, and one in the open waters. In 1997, the Severn Sound Environmental Association (previously, Severn Sound Remedial Action Plan) (took over regular monitoring which continues today. Eleven open water stations are sampled biweekly during the ice-free season (Fig. 12). Samples are taken throughout the euphotic zone at each station (2x Secchi disk depth) and are analyzed for nutrients, including total phosphorus, total ammonia, total nitrate, and total Kjeldahl nitrogen, as well as chlorophyll a. Zooplankton and phytoplankton samples are also collected. Water clarity, vertical profiles of temperature, dissolved oxygen, and conductivity are taken (surface to 1m off bottom). In addition to the eleven Severn Sound Open Water Monitoring Program stations, SSEA monitors at three long term stations around Honey Harbour and seven stations on Lake Couchiching (SSEA, http://www.severnsound.ca/ssea_OpenWater.htm).

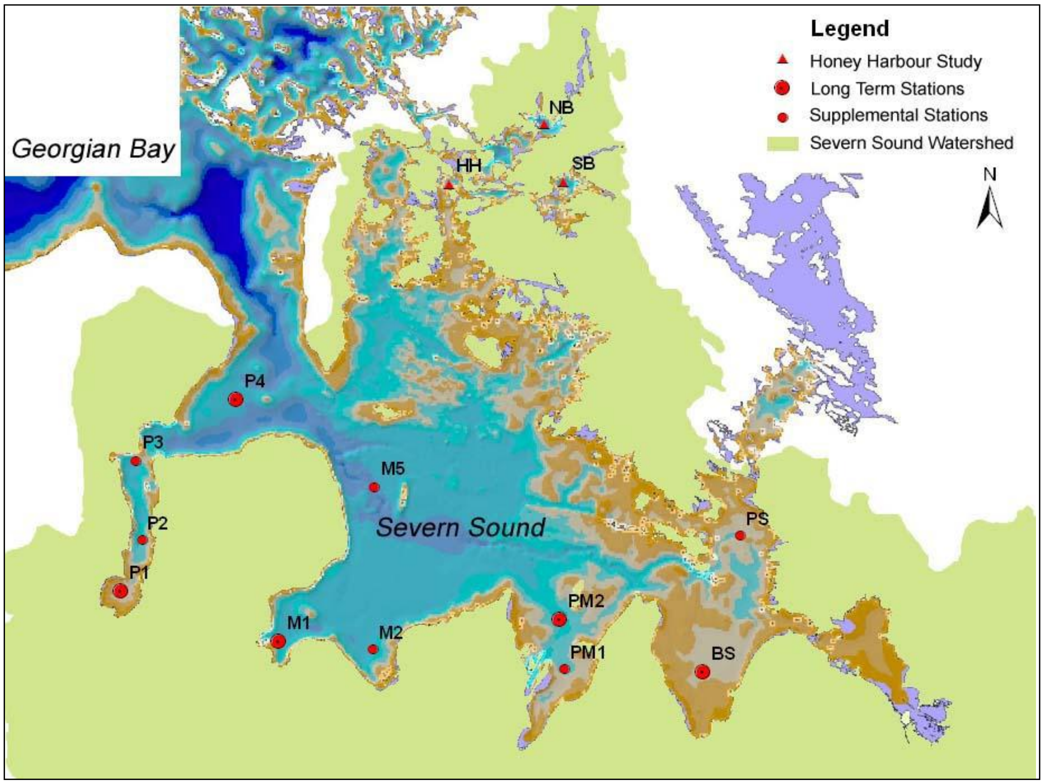


Figure 12 Water quality sampling stations of the Severn Sound Environmental Association.

The remarkable improvement at Penetang Harbour and Severn Sound is shown for total phosphorus in Figure 13. The phosphorus decrease at Penetang Harbour was due to improved sewage treatment and source control of phosphorus in rural and urban runoff. With better sewage treatment, sediment pore water ammonia returned to background levels at stations most affected by organic material in discharges and the pollution intolerant *Hexagenia* mayfly reappeared in most of the harbour. (K. Sherman, SSEA, personal communication).

Monitoring of water clarity (Secchi disk depth) showed a marked improvement with the invasion of zebra mussels in the mid-1990s and improvements in sewage treatment. Subsequently, clarity is decreasing once again. Cyanobacteria are present in small quantities making it imperative that nutrient loads not be allowed to increase so as to prevent blooms. (K. Sherman, SSEA personal communication). Monitoring of the North Bay of Honey Harbour is done bi-weekly allowing some understanding of processes in the bay. MOE collected data over five discontinuous years from 1981-1995 and subsequent data has been collected by SSEA in 1998, 2003, 2005 and 2008-2012 (Figure 14).

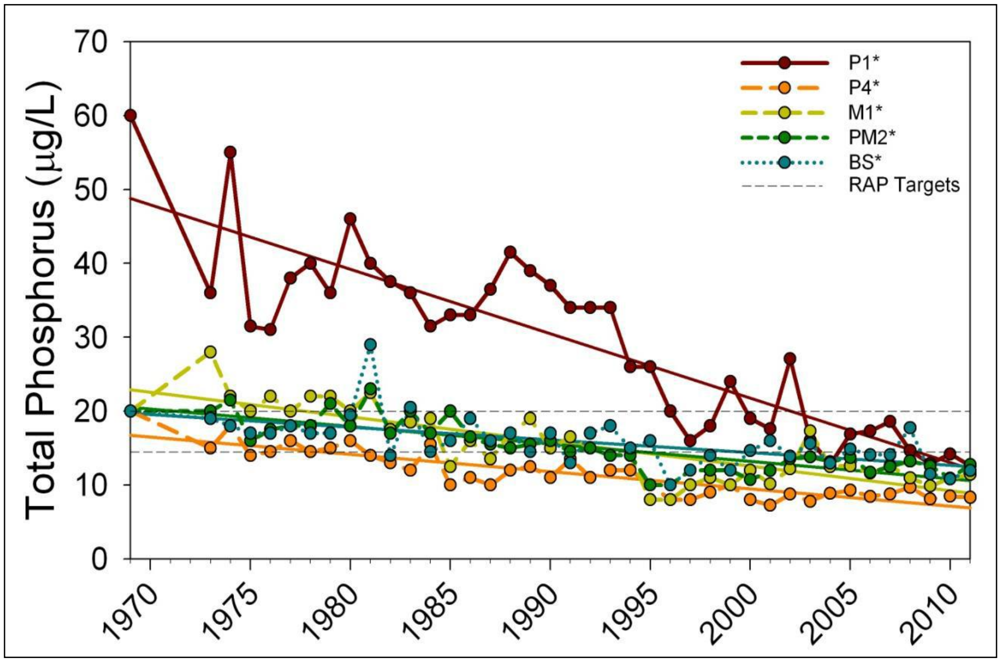


Figure 13 Temporal trend of phosphorus concentrations for Penetang Harbour.

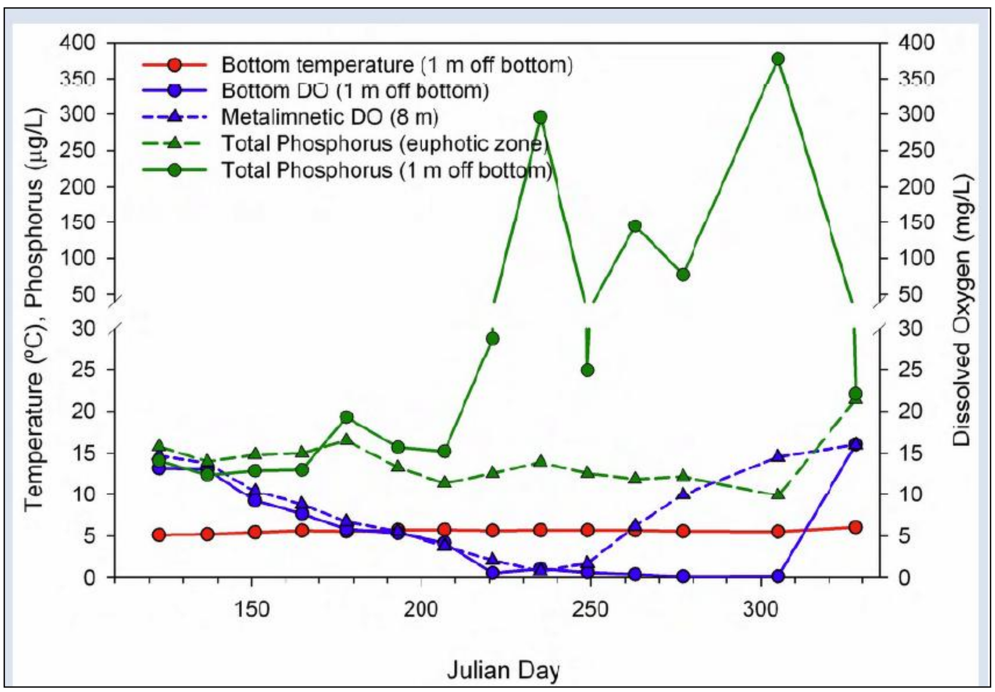


Figure 14 Phosphorus and oxygen concentrations for North Bay, Honey Harbour (2011).

Each year since monitoring began, hypolimnetic and metalimnetic anoxia developed by the beginning of August in North Bay and bottom water data from 2008-2012 shows that release of sediment phosphorus into hypolimnion water coincides with this anoxia. Metals data from 2010-2012 show accumulation of Fe and Mn in the hypolimnion as the associated weakly bound phosphorus was released by low redox conditions. The elevated phosphorous in the hypolimnion did not cause as dramatic an increase as expected in epilimnetic phosphorus during late summer, based on the extremely high phosphorus concentrations observed at 1 m off bottom. As the bottom water became oxygenated in the fall, some of the phosphorus and metals likely re-precipitated; however, there was enough phosphorus dissolved in the hypolimnion to cause an increase in euphotic zone phosphorus of about 10 μg/L on the last sampling date.

The Severn Sound Environmental Association (SSEA) conducted surveys of the sediment and water quality, and benthic macroinvertebrate (benthos) community of the Sturgeon Bay area in support of the Township's Environmental Assessment for the upgrade and expansion of the Victoria Harbour Waste Water Treatment Plant (WWTP). The survey was conducted in conjunction with the Class EA lead by XCG Consultants Ltd. for the Township. A partnership was also arranged with the University of Windsor and Environment Canada. The approach taken was to survey the water and sediment quality, and the benthic community at locations similar to past surveys in the area, as well as at other sites in the vicinity of Sturgeon Bay for comparison. The aim of the survey was to address whether the environmental quality of Sturgeon Bay was being adversely affected by the discharge of treated sewage effluent and whether this location would be appropriate for continued discharge following sewage plant expansion. It was concluded that the original implementation of the sewage plant had little or no effect on the bay other than to reduce phosphorus concentrations. The study recommended that the outfall remain in the same location provided the established phosphorus loading target was not exceeded.

The SSEA monitoring is well suited for trend monitoring, condition description of environmental conditions and process science because: (1)each site is visited each year, (2)bi-weekly sampling contributes robustness, and redundancy and allows for description of seasonal variability, (3)depth series at 1m intervals add needed detail, and (4)metals add process information. Although fisheries work is being done summaries are not available at this time.

Agricultural Best Management Practices: Success and Opportunities:

The Severn sound Remedial Action Plan called for application of best management practices (BMPs) for important watersheds. An assessment of the effectiveness of BMPs was recently completed (Stang, 2011). Overall, the BMPs resulted in a reduction of sediment and sediment bound phosphorus load to Severn Sound via Hog and Sturgeon Creeks. The most widely practiced BMP was stream fencing to exclude livestock from entering streams combined with native tree and shrub planting to stabilize banks. Assessment identified a need to apply other more effective BMPs such as conservation tillage. More work seems necessary on all aspects of nutrient control because soluble phosphorus in streams was not affected as much as particulate phosphorus (Dr. B. Gharabaghi, University of Guelph, personal communication). Nevertheless, efforts to date have been successful albeit with much more implementation still to be carried out. The practice of BMP implementation seems to have ongoing research needs; no-till farming has not turned out to be the panacea it was hoped to be decades ago in Ohio due to increasing levels of phosphorus that has accumulated in surface soils (Lake Erie LaMP, 2010).

2.2.5 Nottawasaga Bay and Watershed

The Nottawasaga Valley watershed is approximately 3700 km^2 with jurisdiction in 18 municipalities and is the source of watercourses that flow into Georgian Bay at Wasaga Beach, Collingwood, and Severn Sound. It includes 35 km of Georgian Bay shoreline along the Wasaga Beach and Collingwood waterfronts (Fig. 3).

Note: The jurisdiction of the Nottawasaga Valley Conservation Authority does not encompass the western aspect of the Penetanguishene Peninsula or its nearshore waters and so this area is not under management by a conservation authority (Fig. 3). Thus, the beach area within Tiny Township does not seem to fall under any conservation authority.

There are numerous sand and cobble beaches lying adjacent to Nottawasaga Bay; 23 within Tiny Township, plus several beaches that form Wasaga Beach Provincial Park. Wasaga Beach Provincial Park, the most southerly, is noted for its intense tourism and its 21 km length. As the world's longest freshwater beach there has long been recognized a need to protect the beach from major influences such as the Nottawasaga River. Also, there is concern about water quality at beaches on the western portion of Penetanguishene Peninsula due to the northward flow along the shore from the Nottawasaga River (Fig. 15) as well as numerous small creeks that discharge at these beaches.

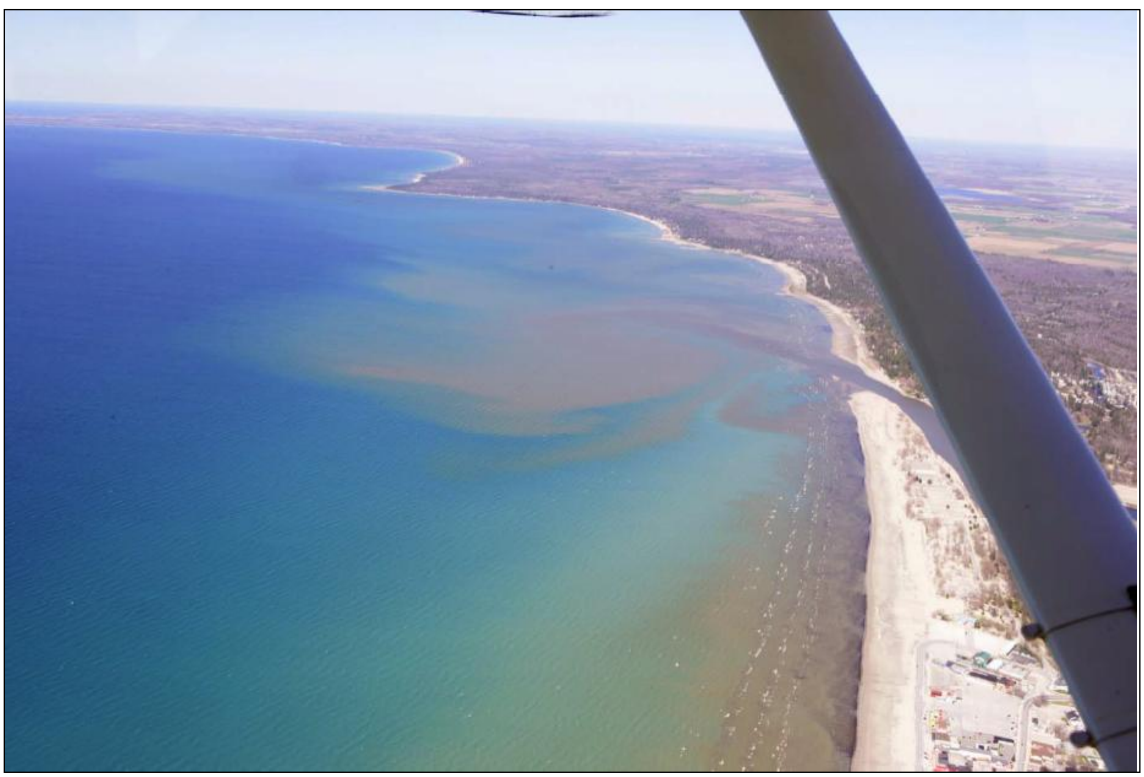


Figure 15 Aerial view of the outlet of the Nottawasaga River showing the sediment plume (SSEA, 2008).

Recently, cottagers in the Township of Tiny were asked to rate a number of environmental concerns. The concerns were ranked as follows (A.S. Crowe, Environment Canada, personal communication):

1. Invasive shoreline vegetation (esp. Phragmites)
2. Loss of beaches/dunes
3. Recreational water quality (E. coli)
3. Low lake levels
3. Botulism
6. Nottawasaga River
7. Algae and nutrients
8. Aquatic invasive species
8. Urbanization of the beach communities
9 Septic systems

While these concerns are relevant to resource management organizations, not all areas have been investigated. Studies are lacking on Phragmites, the ecological impacts of low water levels, botulism and aquatic invasive species. Recreational water quality, however, is one area that has received significant attention.

Nottawasaga Valley Conservation Authority (NVCA) maintains 18 water quality monitoring sites with sampling half at times of base flow and half during storm events. Occasional beach postings seem to be associated with periods of high rainfall and flow. Many of the streams, especially those with groundwater discharge support cold water fish such as brook trout and rainbow trout and Chinook salmon. Warm water habitats support, for example, largemouth bass and brown bullhead. The Nottawasaga River provides spawning habitat for Lake Sturgeon. Creeks that have been damaged by harmful land use practices may contain minnow species, carp and some bass species more tolerant of increased temperature and elevated nutrients. Based on benthic invertebrate data, "there is a marked change in the land uses adjacent to streams rated below potential or impaired". Many of these had been channelized, causing unnatural flow patterns and bank erosion. The majority of sites going through agricultural areas were rated as impaired, as they are impacted by erosion, non-point source runoff of nutrients, and stream alterations. Vegetated buffers can help decrease some of these impacts, but most areas allow for only minimal buffers, if any. Other land uses associated with impaired ratings include the presence of dams or online ponds, the presence of a stormwater pond or stormwater outlet or commercial, residential and urban land uses (which have a high runoff coefficient and very little buffer to attenuate any overland flow)" (Lake Simcoe Region Conservation Authority, 2011).

Environmental monitoring programs conducted by the NVCA have yielded "report cards" that provide general conditions of forest, stream and wetland health and provide recommendations for the protection and restoration of degraded areas. Summary data for selected subwatersheds (Table 4) and surface water quality (Fig. 16) are provided. Streams flowing through areas with healthy forest and wetland cover – such as those on the Escarpment and the base of the Penetanguishene Peninsula– are generally healthy.

Streams that drain highly urbanized or intensively farmed lowland areas are often unhealthy. Innisfil Creek is the most degraded watercourse system – impacts from this system extend downstream into the main Nottawasaga River. Studies have confirmed that high nutrient (phosphorous) loading is the most significant water quality issue within the watershed. Runoff from agricultural and urban lands contributes to these high loads.

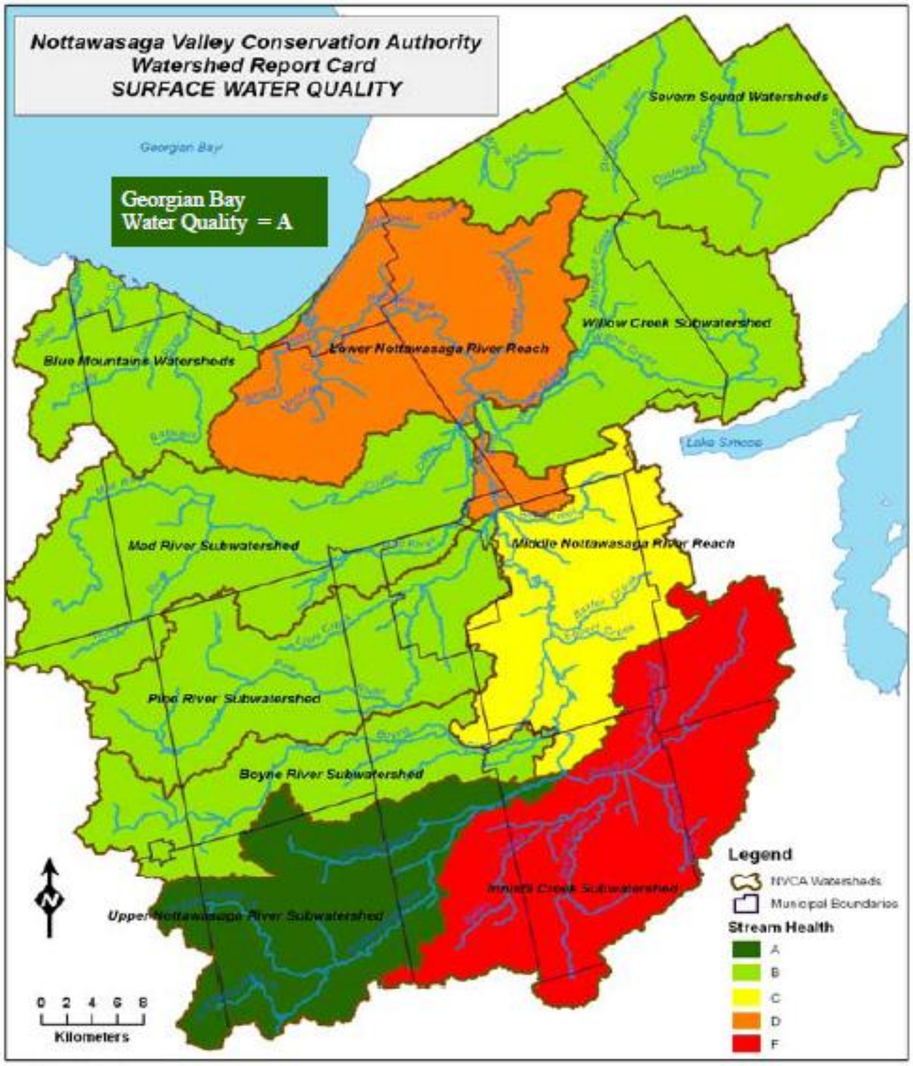


Figure 16 Nottawasaga watershed showing surface water quality grades (A-F) and the degraded sub-watersheds of the lower Nottawasaga River and the Innisfil Creeks.

The lower Nottawasaga River is considered impaired by effects of high turbidity during the growing season, high suspended solids loads and flow reductions from water taking. Treated sewage from three waste water treatment plants is discharged into the lower river. Modification of the Minesing Wetlands means that only the largest storms overflow the channel; this limits the ability to filter water but the effect is still significant. Major constraints to stream health are municipal drains, channelized banks, low base flow and rural and urban non-point sources. Despite the cumulative impacts of development throughout the basin the lower river is still a conduit for migrating fish. Two water quality stations in the lower river had typically more oxygen than the PWQO although it is not known whether sufficient oxygen sag studies have been done. Average total phosphorus was above the PWQO of 30 µg/L with values of 40 µg/L at one station and 52 µg/L at the other (Berger-Greenland, 2006).

Table 4. Nottawasaga Valley Conservation Authority watershed sub-watershed quality (NVCA, 2007).

Category	Nottawasaga River				
	Lower	Mid	Upper	Blue Mountain Watershed	Severn Sound Headwaters
Forest Cover (%)	28	28	35	32	46
Riparian Cover (%)	29	41	50	44	51
Benthic Grade (1 to 3)	1.9	2.1	2.4	2.3	2.5
Total Phosphorus (µg/L)	36	22	7	9	7
Suspended Solids (mg/L)	13.9	8.3	2.0	3.9	N/A
E.coli (cfu/100mL)	300	361	281	384	N/A
Wetland Cover (%)	15	13	11	6	12
Overall Grade Water	D	C	A	B	B

In many respects the lower Nottawasaga River is typical of the lower reaches of many rivers. Storm events cause erosion and high suspended solids. A high degree of deforestation plus farm drains contribute to high flow velocities. These events are highly visible where the river discharges to Georgian Bay at Wasaga Beach. Treated sewage and agricultural fertilizers increase the nutrient content so algae can grow in quieter reaches. The monitoring stations are of use to determine loads of materials in the water and some net effects through indicators such as such as benthos populations. The monitoring, however, does not appear to be set up to target specific management questions such as the effects of dams and impoundments, channelization of wetlands or to collect details such as horizontal distribution of parameters across the river. Recognition of program limitations represents more of an opportunity than a criticism.

Nottawasaga Bay itself is rather underrepresented in the scientific literature. Open water monitoring (Fig. 1) shows that, for example, phosphorus concentrations are the same in the middle of the Bay when compared to the middle of Georgian Bay. There is little information, however, for the nearshore. The majority of the information seems to be from beach bacteria monitoring (see next section). There is little information on benthos, fish, plankton, wildlife, fish habitat, non-native aquatic species or the cause of extensive fish and bird deaths due to botulism. For such a sizeable body of water the virtual lack of information represents an important opportunity for coordinated monitoring and research first to better characterize the area then to address specific management issues that may arise. This baseline information will be important to assess the effects of ongoing development in the Nottawasaga Valley as well as the efficacy of best management practices needed to minimize those effects. As in other Great lakes studies, repetition and adequate spatial and temporal data coverage are key to understanding whether or not changes actually occur.

Conditions in the lower Nottawasaga River deserve special attention. Despite reassurances from models on the size and influence of the plume from the river, the public see the situation differently. From shore, the turbidity plume can appear substantial and represent an undesirable discharge at one of the most treasured of Great Lakes beaches. The causes of the turbidity can be both suspended sediment and algae, the latter being more prevalent at low flow times. Therefore a study to partition the turbidity into algal and sediment components is needed in order to understand better how to manage the properties of the plume. The load of sediment should be calculated to confirm results of the modeling. The fate of phosphorous bound to suspended sediment should be investigated to determine whether significant amounts of algae-stimulating soluble phosphorus are released from the sediment. This information could be used to inform on the concept of phosphorus trading between treated sewage sources and erosion sources. The effects of summer low-flow conditions of oxygen, turbidity and algae on warm and cold water fisheries should be determined to help prioritize remedial works. Monitoring should be done to measure the effects of the removal of in-stream impoundments and the construction of sediment/nutrient trapping floodplains (Fred Dobbs, NVCA, personal communication).

A suite of "assimilative capacity studies (ACS)" of Lake Simcoe and the Nottawasaga River was completed in 2006 (Greenland, 2006). Water flow, sediment and phosphorus sources, best management practices (BMPs), and future population growth scenarios as well as other parameters were taken into account using the Canadian ArcView Nutrient and Water Evaluation Tool (CANWET) modeling system. A Hydrodynamic Mixing Zone Model was created to enhance the understanding of the Nottawasaga River mixing zone with emphasis on phosphorus and nutrient loading and resultant biological, chemical and physical relationships. The report noted some deficiencies of the water sampling such as lack of event based sampling which has since been rectified. The report generated these conclusions:

- Water quality within the Nottawasaga River is impaired to varying degrees;
- There is no appreciable cumulative change in river plume phosphorus associated with committed population growth provided that a suite of BMPs are implemented in each subwatershed;
- Agriculture remains the largest source of phosphorus and sediment in the Nottawasaga watershed, and
- Further monitoring is needed to enhance the model and to track BMP implementation.

Results of the "CANWET" exercise were used as a base for a study of the Nottawasaga River mixing zone in Nottawasaga Bay. The hydrodynamic modelling allowed an assessment of the impact of land development scenarios on Nottawasaga Bay (SNC, 2006). The conclusions were:

- The average annual phosphorus loading to the Nottawasaga Bay is 47 tonnes;
- "The NVCA Mixing Zone Model does not predict any widespread impact associated with the discharge from the mouth of the Nottawasaga River;

- The hydraulic processes for the Bay are primarily wind driven and in general, the river discharge mixes well under these conditions;
- The bay water quality, while slightly impacted within the mixing zone, is not a limiting factor when developing Total Maximum Monthly Loads for the Nottawasaga River;
- The near-field mixing extends about 1200 m offshore and covers about $2km^2$. The modelling indicates that there is little difference in plume size between conditions of present and future land use, and
- Monitoring recommendations include systematic water quality and current monitoring at the mouth of the Nottawasaga River and the near-shore regions of Nottawasaga Bay, as well as periodic monitoring at additional sites in the river and in the Nottawasaga Bay. This increased monitoring will assist in refining the model and adding to the strength of the modeled results. New stations have been added and both baseflow and storm events have been targeted.

The assimilative capacity studies called for more studies of water quality, for example to describe the link between phosphorus and suspended solids and turbidity. A study was conducted of water quality conditions before and after a summer storm in the Nottawasaga River and its tributary Innisfil Creek (Chow-Fraser, 2006). Results were somewhat surprising in that only two of 10 stations experienced a large increase in suspended solids due to the storm. The largest increase in suspended solids was associated with mainly organic matter. In other reaches the additional storm water was not accompanied by sediment. The study tested a multi-sensor electronic probe against laboratory measurements of chlorophyll as a measure of algal population (CHL-a), total phosphorus (TP) and total suspended solid (TSS). Strong relationships were found between probe turbidity and TSS, probe turbidity and TP, and probe CHL-a and laboratory CHL-a. The probe appears useful for monitoring purposes when there are insufficient resources for laboratory analyses.

Nottawasaga Bay Beaches

The Severn Sound Environmental Association Beach Monitoring Program is a partnership between the Simcoe Muskoka District Health Unit (SMDHU), the Ontario Ministry of the Environment, the municipalities within the Severn Sound watershed, Parks Canada (Georgian Bay Islands National Park) and the SSEA. The purpose of the program is to provide regular monitoring of microbiological water quality at selected swimming areas within the watershed. The results are used by the Health Unit to assess the risk that recreational use of the water may result in waterborne illness, and to provide warnings or advisories to the public. The sampling procedure follows the Ministry of Health Beach Management Protocol.

The concern over beach quality in the Township of Tiny also led to a study by The Severn Sound Environmental Association (SSEA, 2008). Wasaga Beach Provincial Park also monitors *E. coli*. Overall, local beaches did not exhibit signs of gross pollution but there were often *E. coli* counts greater than the provincial standard for recreation of 100 cfu/100mL. Some beaches are posted quite often. Exceedances of the standard were mainly, but not entirely, related to rain events, rough weather and elevated turbidity. The report considered that sources to beaches included sources to streams flowing onto beaches, faulty or substandard septic systems, sources to urban runoff, feces of water birds, and other watershed sources. The *E. coli* concentration was greater than 100cfu/100mL in more than half of the streams during dry weather with some much higher. Thus, streams can contaminate the beaches albeit with usually low levels of *E. coli* which are then subject to nearshore mixing and dilution. Small streams lack the flow velocity to carry material offshore so their flow can be entrained into alongshore currents thereby impacting beach water quality. The degree of beach sheltering was thought important especially alterations derived from artificial structures such as groynes. The report opined that these might be modified or removed and stream outlets could be directed further offshore from beaches. The SSEA, in partnership with Parks Canada, Ontario Ministry of the Environment, Simcoe Muskoka District Health Unit (SMDHU), and the municipalities within the Severn Sound watershed monitors beach water quality at the stations shown in Figure 17. However this monitoring focuses only on the sections of the beaches that are public, and the public portion of the Tiny Township beaches represents only a small portion of the total beaches. Since 1998, the Federation of Tiny Township Shoreline Association (FoTTSA) has undertaken a program to monitor *E. coli* levels at the non-public beaches and at the small streams that discharge at the beaches (see FoTTSA web site).

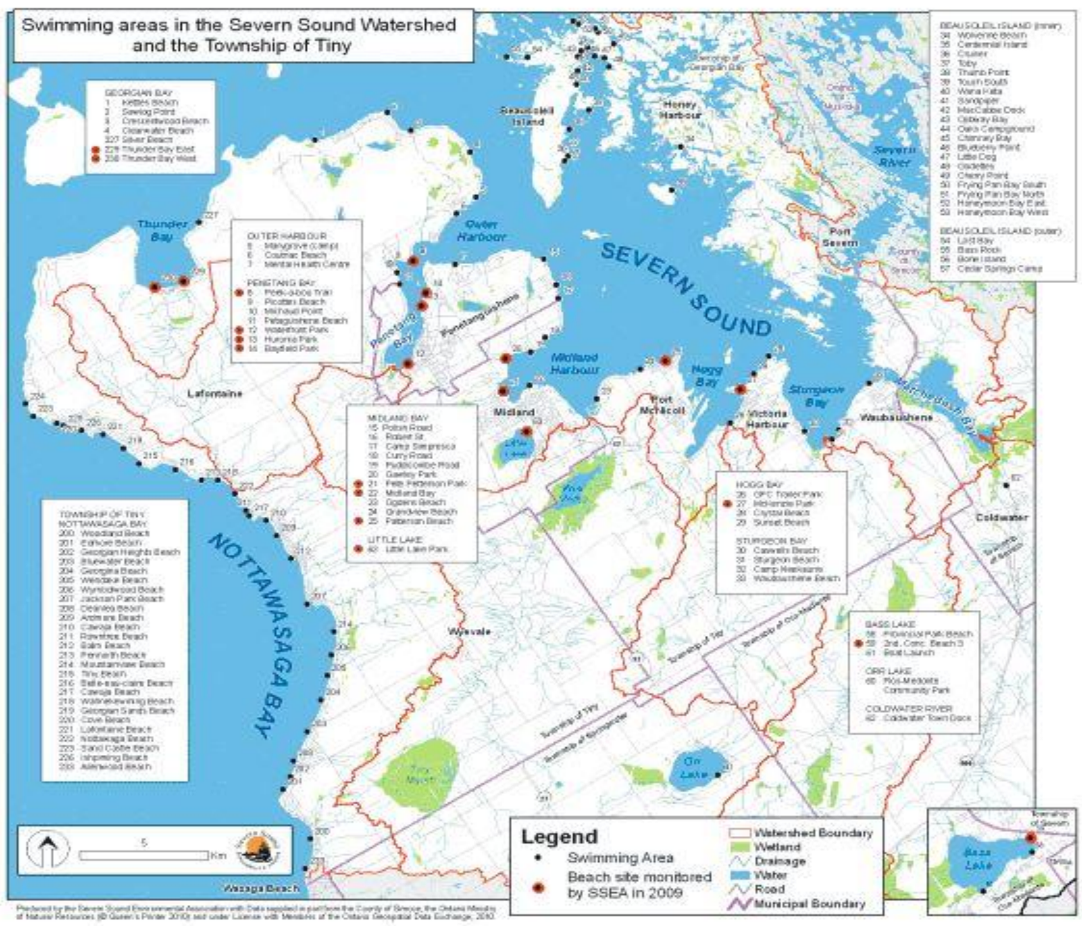


Figure 17 Beach monitoring program locations for Severn Sound and Township of Tiny.

In the last 10 years the understanding of *E. coli* problems at beaches has developed considerably, sometimes in surprising ways (Crowe and Milne, 2012, Whitman and Nevers, 2003).

NOTE: Generally *E. coli* is still a good indicator of health risks in swimming waters (i.e., increased levels of *E. coli* are associated with increased indices of illness), but *E. coli* is not a good indicator of health risk in sand (i.e., although there are extremely high levels of *E. coli* in sand, studies have shown very few, if any pathogens, and very low instances of illnesses).

- *E. coli* survive longer in the aquatic environment than previously thought; this allows accumulation in water, sediment, and sand not realized before and also calls into question its usefulness as an indicator of recent fecal contamination.
- Recent studies have indicated that *E. coli* not only survive in sand, but may also reproduce (Beversdorf et al. 2007).
- The *E. coli* test is not specific for human bacteria; birds and other wildlife can contribute to the load. The standard test cannot detect *E. coli* 0157H an enterohemorrhagic strain of the bacterium.
- Transects of *E. coli* concentrations in nearshore lake water show a large increase as sampling sites approach the beach. The highest concentrations are at the water's edge where children play.
- Extremely high levels of *E. coli* are typically found in the sand adjacent to the shoreline. *E. coli* stored in sand in the swash zone can enter the near-shore lake water either through groundwater discharge of the *E. coli* in the sand, or through erosion of the shoreline. Thus, the bacteria causing beach postings may come from the beach itself.
- Gulls and geese seem to be an important primary source and may be the only source of E. coli in some beaches.
- The significance of *E. coli* from birds as indicators of human pathogens is not yet clear (EC, 2011). Contamination by *E. coli* from known human sources is associated with illness caused by human pathogens.
- It is not clear whether there are temporarily contaminated stream flows from agriculture areas in the spring that may initiate *E. coli* contamination at beaches.
- Groundwater of natural, "dry" beaches with dunes and beach grasses does not contain *E. coli*. These beaches have a noticeable slope with dry sand that does not encourage survival or penetration of *E.coli* into groundwater. The grasses of "dry" beaches tend to discourage geese.
- Groundwater of "wet" beaches contains *E. coli*. These beaches have less slope, sometimes have ponding and different vegetation that encourages geese. Some "wet" beaches are the result of misguided modifications that have removed the dunes and encouraged lawns that facilitate pollution by geese.
- Wave run-up and wind driven water level increases can push water with *E. coli* from the water's edge into the groundwater. Groundwater flow, however, is always toward the lake.
- The *E. coli* found in groundwater below some beaches comes from either (1) surface feces bacteria migrating downward during infiltration of precipitation, or (2) downward migration of lake water which typically contains *E. coli*, during large scale wave runup and flooding of beaches.

- Beachfront cottage septic systems that are well designed, located, and functioning properly do not appear to be a cause of *E. coli* at the water's edge.
- Land drains and poorly constructed/located/maintained septic systems may cause beach wetness and contamination as well as contamination of streams flowing to the lakeshore.(A.S. Crowe, personal communication).
- The common reed, *Phragmites australis*, is spreading along Georgian Bay beaches to the extent that herbicides are considered for control of this invasive species (Crowe et al. 2011) Also it may be possible to remediate flat wet beaches by installing fencing to trap sand. (The Tiny Cottager, 2010.

There are still questions regarding *E. coli* sources, the effects of streams and groundwater on beaches and the overall significance of *E. coli* as an indicator of human pathogens if the source is primarily water birds. Also there are many issues and needs related to invasive vegetation on beaches, relationship to increased nutrient loading, and impact on water quality.

Shoreline Alterations and Links with Water Quality

The Southern Georgian Bay coastal and nearshore ecosystems are threatened by the cumulative impacts of significant human development and shoreline alteration. Shoreline development and alterations remove and/or degrade coastal wetlands and other fish and wildlife habitat and also disrupt flow and littoral circulatory patterns, nutrient cycles, sediment transport, and other coastal processes. Left unchecked, these activities could exert even greater detrimental impacts on nearshore and coastal habitats and species.

Prompted by public concern and seeking a way to resolve these issues, the Southern Georgian Bay Shoreline Management Initiative was established in 2009. The purpose of this task group of federal, provincial, municipal and conservation authority representatives is to discuss, identify and implement actions to balance shoreline development with the needs of the environment. General goals include conserving, protecting and restoring nearshore aquatic and coastal ecosystems of the southern Georgian Bay shoreline.

A comprehensive shoreline alteration inventory was completed to assess the type, extent, and impact of shoreline alterations between Tobermory and Port Severn (OMNR, 2010). The project involved the use of geographic information system (GIS) to map dredge cuts, groynes, docks, marinas and hardened shorelines (Fig. 18). Overall 67.4% of the southern Georgian Bay's 660.8 km (Tobermory to Port Severn) shoreline has a high amount of development while only 7.3 % is in the very low development class. A total of 80.5% of the shoreline has moderate to high amounts of cumulative shoreline development.

When the impact of shoreline hardening, marinas, and bridges is considered, the Town of Midland's shoreline is highly altered (51.7%). More than a third of the Town of Collingwood's shoreline is highly altered (34.8%). The Town of Penetanguishine (29.2%), Town of Wasaga Beach (23.3%), Township of Tay (22.6%) and the Township of South Bruce Peninsula (20.9%) are very highly altered. The shoreline east and west of

Collingwood has moderate to high levels of shoreline hardening with up to 30 groynes and 11 - 30 dredge cuts per km of shoreline.

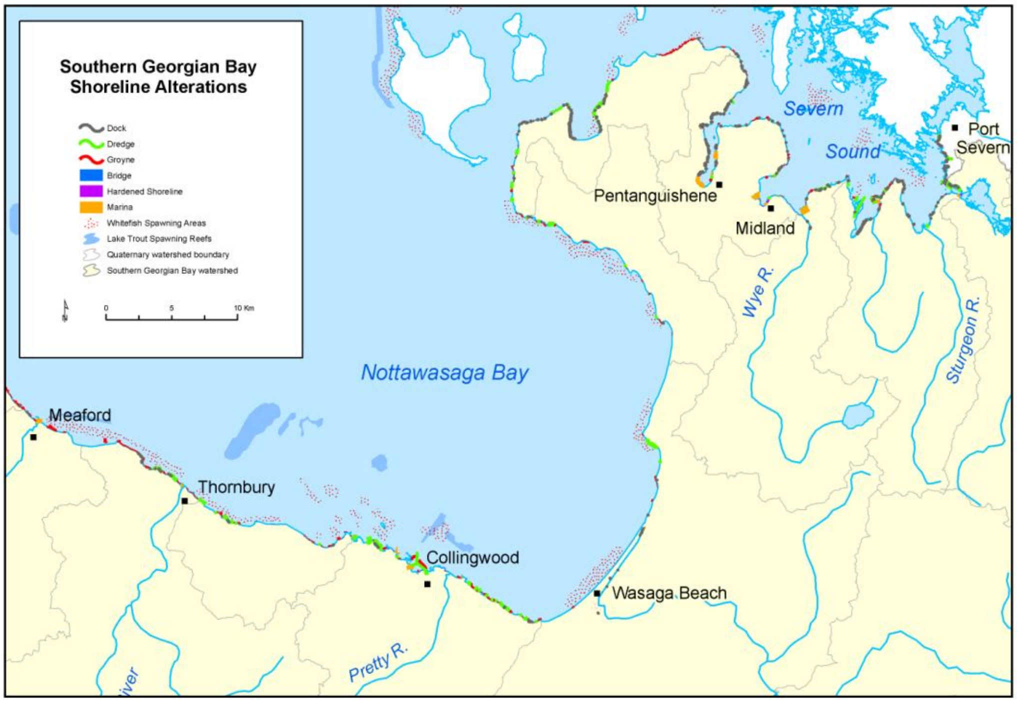


Figure 18 Map showing the type and extend of shoreline alteration (OMNR,2010).

Shoreline communities with high density housing serviced by septic beds are common on the Penetang Peninsula and groundwater seepage into the Bay occurs along the beach face carrying nutrient-rich waters to the nearshore system. Dredging and the construction of docks are expected to continue given extreme low water levels and people's expectations for water access. In some areas, shore-perpendicular groynes built in the 1960s have created a low energy zone between large stable offshore bars and the shoreline. Small groynes, formed by local beach-front residents moving cobbles in the water are numerous along the western shore of the Penetang Peninsula characterized by cobble beaches and shorelines. Results from a modeling study by Coldwater Consulting Ltd. (2012) show a decrease in fresh water exchange, wave action and circulation at Lafontaine Beach. The presence of nearshore algae, eutrophication and fine sediments is directly related to the sheltering effect of groynes. Water and beach quality are now degraded and septic field leachate and urban runoff are thought to be the major sources of excess nutrient loading in that part of Nottawasaga Bay. Opportunities for groyne removal and beach restoration should be pursued in Nottawasaga Bay.

Beaches are also lost due to invasive vegetation. These are both local and native hydrophytes typical of wetland environments, and the non-native common reed (*Phragmites australis)*. The presence of hydrophytic vegetation on beaches has always occurred during past low lake levels. Typically these past low lake levels would last for a year or two, then rising lake levels would remove this vegetation from the sand. However, given that the current period of low lake level has lasted for 13 years with no foreseeable rise, invasive Phragmites has become established to the extent that beaches have disappeared. Phragmites has had detrimental impacts on the native plants and fauna habitat on coastal wetlands and beaches (Ontario Ministry of Natural Resources, 2011).

Fisheries, Wetlands and Water Levels

The capacity to measure fish populations and the condition and extent of their habitat (e.g., wetlands) is crucial to managing aquatic habitat resources. Example programs are the end-of spring trap-netting (ESTN) program of OMNR (McIntyre, 2010 Liskauskas, 2011), young of the year fish assessments (Speers, 2012), McMaster University's coastal wetland monitoring and research (Midwood and Chow-Fraser, 2012) and the Great Lakes Coastal Wetlands Consortium (Uzarski et al. 2012).

McIntyre (2010) and Liskauskas (2011) summarized fish population data for select areas around Georgian Bay by using a standardized test netting protocol to ensure data comparability through time and between areas. There is much inter-annual variability in the catch per unit effort (CPUE). While Severn Sound is the only area with significant multiyear data (1999 to 2010), there is no apparent trend in fish abundance. This data set is important partly because it shows the scale of variability in fish abundance data. The catch per unit effort (CPUE) varied by a factor of 2 or more for some species between adjacent years. Pike in the Wah-Wah-Taysee area seem to be doing well despite concerns for decreases in wetland spawning habitat due to low water levels. Smallmouth bass are doing well despite the presence of round gobies.

Climate change was thought capable of causing an eventual loss of up to 2.5 m in water level which would greatly exacerbate wetland loss (Midwood and Chow-Fraser, 2012). Percentage of wetland area and wetland connectivity to Georgian Bay (Severn sound to Key River) was used as a performance indicator during the Upper Great Lakes Water Level Study. Modeling results suggested that there is a sharp, linear increase in habitat loss between 176 and 173 m (above sea level; Chart Datum). This performance indicator estimated a loss of 28% of fish habitat with each metre of water decline (Chow-Fraser and Fracz, 2010).

A review of level scenario modeling appeared in the recent IJC report on Lake Superior regulation (IJC, 2012). The present view is that climate-induced water level changes may be negative or positive and would likely be much less than formerly believed. Nevertheless, the concern for wetland ecology and the effects of prolonged, near record low levels is well founded. Coastal wetlands in Georgian Bay support critical spawning and nursery habitat for the Lake Huron fish community. They also provide refugia or produce prey fish that help sustain larger predator fish populations (Midwood and Chow-Fraser 2012). Sustained low water levels and less variability in levels have changed the amount and type emergent and submergent vegetation in wetlands and in certain areas left wetlands high and dry. The differences in plant communities have correspondent effects on fish communities.

There is insufficient digital elevation data to accurately represent, model or forecast coastal wetland loss due to sustained low water levels. Existing data had to be collected manually which is time consuming and costly. Remote sensing such as Laser Imaging Detection and Ranging (LIDAR) offer a cost effective method to obtain elevation data for a large geographic scope. The value of this type data cannot be overstated given its application in modeling water level scenarios, identifying wetlands resilient to sustained low water levels, prioritizing wetlands for provincial evaluations and putting in place appropriate conservation and protection tools to inform municipal official plans.

The kinds of studies above are quite different but are connected. The Northern Pike population (see below) is an interesting topic that connects fisheries, wetlands, and water levels. The ESTN protocol uses trap nets designed for lake shores with a depth minimum of 2m and a mesh size that does not retain small fish (McIntyre, 2010). The Midwood and Chow-Fraser (2012) study used smaller trap nets suitable for wetlands that did retain small fish. Nevertheless, seven of the 13 most common species in the wetland study were also represented in the lake shore studies. It is not clear which species migrate out of the wetlands to become prey or which species migrate into the wetland to consume prey. Thus, the relationship between wetland and lake populations is not as well elucidated as would be desirable to understand the importance of wetlands on fish generally. Midwood and Chow-Fraser (2012), however, compared wetland plants and fish populations in two periods 2003 to 2005 and 2009. Fewer fish species were found in 2009 which was thought to be caused by changes in the aquatic vegetation community assemblage within wetlands. Unfortunately, the variability between the years is unknown so the representativeness of the few years of data may only become apparent with further sampling.

A study of muskellunge habitat showed that the spawning and nursery areas were reduced when 1981 data was compared with 2007 data for Severn Sound (Hurley, 2008). The outward migration of the shoreline due to lower water levels reduced the amount of available fish habitat. Although this was essentially a two year study the lack of muskellunge in 2007 is perhaps consistent with reduced recruitment. Again, continuing this research will be useful to understanding effects of level changes.

Pike populations also seem affected by lower water levels and their effects on wetlands. Pike spawn in shallow areas of bays which may disappear or become disconnected depending on the shoreline morphology and water level. A population data set (Fig. 19) going back to 1982 in Severn Sound indicates a drastic decline in Pike populations beginning in 1999 when water levels decreased (Gonder, 2003). Pike populations have remained low up to 2010 (Liskauskas, 2011).

Water quality in marshes or wetlands can be affected by land use and nutrient loading. The most diverse marshes have the cleanest water; high nutrient concentrations can cause turbidity that limits plants (see review in Cvetkovic et al. (2010). In an examination of the various factors that correlate with fish populations Cvetkovic et al. (2010) found that plants are better predictors of fish than are water quality parameters. A study of young of the year fish in Severn Sound showed that, for many species, this crucial life stage was more abundant and more diverse in mixed submergent plant communities (Leslie and Timmins (1994).

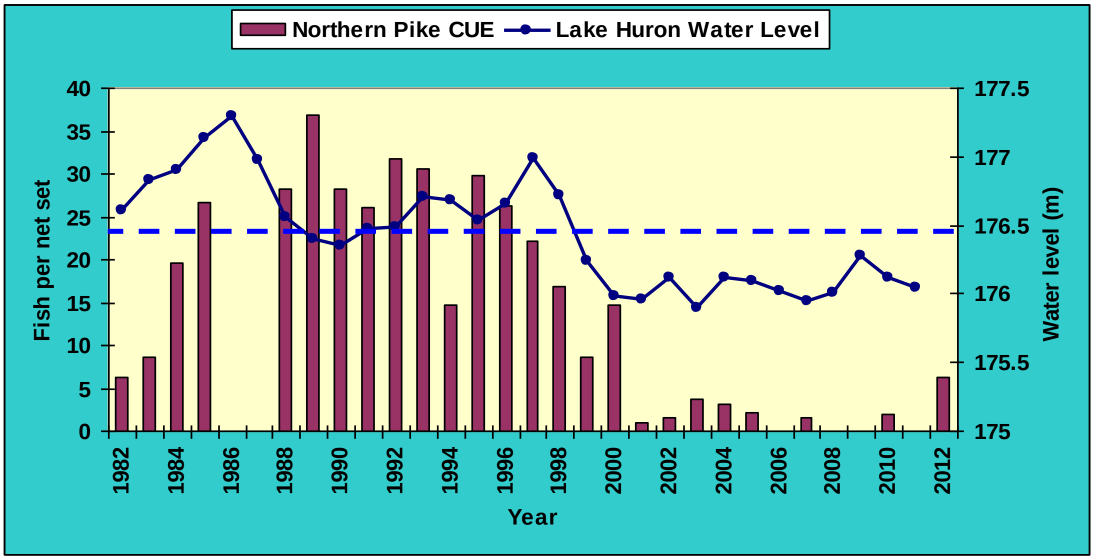


Figure 19 Abundance of northern pike (fish per net set) correlated with Georgian Bay water levels, 1982 to 2012. Dashed blue line represents average GB water level over the time period. (A. Liskauskas, OMNR, personal communication)

A large review of the literature on physical habitat structure and fish populations showed that structural habitat complexity is beneficial for fish and management efforts to preserve habitat and prevent habitat loss (Smokorowski and Pratt, 2007). Thus, fish need diverse aquatic plant communities and plants grow in marshes and wetlands and shallow areas. Water level changes that threaten plants therefore threaten fish. Other aspects of habitat such as type of substrate, fetch, and temperature are also important in addition to the presence of macrophytes (Randall et al. 1998). Not all fish are found in wetlands all of the time, therefore, the importance of substrate type in fish habitat and the relationship to fish populations in the nearshore was a focus of the Randall et al. (1998) study. Rock and sediment habitats are indeed important and these a less threatened by decreases in water levels.

Water levels affect the accessibility of wetlands and the amount of area in a wetland that is suitable for fish habitat. The impact of lower water levels on fish habitat was modeled by Fracz and Chow-Fraser (2013). Levels below 176 m above sea level (m asl) drastically reduce the number of wetlands and the area available for fish. At the end of December 2012 the level was 175.51 m asl which is similar to the all-time low in the historic data. Depending on which climate change effect scenario is chosen levels as low as 174 m asl may occur. This would potentially cause the loss of half of the number of wetlands and half of the total area of wetlands (Fracz and Chow-Fraser, 2013). At the same time it is conceivable that wetlands may fill in new shallow areas with suitable bottom substrate that were too deep for vegetation at higher water levels; more research could be done on this possibility.

Clearly, stakeholders around Lake Huron have been affected by lower levels and the protracted period of low levels seems unusual. Yet, solutions of increasing flow from Lake Superior and/or decreasing flow from Lake Huron have cascading implications that would mitigate against a speedy resolution. In this light, studies could be done to determine whether some sort of habitat reconstruction or rehabilitation could be effected that would exploit the lower water levels as a way of maintaining more fish habitat. Modeling to identify wetlands resilient to future water level declines should be considered and appropriate conservation protection approaches should be designed for municipal application. Additionally, stranded and dried wetlands previously under water should be preserved to ensure wetland habitat availability should higher water levels return.

There are fisheries issues in Georgian Bay that may largely be caused by factors other than nutrients and other forms of pollution or lake levels. The Moon River walleye population decreased from about 25,000 spawning fish in the late 1960s to less than 2,000 in 2005 (Eastern Georgian Bay Stewardship Council (EGBSC), 2007). In general, walleye populations in eastern Georgian Bay are low compared to elsewhere in the Provincial database. In the case of the Moon River, the river water flow variations present a natural challenge for the fish that may explain some of the large variability in recruitment as is typical across their range. The river system has been regulated by a dam since 1938 with resultant spikes in flow and extremely low levels which cause stranding and desiccation of fish spawn. Other factors likely involved in the decline include the small size of the spawning area, invasive species, and angling pressures. The EGBSC (2007) Moon River Plan called for enhanced spawning habitat, regulating flows to prevent spawn desiccation, more regulation of the fishery, stocking and ongoing assessment. The habitat augmentation was completed in 2008 and the net effects of this and other aspects of the plan are under assessment but show positive results for both Walleye and Lake Sturgeon. A similar approach was implemented on the Musquash River. These types of fish habitat restoration/rehabilitation projects are important to the Lake Huron fishery and should be pursued elsewhere.

In the Severn Sound area, an ongoing concern is that walleye may be over exploited (Gonder, 2003). Nevertheless, Liskauskas (2011) concluded “the fish community in Severn Sound as determined by the 2010 ESTN survey is diverse with 21 fish species represented”. Walleye and in particular smallmouth bass are well represented in this fish community. There is ample evidence that the local walleye populations are reproducing naturally with an exceptionally large year class produced in 2005. This recent increase in natural recruitment and relative abundance is an improvement over the status of Walleye populations in the late 1990s (Gonder, 2003). As well, the proportion of sport fish in the overall fish community has met or exceeded the delisting objectives as set out in the Severn Sound RAP (SSRAP 2002). Throughout the fisheries literature the variable recruitment success of some species and the unknown harvest of sport fishers imparts an element of variability that makes management very difficult. Assessment of the actual populations by test netting seems to be a good way of assessing populations and enabling adaptive management of the fisheries resources. The scientific challenge is to sort out what causes what and how to deal with whatever the problem may be. Fish habitat and exploitation seem to be the main issues.

Lake trout have been declining in most of Georgian Bay. The Parry Sound population, however, has been rehabilitated through a combination of stocking and harvest control that has returned the population to historic levels of abundance according to the Ontario Ministry of Natural Resources (OMNR, 2010). Parry Sound is unique with its size, human population, and fish farm. An investigation of why the Lake Trout recovery has happened only in Parry Sound would seem overdue if it has not been done already.

The aquatic food chain in Lake Huron and Georgian Bay is changing resulting in massive population fluctuations. For example, a large decrease in alewife numbers was documented for the period 2000 to 2004 by Dunlop et al. (2010). They also noted a possible antagonistic effect of alewife on walleye. By 2011, high catches of Alewife were restricted to Blackstone Harbour but the numbers were 1/7 of those in 2010. Round Gobies are still increasing in Georgian Bay and the exotic bloody red shrimp *Hemimysis anomala* persists only in Goderich (Speers, 2011). By 2012, gobies were still increasing, Alewife was more abundant in specific areas of Georgian Bay and the bloody red shrimp was not found in Goderich (Speers, 2012). There is still the impression that Dreissenid mussels are slowly expanding their range. The advance of exotic species represents a real change in one direction; when the distributions are fully developed then fluctuations in these relatively new populations can be expected as well.

The changes in Lake Huron and Georgian Bay seem to have combined in an unforeseen manner that has resulted in what has been termed a "rapid regime shift" (Ridgway, 2010). The large number of references precludes a thorough review but material from Ridgway (2010), Barbiero et al. (2009), Nalepa et al. (2009) and OMNR (2006) and Hecky et al. (2004) will be used to illustrate some of the observations:

- Cormorant nests increased from very few in 1979 to about 15,000 in 2001 after which they declined to about 10,000. Analyses of predation by cormorants on fish and other environmental effects of the birds were documented in OMNR (2006);
- The recent decline in cormorants may be an indication of carrying capacity;
- Alewife declined in all areas including those not frequented by cormorants therefore their decline was not due to cormorants;
- Alewife remain almost absent in many areas for Lake Huron;
- The trophic state (productivity potential) of the Lake changed with a decrease in total phosphorus of 60% between 1996 and 2004;
- Deepwater populations of quagga mussel (Dreissena *bugensis*) increased by a factor of 5 between 2003 and 2006;
- Mussels are thought to filter nutrients from circulating water and cause a deposition in nearshore areas. Advection of these deposits to deep sediment areas may occur;

- With the advance of the dreissenids, the deepwater amphipod *Diporeia* the fingernail clam Sphaeridae spp., and chironomids, all important fish food items largely disappeared between 2002 and 2004;
- The important whitefish were forced to make up for the loss of Diporeia by eating Dreissenids and more zooplankton. Nutrient poor dreissenids are not a good replacement food item;
- Beginning in 2003 the dominant cladoceran zooplankton virtually disappeared, cyclopoid zooplankton declined as well, and
- A botulism outbreak resulted in the death of thousands of birds and fish deaths in Georgian Bay during 2011 (http://www.simcoe.com/news/article/900381--botulism-may-be-cause-of-dead-birds-fish).

Programs to address these changes are largely in place. These will provide the basis of learning needed to cope in the future if, for example, climate changes cause permanent low lake levels. Similarly, botulism outbreaks may be linked to warmer temperatures (Lafrancois et al. 2011) – documentation and study will be important for understanding outbreak triggers. The ongoing assessment of fish stocks at all age groups and habitat availability is needed to understand the reaction of fish resources to changes and to allow adaptive management. Some ideas such as relaxed nutrient controls might be interesting as a way of increasing productivity but most of the nearshore is rocky habitat ideal for growing nuisance attached algae which thrives on small amounts of phosphorus. In addition, attached filamentous algae growth responds to temperature and is implicated in botulism outbreaks (Jackson, 1988, Lafrancois et al. 2011). Thus, holding nutrient concentrations low and monitoring the filamentous algae distribution would be useful to communicate whether the situation is changing. The advance of exotic species monitored with regular sampling would help to, explain some changes.

3.0 Research and Monitoring Recommendations

Eastern Georgian Bay

- Investigate the sporadic elevated phosphorus conditions and sources in the French River. Phosphorus in the river should be compared with phosphorus in Lake Nipissing outflow.
- Survey Parry Sound to establish background conditions in bays and population centres.
- Investigate the cause of sporadic high *E.coli* at Skerryvore.
- Monitor the total phosphorus contributions and study the associated impacts of sewage and grey water inputs from high density boating (e.g., Bays of Bone Island, Georgian Bay Island National Park).
- Research the sources of organic material along the Georgian Bay shoreline and how this contributes to issues with hypoxia and internal phosphorus loading.
- Determine whether lengthening of the stratified period is occurring in Georgian Bay.
- Synthesize and report on temporal trends of total phosphorus concentrations for problem Bays mentioned in this report. Investigate causes of oxygen depletion in problem bays. Determine if the oxygen depletion is caused by algae or lack of vertical circulation. Determine if there is significant “under ice” oxygen depletion and whether

that is equilibrated before stratification in the spring. In order to help with the diagnosis, oxygen depletion should be checked against models such as Charlton 1980 or Cornett and Rigler (1980) to determine if there is an unexpected degree of depletion relative to chlorophyll a or total phosphorus.

- Investigate and compare nutrient concentrations in streams feeding into problem areas such as Sturgeon Bay, Cognashene Bay, and Twelve Mile Bay etc.
- Additional monitoring and modeling of E. *coli* should be considered to shed light on sources, the zone of influence of these sources and how circulation and mixing influence spatial concentration trends.
- There is little recent evidence offered to support the often repeated idea that lakeshore development is responsible for algae and oxygen problems. This does not mean there is no effect; instead it would be preferable to cite studies rather than state common sense opinions that cannot be substantiated. The few studies of septic systems, such as they are at Sturgeon Bay, do not indicate a large effect on the lakes. Yet, the potential long-term effect of storing human waste in the ground at the shoreline of the lakes over prolonged time periods is of major concern. There should be a correlative study to see if water quality is related to cottage development– compare bays and lakes of equal size and depth. For example, in the case of Sturgeon Bay it may be instructive to compare nearby Cranberry Lake and Naiscoot Lake.

Sturgeon Bay

- Determine the significance of Sturgeon Bay's north basin watershed as a source of elevated phosphorus during late summer and establish a phosphorus budget.
- The cause(s) of the phosphorus concentration gradient from south to north (highest concentrations are in Provincial Park Bay) should be examined to determine whether there is a manageable nutrient source responsible.
- Determine the importance of sediment sources and regeneration of phosphorus (internal loading) to the algae bloom problem. Conduct a mass balance approach to understand the fate of (internally loaded) phosphorus in the hypolimnion. Examine whether shoreline owners can do something different with sewage.
- Examine the various principles laid out by Burns (1976) (e.g., diffusion of phosphorus upwards, diffusion of heat downwards and from sediment, residual incorporation of metalimnion water derived from heat budget, expected total phosphorus increase by incorporation of hypolimnion into epilimnion compared to observations as well as downward flux of phosphorus). Do we see the expected phosphorus increase in the surface water? Confirm if total phosphorus of surface water are linked with the hypolimnion.
- Examine the metabolism and fate of internally loaded phosphorus in terms of precipitation reactions that may determine whether phosphorus in the bottom water precipitates with presence of oxygen towards the end of summer.
- Monitor and confirm the relatively high phosphorus concentration in streams and Cranberry Lake are due to natural causes.
- Examine the probability of cyanobacteria blooms given the phosphorus concentrations in the spring time and determine if blooms are dependent on hypolimnion phosphorus?

- Examine and confirm the alternative bloom stimulation hypotheses such as the importance of iron (Fe) (Molot et al. 2012).
- Implement novel source tracking methods (e.g., isotopes) to determine the various sources of phosphorus in problem areas of eastern Georgian Bay.

Severn Sound

- Determine the source(s) of unexpected high phosphorus concentration in the Severn River downstream of Lake Couchiching and of Big Chute at Port Severn and examine if earlier observations are repeatable.
- Investigate the causes of low dissolved oxygen and increasing phosphorus in Little Go-Home Bay and Baxter Lake and their relationship to the South Bay of Honey Harbour.
- Evaluate water quality trends in North Bay and Honey Harbour in relation to multiple factors such as: climate variables (air temperature, wind speed and direction, precipitation, timing of ice on/ice off), water levels, changes in land use, septic inspection results, Dreissenid mussel density, and changes in temperature and oxygen regimes, both seasonally and inter-annually.
- Compare present day water quality in North Bay with diatom and chironomid-inferred water quality from paleolimnology studies.
- Model and calculate the degree of water circulation and exchange at different water levels for isolated embayments such as North and Sturgeon Bay.
- Calculate the amount of bottom substrate area that lies within the littoral zone under different water level scenarios to better understand the importance of the littoral zone in oxygen dynamics in North Bay.
- Continue the investigations into the relationships between the Chrysosphaeralla peak and phosphorus and micronutrient availability in North Bay.

Nottawasaga Bay

- Determine conservation methods to prevent the establishment of invasive vegetation (Phragmites) on sandy beaches and coastal wetlands.
- Determine if avian botulism incidents are linked to changes such as low lake levels, increased nutrient loadings, levels of bacteria and invasive species.
- Increase monitoring and baseline data as well as science activities in the Nottawasaga Bay to better understand water quality, fish population, fish habitat, plankton, alien species, and benthos. These data could provide the foundation to determine aquatic ecosystem changes and condition.
- Study the Nottawasaga Valley tributaries and determine opportunities to improve fish habitat, research effects of impoundments to understand phosphorus sources, fate, and impacts. Examine the use of wetland areas for water management and other ecosystem services. Research methods to reduce rapid flow events during storms.

All Areas

- Enhance nearshore water quality monitoring.
- Given the wide spread trophic changes, dreissenid mussels and larvae should be monitored to establish baseline conditions, relative abundances, colonization success and future distributions predicted. Establish correlations between water quality and

dreissenids as well as other benthos especially in shallow, sensitive area. Areas most prone to the mussels should be protected against further nutrient enrichment but this should be based on more research.

- Monitor the spread of attached algae and determine the presence of small nearshore sources of phosphorus; extend studies to bays with eutrophication issues.
- Summarize the accumulated fisheries data and transfer knowledge to stakeholders. Consideration should be given to preparing a historical back-drop (to the more recent fish community surveys) using the old Parry Sound fish community surveys. Conduct studies to determine opportunities for habitat rehabilitation could be effected to compensate for fish habitat losses due to low lake levels.
- Invest in remote sensing technology (oblique imagery) to accurately establish baseline coastal condition. Obtain accurate elevation data (e.g., Laser Imaging Detection and Ranging (LIDAR)) to model water level scenarios and identify resilient coastal wetlands for the purpose of planning, policy, protection, creation and rehabilitation.
- Research and model watershed conditions in the Nottawasaga Valley and Severn Sound watersheds to determine optimal locations for agricultural best management practices. Research new best management practices and the efficacy of those in already place.
- Determine cooperative science and monitoring strategies to find out whether the probability of detecting changes can be maximized.
- Determine how best to characterize ecosystem change and variability and conduct science and monitoring to measure aquatic ecosystem and water quality change.

4.0 Conclusion

The ability to fully understand and manage this region's aquatic resources appears to be compromised by a lack of regular nearshore water quality monitoring and science activities. With the exception of Severn Sound, many studies are conducted at irregular intervals or so far apart in time that the ability to detect ecosystem changes and causes is diminished. Yet, instances of severe water quality degradation have been reported in the nearshore and protected embayments of south-eastern Georgian Bay over the last decade. Of primary concern is increased development, phosphorus loading, eutrophication, increases in attached algae and harmful cyanobacteria blooms, hypolimnetic dissolved oxygen depletion and degradation of aquatic habitat. Recent concerns about sustained low water levels, changes in nearshore nutrient cycling and trophic status as well as the recurrence of local and regional water-quality problems provide ample justification for enhanced monitoring and science. Science and monitoring information to guide management and development plans is needed to mitigate current and future impacts; otherwise we might expect these conditions to be a portent of the future state of southeastern Georgian Bay.

Federal, provincial and local resource management organizations, academic institutions and environmental non-governmental organizations with an interest in science and monitoring in this region may benefit from regular communications sessions with strategy development and coordination.

The information obtained from the recommended science and monitoring activities can provide the foundation for science-based management actions to reduce nutrient inputs to South Eastern Georgian Bay; information transferable to all regions experiencing nutrient-related water problems. It will also guide agricultural and urban best management practices, aquatic and beach habitat conservation and stewardship measures needed to meet the commitments of the Great Lakes Water Quality Agreement and the goals of the Lake Simcoe/South-eastern Georgian Bay Clean-Up Fund.

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