Leonard Lake Plan

December 21, 2020

Leonard Lake Stakeholders Association

Preface

The adoption of a renewed Leonard Lake Plan (the Plan or Lake Plan) is designed to find common ground for the diversity of needs and interests that exist among those who have a stake in, and an impact on, the continued health of Leonard Lake (LL or the Lake). The Plan is a cornerstone to protect what we, in common, value. The vast majority of our community, above all else, value the preservation and improvement of the natural environment.

Although the District and all Muskoka Municipal Official Plans are designed to manage growth while protecting all Muskoka lakes, it is recognized by these levels of government that the general policy framework of an Official Plan (OP) may not be sufficient to respond to the character, extent of natural features and constraints, physical capabilities and carrying capacity of a given lake.

In various discussions between Leonard Lake Stakeholders Association (LLSA), the Township of Muskoka Lakes (TML) and the District Municipality of Muskoka (DMM) it was recommended by both the TML and DMM, that LLSA pursue the completion of a new Lake Plan that could address key Lake challenges. This document reflects the research and work undertaken by the LLSA and lake residents over the past several years in realizing this goal.

This completed Lake Plan reflects a two-fold purpose:

1. Actions that the LLSA will undertake related to goals outlined in the Plan, apart from land use planning regulations; and,
2. Land use planning policy recommendations specifically tailored to Leonard Lake that could potentially be included in the TML Official Plan, and where required, the TML Zoning By-law, thus enshrining protective measures in the context of land use planning rules for Leonard Lake.

While recognizing the rights and interests of property owners, the Lake Plan seeks to balance those rights with the imperative protection of the Lake and its watershed. These are not mutually exclusive ideals. Continued and improved health of the lake and surrounding lands and waters is essential to maintain and increase property values, and to protect the significant financial investment of Leonard Lake stakeholders going forward.

The Leonard Lake Plan is organized into four major sections: “Introduction”; “Principles, Vision, Goals and Accountabilities”; “About Leonard Lake”; and lastly, “Leonard Lake and The Township of Muskoka Lakes Official Plan”

Although the Plan as a whole provides answers to key questions such as the purpose and process of getting here; lake strengths and vulnerabilities; and a detailed description of all major Lake aspects, two sub-sections in particular provide the rationale for the specific policies and context pertaining to Leonard Lake that will be presented to the Township of Muskoka Lakes for potential inclusion in the OP. These sub-sections, found in Section 3, include “Water Quality and the Relationship to Development Capacity” and “Development Potential and Capacity”.

The specific land use policies that will be presented to TML subsequent to Leonard Lake property owner review and approval, can be found in sub-section 4.4. The Township as part of their current Official Plan review will consider the Leonard Lake Plan for adoption, in whole or in part, and as a part of the OP, will be subject to the Municipal process and Council approval.

It is hoped that our renewed Plan will provide the opportunity and the momentum for all people committed to the future of Leonard Lake to stand together in this endeavour. The Plan will have a direct impact on all Lake residents, both in terms of environmental protection and land use planning policies. Now is the time to act, to preserve both the value of investment by stakeholders in Leonard Lake waterfront and backlot properties, and the health and viability of our Lake for future generations.

Acknowledgements

Sincere appreciation to Mark Scarrow, LLSA President, who provided momentum, guidance and team support throughout the life of the Lake Plan project; rallied enthusiasm when needed; and represented our Lake and Lake Plan in discussions with the Township of Muskoka Lakes.

…to Bob Manning for invaluable early leadership; and setting in place a framework for the Plan that guided the work from start to finish.

…to Marilyne Doyle for the lead as overall Project Captain; for extensive research, project and Plan co-ordination, content writing and editing.

.. to Gord Roberts and LLSA board members Bruce McNeely, Steve Rohacek and Ken Riley, for specific content writing, research, and indispensable discussion and feedback along the way.

.. to the stakeholders of Leonard Lake for their contribution of ideas to a renewed Leonard Lake Plan at the 2018 LLSA Annual General Meeting; and through their Leonard Lake survey responses in 2020.

.. to other members of the LLSA board - Ann Lowry, Deb Solarski, Lynn Jewell Coon and Mark Greenham and lake volunteers for their support and ideas throughout the life of the project.

.. to the survey team - Lake volunteers including Steve Solarski, and LLSA board members, for excellence in survey design, compilation, and analysis and most importantly, dedication to data integrity and stakeholder privacy.

…to Charles Burgess, Burgess Gleason Environmental, for professionalism in Plan presentation, and constructive feedback in the structuring of the Specific Policies for the lake.

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SECTION 1: INTRODUCTION

1.1 Purpose and Scope of the Lake Plan

The scope of the Leonard Lake Plan includes the Lake, the watershed, the islands and lands and backlots surrounding the Lake, accessed by Leonard Lake Road #1, Leonard Lake Road # 2, Glen Gordon Road, and downstream property owners to Highway 118 West *(see Figure 1).*

Figure 1: Aerial of Leonard Lake and surrounding roads (Source- Google Earth)

The Plan provides a framework to proactively manage the Lake and surrounding watershed as an integrated natural resource, while protecting special areas and features and Lake character.

To ensure increased protection for the Lake and its watershed, property development and redevelopment must be managed effectively through land use planning policies that are tailored to Leonard Lake, and that respect the Lake's capacity.

Sustainability of the Lake system is fundamental to this Plan and a balance between stakeholder uses and the Lake's natural environment and water quality will be sought through ongoing community education and stewardship, and best management practices.

This roadmap will help to ensure that Leonard Lake evolves in a way that ensures the long-term protection, maintenance and restoration of the Lake's natural, social and physical features including water, wildlife, shoreline, watershed and adjacent lands.

1.2 Background and Plan Renewal Approach

In 2004 a number of Leonard Lake (LL) stakeholders met to discuss how best to work together to protect the Lake for future generations resulting in the incorporation of the Leonard Lake Stakeholders Association (LLSA) in 2005. LLSA remains active today with an average annual membership of 90 members - approximately 60% of the property owners on the Lake.

Since 2004, LLSA has delivered several relevant programs through engaged volunteers, including water quality testing, community building, shoreline revitalization, invasive species awareness and communication. On behalf of Leonard Lake stakeholders and Lake health, LLSA has worked to build trust and credibility with key organizations such as the Township of Muskoka Lakes, the Muskoka Watershed Council, the Muskoka Lakes Association, and the District Municipality of Muskoka.

Work on the first Leonard Lake Plan commenced in August of 2005. A survey was distributed to all LL stakeholders, and survey respondents identified key values and concerns and provided suggestions regarding the protection of Leonard Lake and its watershed. This input formed the basis of the first Lake Plan, approved by the LLSA membership in 2008, and the Lake Plan has continued to guide the work of LLSA and engaged stakeholders.

In 2017 the LLSA initiated a volunteer program “Eyes on the Lake” to enhance citizen science projects on Leonard Lake and to assist LLSA and stakeholders to better understand and assess current Lake status and degree of Lake health stability.

In 2017 three studies were commissioned regarding Lake health and Lake capacity, the results of which pointed to the need for several actions:

- To create an expanded Lake Plan, parts of which could be incorporated into the Township of Muskoka Lakes Official Plan, and, as required, its Zoning by-law;
- To identify best practice work with stakeholders with a holistic view that would encompass “lake health” rather than recreational water quality; and
- To foster cooperative efforts with all levels of government in the interest of protecting the water quality and health of Leonard Lake, and generally, all lakes in Muskoka.

In 2018 LLSA and stakeholder concerns regarding waterfront and backlot development on LL were raised, highlighting the need for improved education and land use planning protective measures for the Lake. A public health notice was posted for Leonard Lake following the Ministry of Environment Conservation and Parks (MECP) and South Muskoka Health Unit confirmation of blue-green algae (Cyanobacteria) in a section of the Lake.

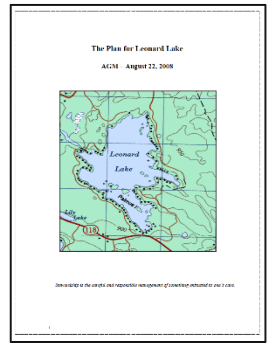
The 2018 LLSA Annual General Meeting of stakeholders included a review of the first Lake Plan, and an open discussion of the changes that had occurred since 2008, such as demographic shifts in Lake property ownership, ageing infrastructure of buildings and septic systems, and the need for intensified Lake stewardship given increased land and water vulnerabilities. LLSA members confirmed that the existing Lake Plan's values and principles remained relevant but agreed and voted to pursue a revised Lake Plan that would better protect and preserve Leonard Lake and its watershed for now and into the future.

- **Phase I:** Preliminary Lake Plan Discussion with LL Stakeholders *(July 2018)*
- **Phase II:** Leonard Lake Stakeholder Survey (*May, June 2020*)
- **Phase III:** Preliminary Plan consultation with Township of Muskoka Lakes (*March 2020)*
- **Phase IV:** Leonard Lake Stakeholder Draft Lake Plan Review (*October-November 2020)*
- **Phase V:** Plan Presentation to Township of Muskoka Lakes and Public Meeting *(October, November 2020)*
- **Phase VI:** Implementation (*post Township of Muskoka Lakes discussions)*
- **Phase VII:** Ongoing Review and Further Plan Evolution

This Lake Plan is a living document that will progress and evolve in response to the natural environment, planning best management practices and community needs. As this Plan is implemented, LLSA will strive to expand stakeholder awareness regarding the value of a holistic watershed planning approach. This Plan acknowledges that the Leonard Lake watershed spans an area greater than the current stakeholder properties fronting and backing the waterfront and that this linked property line may exclude certain upstream watershed lands. While these upstream lands may not be extensive in scope, they are within a watershed that feeds into the Lake and are integral to its residents, wildlife, and ecosystem.

This Lake Plan encourages activities that explore the needs and proper management of the watershed. The objective is to understand and implement best management practices throughout the watershed on a go forward basis as we gain a more thorough understanding of the relevant issues.

1.3 Information Souces and Support



1.3.1 Leonard Lake Plan - First and Renewed

Consultation and interaction with members of the Leonard Lake community over several years informed the preparation of the first and second Lake Plan. The most significant of those efforts include:

- **2006, a "Lake Values and Opinions Survey"** was distributed to 150 Leonard Lake shoreline and backlot property owners. 86 surveys (57.3%) were completed and returned. Stakeholder input from the survey formed the basis of the first Leonard Lake Plan. (See Appendix A Values and Concerns, 2008).

- **August 2008, the first Lake Plan** for Leonard Lake was approved by LLSA membership vote.

- **July 2018, a Lake Plan Renewal** was proposed to the LLSA Annual General Meeting membership and feedback from members was noted by the LLSA Board.

- **June 2020, the LLSA Lake Plan 2020 Survey** was distributed primarily through electronic means to 248 Leonard Lake property owners and family members that represented 156 shoreline, island and backlot properties. 160 surveys were completed and returned, 62% of which were completed by property owners (See Appendix A Values and Concerns, 2020).

- **September and October 2020, Survey Results** were provided to stakeholders.

- **October and November 2020,** Sessions were organized for stakeholders to provide feedback on the new draft Lake Plan.

1.3.2 Environmental Policies

Although the District and all Muskoka Municipal Official Plans are designed to manage growth while protecting all Muskoka lakes, it is recognized by levels of government that the general policy framework of an Official Plan may not be sufficient to respond to the character, extent of natural features and constraints, physical capabilities and carrying capacity of a given lake. The Township of Muskoka Lakes, along with other municipalities, encourage the development of individual lake plans that provide more detailed and lake specific policies.

In discussions between LLSA, the Township of Muskoka Lakes and/or the District Municipality of Muskoka, it was recommended that LLSA pursue the completion of a new Lake Plan that could set in place protective measures to help address key Lake challenges. If accepted, elements of the Plan could be considered for inclusion into the TML Official Plan and Zoning By-law, as appropriate, thus enshrining protective measures in the context of land use planning rules for Leonard Lake, specifically. The preparation of this new Lake Plan has had regard to the policies of the District's Official Plan including subsections C2.6.2h), C2.6.6.1i), J4.3k), and J4.3n).

1.3.3 The Science of Leonard Lake

Research has been undertaken by LLSA and volunteers that includes the assembly of Lake-specific information from scientific data, research and reports about water quality and water levels; fish, birds and other wildlife use of the Lake and its watershed; inventories of flora and forests; information about the lands adjacent to the Lake and its minerals; applicable legislation and regulation compliance; and histories of human activity around the Lake. In addition, LLSA has engaged in partnership initiatives that provided baseline data regarding shoreline use and shoreline improvement projects. The list of research documents includes:

- **Leonard Lake: Water Quality and Algal Blooms: Status, Monitoring and Management** (*2017*), Dr. Sue Watson and Hedy Kling (Appendix G)
- **Internal Phosphorus Load** (*May 2017*), Gertrud Nurnberg, Ph.D., Freshwater Research (Appendix H)
- **Leonard Lake Recreational Carrying Capacity Study** (*July 2017*), Jim Dyment, MHBC Planning Urban Design & Landscape Architecture (Appendix B)
- **Leonard Lake Shoreline Assessment Survey Report** (*2015*) Love Your Lake, Muskoka Watershed Council (available on request)
- **Leonard Lake Water Quality in 2017 and 2018** *(2018*), Gertrud Nurnberg, Ph.D., Freshwater Research (Appendix I)
- **Leonard Lake Land Use Survey** (*2006, Updated 2017*) District of Muskoka, Ministry of Natural Resources (Appendix E)

- **Brooklands Farm Wetlands and Leonard Lake Shoreline Inventory and Assessment** (*2011*) Jasmin Chabot, B.Sc for the Toronto Zoo and French Planning Services (available on request)

1.3.4 Engagement of Planning Expert

LLSA has retained Charles F. Burgess, MCIP, RPP who is a Professional Planner with Burgess Gleason Environmental. This firm assisted with the land use planning component of this Plan (see section 3.4).

SECTION 2: PRINCIPLES, VISION, GOALS AND ACCOUNTABILITIES

2.1 Principles

- → The protection of water quality and the environment is imperative in every action
- → Stakeholder commitment is fundamental to the success of our Lake Plan
- → Stewardship unifies Lake residents around a common goal
- → Voluntary compliance is always the preferred approach
- → Building and maintaining partnerships with government and community agents can lead to resilient solutions for the protection of the Lake
- → Respecting the diverse needs and interests of Lake users fosters Lake Plan interest and support
- → Minimizing the environmental impacts of development is a priority

2.2 Vision

How do we envision Leonard Lake in the future? The following statements reflect the values and desires of the Leonard Lake community.

Leonard Lake and the surrounding watershed is a place where:

- → The stewardship of the Lake and the watershed is embraced and championed through stakeholders of all ages
- → Development decisions are made within the context of the Lake and watershed capacity and reflect best practices in land use planning
- → The beauty of the landscape and shoreline, the tranquillity of the surroundings and the diverse ecosystem are protected and preserved
- → Preference is given by all to actions and activities that sustain the natural qualities and character of the shoreline, the Lake and its watershed
- → Water quality and quantity, wildlife, fish and natural habitat are safeguarded

- → Our Lake is a shared experience, where respect on the land and water is shown to others and expected in return

- → Activities are in place to foster friendship and community

2.3 Goals

2.3.1 Water Quality

- → To restore the water quality of LL as near as possible to natural historic levels, (i.e. the level of contaminants that would occur in nature prior to human habitation).

2.3.2 Stewardship and Education

- → To strengthen environmental stewardship through communication, engagement, awareness building and development of the LL volunteer network.

2.3.3 Lake Capacity

- → To protect the Lake from over-development, through the application of the Recreational Carrying Capacity model.

2.3.4 Property Development and Land Usage

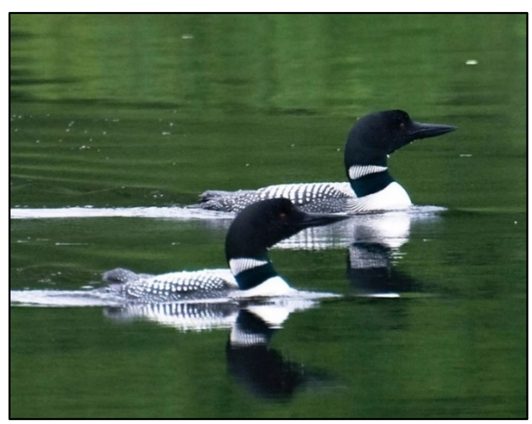
- → To maintain LL as a residential lake and protect the natural character and capacity of the Lake, water quality and the environment, deploying land use best management practices and appropriate planning policies.

2.3.5 Natural Shorelines "Ribbon of Life"

- → To promote the preservation and rehabilitation of the Lake shoreline to its natural state, to best support the diverse ecosystem habitats and contribute significantly to Lake health.

2.3.6 Trees and Vistas

- → To preserve and promote the natural tree canopy and ensure that the design and layout of buildings, structures and objects have minimal impact on the natural appearance of the shoreline and the view-scape from the Lake.



2.3.7 Fish and Wildlife

→ To support sustainable fish and wildlife populations and maintain stability in the bio-diverse wildlife species and their habitat through the implementation of sound environmental practices.

2.3.8 Watershed and Wetlands

→ To broaden knowledge and understanding of the LL Watershed and wetlands and raise awareness of the value of protecting our Lake and ground water.

2.3.9 Sense of Community

→ To foster an inclusive and mutually supportive community of all ages, based on a shared interest in, and responsibility for, protecting the natural environment of the Lake, and mutual enjoyment of the Lake.

2.3.10 Water Safety and Boating

→ To encourage safe and responsible boating and water recreational activities of all types that balance the diverse recreational interests of Lake residents; that preserve the shoreline, water quality and wildlife; that respect the desire for peace and tranquillity; that protect personal and common property; and ensure the safety of swimmers, boaters, Lake residents and their guests.

2.4 Shared Lake Plan Accountabilities

→ **All Leonard Lake Stakeholders** will strive to be good stewards of the Lake and its watershed and to foster cross-generational stewardship through positive example. Stakeholders will share the Lake in a way that respects the interests and property of others and ensures that visitors and renters are provided with the information and guidance to do the same.

→ **The Lake Association** will respect the rights of individual property owners while responding to changes and issues that could adversely affect the natural, social and/or physical features of the Lake or watershed. LLSA will work in partnership with government and other agencies to implement the Lake Plan vision and goals.

→ **All Lake Users** other than stakeholders (i.e. visitors, renters) will be made aware of and encouraged to act in accordance with the values of the community.

SECTION 3: ABOUT LEONARD LAKE

3.1 Township of Muskoka Lakes Official Plan 2013 Section B Waterfront, Subsection 14.1 Lake Plans

Policy 14.1 of Section B of the Township's Official Plan states that the creation of Lake Plans is encouraged for all lakes and rivers within the municipality. As a result, the creation of the Leonard Lake Plan helps fulfil this Official Plan policy.

3.2 Township of Muskoka Lakes Official Plan 2013 Section B Waterfront, Subsection 14.2 Lake Plans

This policy identifies that the land use aspects of a Lake Plan can be incorporated into the Township's Official Plan by way of Official Plan Amendment. Given that the municipality is currently in the process of updating the existing Official Plan, there is an opportunity to integrate the land use aspects of this Lake Plan into the Township's policy document. Subsection 3.4.4 of this Plan identifies the recommended policies to be included into the Township's new or updated Official Plan.

3.3 Township of Muskoka Lakes Official Plan 2013 Section B Waterfront, Subsection 14.3 Lake Plans

The following pages set out matters relating to land use as described in the Township of Muskoka Lakes Official Plan Consolidation (2013) Subsection 14.3, "that should be identified in a Lake Plan".

3.3.1 Location and Access (14.3 i)

Leonard Lake is situated in the geographic Township of Monck within the Township of Muskoka Lakes. The Lake is located approximately halfway between the Town of Bracebridge and the village of Port Carling, north of Hwy 118 West. Leonard Lake flows into Lake Muskoka at Milford Bay with a single usable public access boat launch location.

3.3.2 Location Within the Watershed (14.3 ii)

The District Municipality of Muskoka extends over a vast land area and includes hundreds of lakes within its boundaries. There are three major watersheds within Muskoka, including the Muskoka River, the Black River, the Severn River and a series of small rivers that flow into Georgian Bay.

Leonard Lake (elevation 275 metres above sea level) is a headwater Lake which cascades out through the historical Riley Farm, then meanders down to Milford Bay and out into Lake Muskoka (elevation 225 metres above sea level). The Lake has a watershed area of 4.19km^2 and is fed primarily by watershed precipitation and springs that release water from the Lake bottom. The map below illustrates the Leonard Lake watershed *(see Figure 2).*

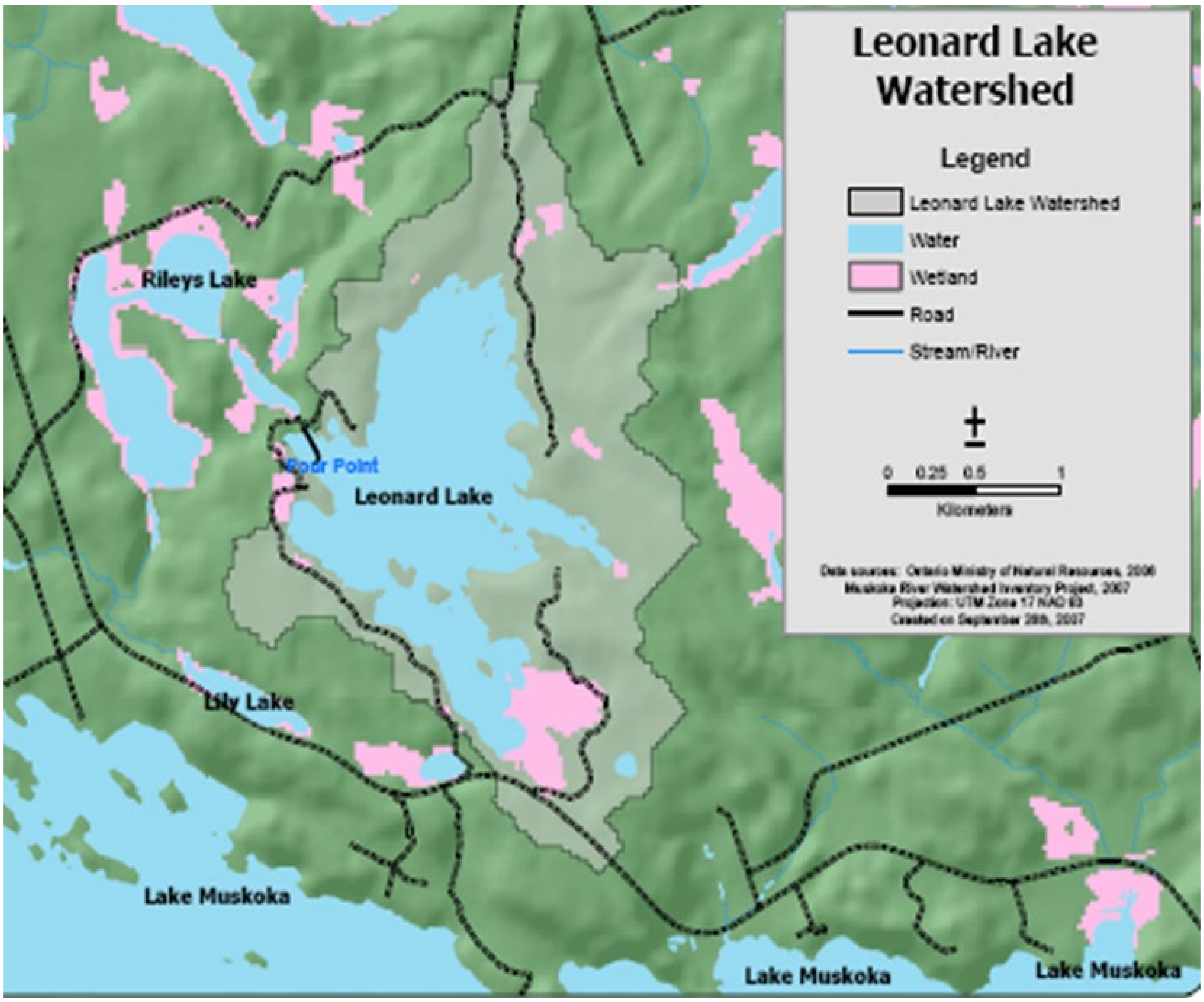


Figure 2: Leonard Lake Watershed (source - Leonard Lake Plan 2008)

3.3.3 Size and Shape of Leonard Lake (14.3 iii and iv)

Leonard Lake is a small-medium sized lake with a surface area of 195 hectares. The key facts about Leonard Lake are included in *Table 1* below. There are several maps that display the shape of the Lake included in this Plan *(see Figures 1, 2, 3 and 4).*

Table 1: Leonard Lake Fact Sheet (source - extracted from MNR, Parry Sound District 2010, updated 2015)

Leonard Lake Fact Sheet	
Official Name	Leonard Lake
County/District	Muskoka
Geographic Township	Monck
Municipality	Township of Muskoka Lakes
MNR Admin. Area	Bracebridge
Lat./Long	45.074 N -79.447
W UTM (NAD83)	17 622268 4992393
Topographic Map (1:50,000)	31E03 Drainage
Basin: Basin	Muskoka River – Lake Muskoka
Surface Area (ha)	195
Maximum Depth (m)	18.3
Mean Depth (m)	6.8
Elevation (m above sea level)	275
Perimeter (km)	13.9
Island Shoreline (km)	3.7
Volume (104 m^3:)	1330
Watershed (km^2)	3.9 (excludes area of lake)
Crown Land (%)	0
Provincial Parks	None

3.3.4 Number and Location of Islands (14.3 v)

Leonard Lake has a total of twenty-one islands ranging from 0.02 acres to 4.0 acres in size. Only nine of the islands are used during the open water seasons by eight owners. Of the nine seasonally used islands, six have permanent structures, one island has been used for camping with a seasonal tent structure, one has just a dock used for docking boat and swimming and one other island is also used for camping and has a storage structure *(see Table 2).*

Table 2: Inventory of seasonally used Islands on Leonard Lake - extracted from TML property assessment roll, 2019

Designation	Shoreline	Acres	Designation	Shoreline	Acres
Island A*	1450	3	Island N*	710	0.55
Island C*	1770	4	Island O*	775	0.66
Island D	n/a	0.03	Island P	250	0.12
Island E*	420	0.29	Island R*	360	0.18

Island F*	582	1.5	Island S	300	0.07
Island G	200	0.05	Island T*	n/a	0.65
Island H*	300	0.11	Island U	n/a	0.03
Island J	130	0.02	Island V	n/a	0.07
Island K	130	0.02	Island W	n/a	0.24
Island L	130	0.02	Island X	185	0.04
Island M	130	0.02	* Island - Seasonally Used		

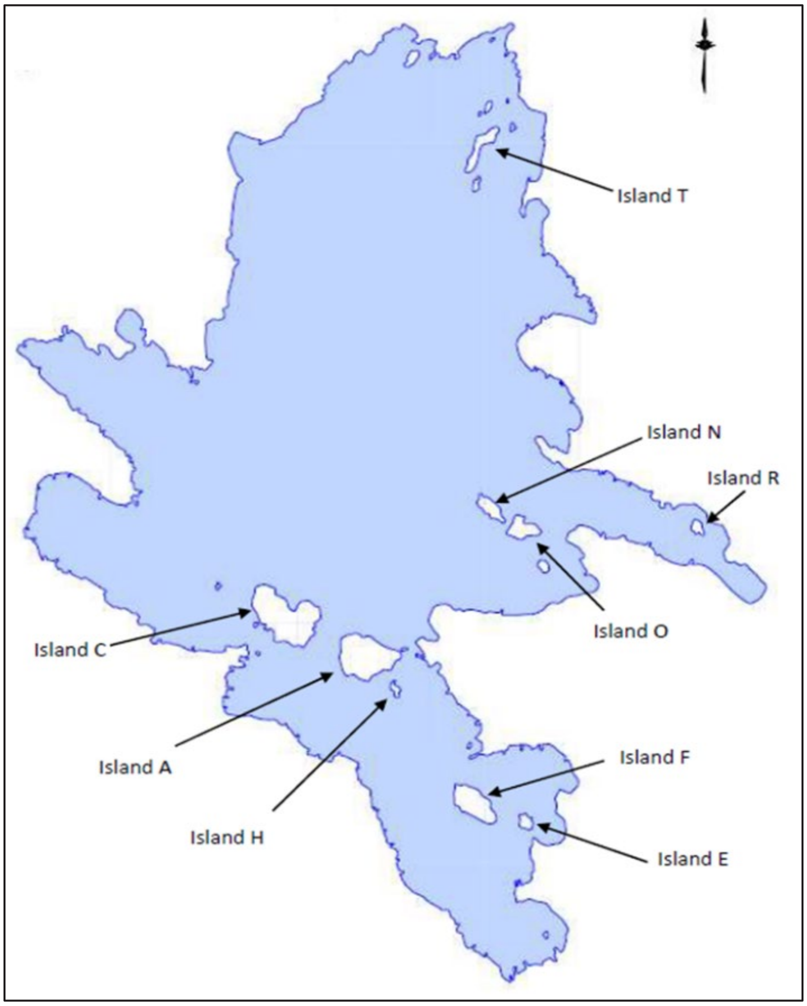


Figure 3: Location of 9 seasonally used Islands in Leonard Lake

3.3.5 Locations of Areas of Steep Slopes and Narrow Water Bodies (14.3 vi)

A Love Your Lake study in the summer of 2013 (Leonard Lake Shoreline Assessment Survey Report, 2015) assessed 188 properties on Leonard Lake, totaling 15,053 metres (100%) of the shoreline. Trained staff from District Municipality of Muskoka (DMM), in conjunction with the Muskoka Watershed Council, performed a detailed assessment of assessed each individual property.

3.3.6 Steep Slopes

Average slopes were recorded, and one property, or 0.5% of the properties assessed, had a very steep slope, 16 properties (8.5%) had steep slopes, 63 properties (33.5%), had moderate to steep slopes and 108 properties (57.4%) had gentle or flat slopes.

3.3.7 Narrow Water Bodies

The Lake includes a narrow eastern bay that ends at shoreline wetlands (Leonard Lake Watershed Map, MNR 2006) and may meet the definition of a narrow water body, that is, a navigable lake with a minimum distance from shoreline to shoreline of generally less than 150 metres (500 feet) for at least 100 metres (330 feet) along both shorelines and a perpendicular distance generally along the bay's axis from the shoreline to shoreline measurement to the end of the bay of at least 100 metres (330 feet).

3.3.8 Topography, Landscape, and Shoreline Features (14.3 vii)

Leonard Lake has a complex shoreline morphometry, largely composed of exposed bedrock or stones with a few proximal or shoreline wetland areas. The Leonard Lake Shoreline Assessment Survey Report (2015) reported that 85% of properties have buildings set back less than 30 metres and 91% of properties on the Lake have thin soils.

The Shoreline Land Use Survey (Map) for Leonard Lake, produced in 2006 by the District Municipality of Muskoka and updated in 2017 (see Appendix E), records data on shoreline vegetation, shoreline structures and the first 20 metres of land surrounding a waterbody. *Table 3* from the 2017 Survey located below, identifies the Leonard Lake shoreline lengths, and percentage results for various shoreline features.

Table 3: Shoreline Inventory results. (source - 2017 Shoreline Land Use Survey)

Shoreline	Type	Length (m)	Percent
NB	Beach	43.75	0.25
NM	Mud	24.75	0.14
NR	Rock	9,835.34	56.18
NS	Shrub	6,396.53	36.54
OMMB	Man Made Beach	40.01	0.23
OMR	Marine Railway	33.60	0.19
OSD	Deck	103.14	0.59
RC	Concrete Ramp	45.80	0.26
RN	Natural Ramp	10.71	0.06
RS	Stone Ramp	25.72	0.15
RW	Wood Ramp	26.32	0.15
SWS	Wood Shore Wall	146.03	3.15
SWW	Stone Shore Wall	551.66	0.83
YLU	Unbuffered Lawn	222.59	1.27
Total		17,505.94	100.00
Natural		16,300.37	93.11
Altered		1,295.57	7.40

3.3.9 Wetlands and Identified Natural Heritage Lands and Locations of Species of Conservation Concerns (14.3 viii)

"How Much Habitat is Enough" (Environment Canada, 2013) states that wetlands can provide benefits anywhere in a watershed, but in key locations such as headwater areas (for groundwater discharge and recharge) particular wetland ecological and hydrological functions can be achieved that include the protection of groundwater discharge or recharge or both.

Wetlands play a very important role in the natural heritage system, since they provide habitat for plants and animals; store water for groundwater recharge purposes; trap sediments, nutrients and contaminants thereby improving downstream water quality; provide corridors for plant and animal movements; and, provide flood control and protect shorelines from erosion.

In 2011, Adopt-A-Pond, French Planning Services and members of the Lake community conducted a multi-year program, that included Brooklands Farm and Leonard Lake, to identify and protect significant wetlands.

Six different habitat sites were mapped along the periphery of Leonard Lake shoreline including: beaches, exposed bedrock, shady substrate and wetlands that were identified as one or more of turtle nesting, basking, foraging and overwintering sites and fish habitat *(see Figure 4).*

Many of these sites had a vegetation community similar to the fen and bog communities on Brooklands Farm. Two artificial loon nesting sites have been placed on the Lake by local Lake stewards along the eastern shoreline and north-western shoreline.

Invasive species: European Frog-bit is present in small quantities at several locations throughout the Lake. Existing MNR fish habitat mapping correlated with the majority of the mapped wetland habitat types during the shoreline inventory.

Brooklands Farm wetlands and the western shoreline of Leonard Lake are hydrologically connected via stream corridors and groundwater seepage to several “backlot” wetlands. The wetlands mapped in 2011 denote only a portion of the total wetland area in the Leonard Lake watershed and it would be important to map the extent of these areas and work with MNR to ensure standards are met and revised mapping is distributed to all management agencies to protect wetland and fish habitat. *Table 4* includes fauna species identified during the study, however, further classification of wetlands and a full plant species list is required - some may be important species at risk.

The sandy beach areas need protection from incompatible land uses; these areas are important nesting sites for turtles.

Education and awareness efforts are required so that landowners abutting the wetland habitats are cognizant of activity on land during the nesting season.

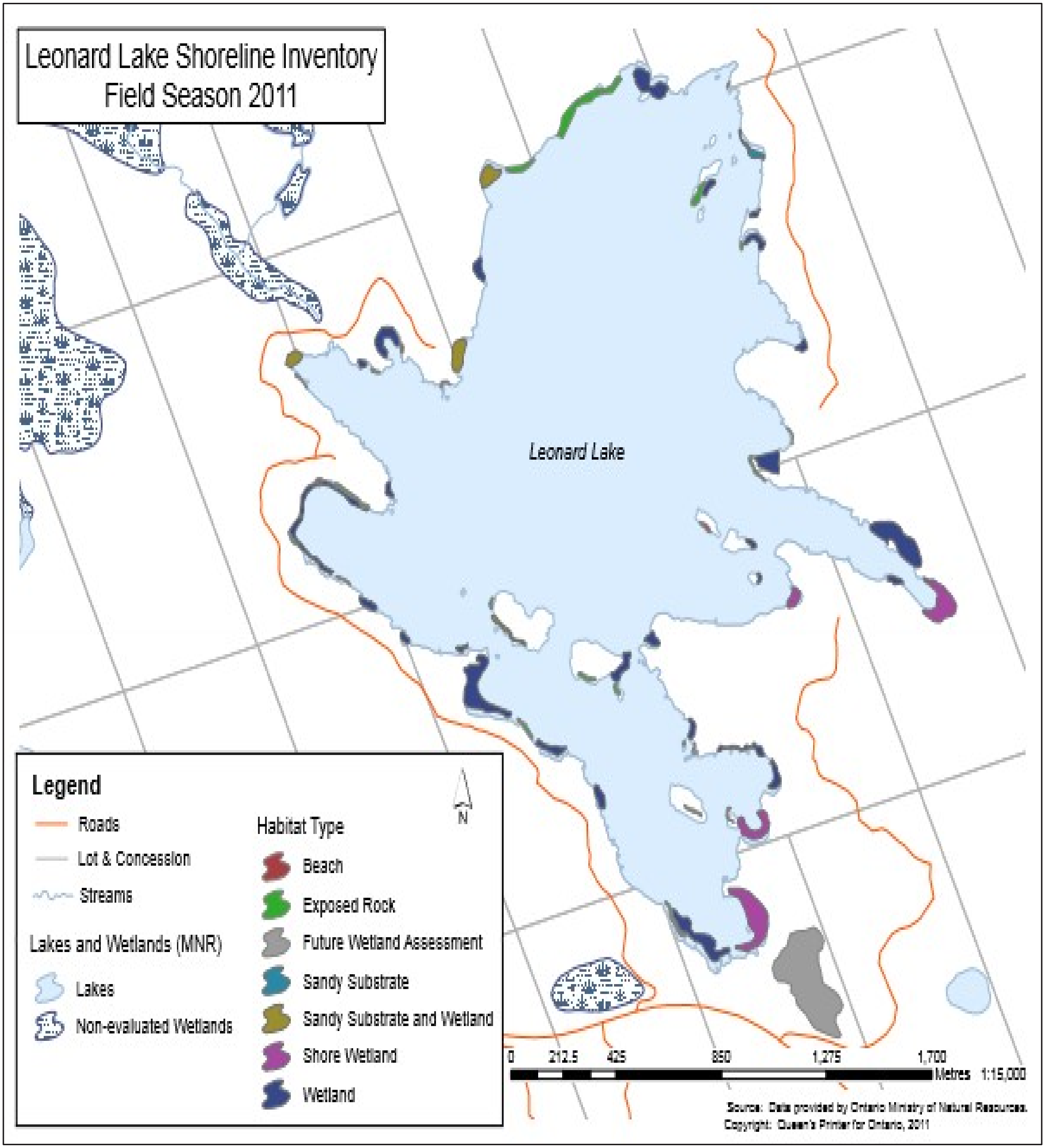


Figure 4: Leonard Lake Shoreline Inventory 2011

Table 4: Leonard Lake 2011 Identified Fauna Species (source – Adopt-a-Pond and French Planning Services 2011)

Leonard Lake - 2011 Identified Fauna Species		
Common Loon American Bittern Great Blue Heron Virginia Rail Double-crested Cormorant Wood Duck Mallard Turkey Vulture Norther Harrier Red-tailed Hawk Ring-billed Gull	Black-billed Cuckoo Norther Flicker Pileated Woodpecker Downy Woodpecker Eastern Phoebe Eastern Kingbird American Blue jay Barn Swallow Black-capped Chickadee Cedar Waxwing Common Yellowthroat Song Sparrow Swamp Sparrow	American Goldfinch Brown-headed Cowbird Green Frog Spring Peeper Painted turtle Pumpkinseed Smallmouth bass Yellow perch Brook Stickleback Fathead Minnow Phoxinus spp. River Otter Muskrat

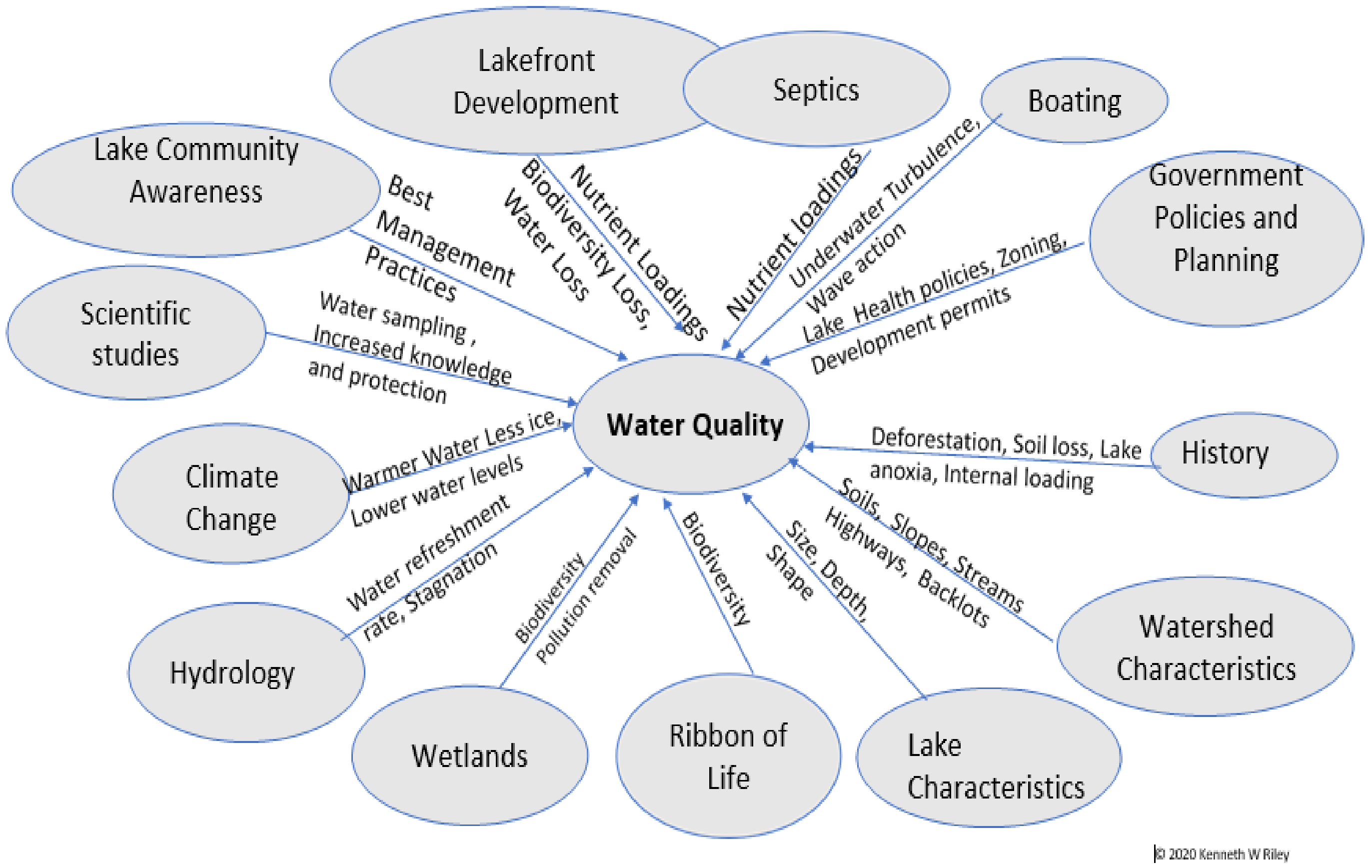
3.3.10 Water Quality and the Relationship to Development Capacity (14.3 ix)

Water quality and Lake health are of primary importance to the enjoyment of our Lake for both present and future generations. In *Figure 5* below, the inter-relationship and complexity of factors, both human influenced and natural, shape the state of water quality in Leonard Lake.

With respect to Lake characteristics, as noted, Leonard Lake is a headwater lake in a small catchment area (4.19 km^2) in the Algonquin-Lake Nipissing ecoregion of the Boreal Shield Ecozone. The catchment is composed of Precambrian bedrock covered by a thin layer of granitic loam sandy till with rocky outcrops. Surface water inputs occur largely from precipitation, direct runoff and small streams. There are groundwater springs in the Lake, but the contribution of groundwater is unknown.

While factors, such as the shape, size, depth, soils, wetland areas, watershed and history are considered as either natural or fixed characteristics, most of the other water quality influencers in *Figure 5* are subject to human impacts that either help to maintain or improve water quality, or conversely, contribute to water quality degradation. Thus, we must understand and take informed action to mitigate negative influencers (e.g. poor development planning, deficient septic systems, excessive turbulence from boating in vulnerable or shallow areas of the lake, lack of effective buffer zones at shorelines, and the leaching of, or direct use in the Lake of pollutants such as soap, shampoo or chemicals) through best management practices and land use policies if we are to effectively maintain our water quality and Lake health.

Figure 5: This diagram was created by Ken Riley to illustrate the factors that directly



impact water quality)

Natural factors such as our rocky shores, infertile soils, good maximum Lake depth, and location as a headwater lake have helped create and sustain water quality, however, other features present challenges. The Lake has a shallow south basin which is generally less than 8m deep, and a deep northern segment (maximum depth 16-17.5 m). The shallow basin rests in the path of a primary motorized boat lane and that is problematic due to the potential release of nutrients from the turbulence of Lake bottom sediment.

A single small outlet at the western side has a discontinuous flow into Milford Bay, Lake Muskoka, and consequently, the Lake has a long turnover rate with about 20% of the total

volume renewed each year. As a result of this limited flushing rate, water quality issues are slow to rectify. In addition, thin soils over-laying steep slopes tend to erode easily when disturbed by development, thus leaching nutrients into the Lake. Finally, about 17% of properties on Leonard Lake have mowed lawns which may require fertilizers and chemicals to thrive. The Muskoka Watershed Council advises that about 55% of lawn precipitation ends up in the Lake rather than filtering through the soil (a process that removes many contaminants and phosphorus enriching nutrients). Lawn grasses also have short root systems and do not bind soils well which leads to erosion problems.

Historical factors including the early pine deforestation of past centuries, and more recently, aged and potentially inadequate septic systems[i] installed with early development, may have contributed to "legacy pollution" in parts of the Lake, manifested by areas of low oxygen, that is, anoxia near the Lake bottom. The impact of climate change on water quality (warmer waters, less ice, erratic rainfall) is likely to become increasingly important as a stressor to our water quality and Lake health.

The cumulative impact of **human-influenced factors** on water quality is estimated to have raised phosphorus in the Lake from a low pre-development average of naturally-occurring phosphorus levels of 4.0 parts per million (ppm) to its present average of 6.3 ppm. Thus, human-influenced factors have resulted in a rise in phosphorus of over 50% above natural levels (using long-term monitoring data from the District of Muskoka and Dorset Environmental Science Centre).

Cooperative work between Leonard Lake and local government is essential, firstly, to fully understand policies regarding land use, but also to ensure that the Lake vulnerabilities are shared and that Leonard Lake is protected through Lake specific enforceable measures enshrined in the Township Official Plan. Our Lake Association has actively supported water quality monitoring and scientific studies for many years, including those led by the District of Muskoka, the Lake Partner Program with the Dorset Environmental Science Centre, and more recently, the Algae monitoring study undertaken in partnership with the Muskoka Watershed Council. We look forward to continued cooperative work in this valuable endeavor.

Three expert-led Lake studies in the 2017 season, ongoing water sampling and testing, and algal bloom events on the Lake have led to an increased understanding of the challenges and vulnerabilities of Leonard Lake water quality. The knowledge gained by such studies can help protect our water quality, but positive change is dependent on stakeholder commitment and stewardship actions, and the implementation of protective measures through legislation and enforcement at the municipal level.

One of the 2017 studies conducted by Freshwater Research (Internal Phosphorus Load, Gertrude Nurnberg, 2017) recommended reduced boat speeds on areas of our Lake, particularly in the shallower south basin where turbulence can release internal loading of nutrients and contribute to further algae blooms and water quality degradation.

A second study (Leonard Lake Recreational Carrying Capacity, Jim Dyment, 2017) indicates that Leonard Lake is currently over-developed by 75% based on current residential units when calculating the recreational carrying capacity of the Lake. Clearly, increased development density will intensify the human impact on water quality in our Lake. Based on this information, it is recommended that new lot creation be prohibited along the shoreline of the Lake.

Development, a known source of nutrient release and leaching must be managed carefully as trees, plants, and soil are cut, uprooted and removed. Existing vacant lots if developed, and a large tract of land on Leonard Lake approved for multiple lot development will concentrate land disturbances and the release of phosphorus[ii] into the Lake. Mitigating practices are required such as meticulous site planning and management and possible staging of building activities. These same standards and best management practices must also be applied to all redevelopment of existing structures on the Lake.

The third 2017 study, “Leonard Lake Water Quality and Algal Blooms” was conducted by S.B. Watson of the University of Waterloo and H. Kling ATEI of Winnipeg Manitoba, both highly regarded water quality scientists.

The major results of this study showed that Leonard Lake has a low to moderate level of biomass growth and a diverse algal community dominated by lipid-rich diatoms and flagellates (high quality food for the upper food-web) and small Cyanobacteria and green algae, indicative of an oligotrophic (nutrient poor) transitioning to a mesotrophic (moderately enriched) lake. A number of major concerns were identified:

→ Testing over the season at different depths and at four sites indicated that nutrient averages (total phosphorus, total dissolved P and dissolved inorganic nitrogen) often exceeded long term averages on record.

→ The study indicated a potential for the low levels of noxious bloom-forming Cyanobacteria present across much of the Lake to develop localized blooms in response to nutrients entering the Lake (e.g. tree and vegetation disruption during development or redevelopment; shoreline septic systems).

→ In 2017 an LLSA "Eyes on the Lake" campaign resulted in 10 reports of possible near-shore bloom sightings. Four of the samples collected in mid-September from surface scums were composed largely of a blue-green algae called *Dolichospermum*, which has been reported as a toxin producer in other lakes.

→ Significant vulnerability to low level dissolved oxygen in bottom waters at several sites across the Lake has implications for both internal loading and the degradation of fish/aquatic invertebrate habitat.

→ Appreciable variances in algal biomass and species composition, and a vulnerability to inshore blooms were noted. This vulnerability is predicted to increase with climate change.

3.3.10.1 Recommendations of the Report included

→ A moratorium on further lot severances apart from consolidations;

→ The restriction of shoreline development to maintain a vegetated buffer strip and to minimize runoff;

→ Continued vigilance on the capacity, age and status of septic and other wastewater systems and to work with the Township regarding septic efficacy assessments;

→ The increase of water quality testing site locations, frequency and type; and the continuation of the LLSA "Eyes on the Lake" program as an early warning system for blue-green algae identification;

→ Stakeholder education regarding the impacts of motor boats on Lake health; and

→ Further water sampling for internal loading due to anoxic conditions in the Lake.

Leonard Lake has experienced three years of algal blooms since 2017: Several small transient blue-green algae (Cyanobacteria) blooms occurred in September 2017 confirmed by our Winnipeg-based algal taxonomist; a Cyanobacteria bloom in August 2018 confirmed by the Ministry of the Environment, Conservation and Parks (MECP), resulting in a posted public health advisory for Leonard Lake residents; and a Lake-wide bloom of golden-brown algae in May-June 2020 confirmed by MECP.

Nutrient loading, a known factor in algal bloom development can occur naturally, but the human-influenced factors, noted in *Figure 5* and the proceeding narrative, are demonstrably additional contributors.

As a direct result of the blue-green algae bloom confirmation on Leonard Lake, and in keeping with section C2.6.3.2 of the District of Muskoka Official Plan (2018), a waterbody-wide causation study tailored to the unique conditions of a lake will be conducted by the District "to determine the cause of and/or relative contributing factors to the water quality indicator". For Leonard Lake, its limited flushing rate and potential for slow recovery from water quality issues could be considered a key factor requiring a study of Lake hydrology.

3.3.11 Historical Development and Cultural Heritage (14.3x)

Robert Greenham, a long-time resident on Leonard Lake since 1955 and advocate of Lake health and the preservation of water, land and wildlife, took time in his senior years to research and document some historical and anecdotal information about Leonard Lake - glacial ice about 50,000 years ago that created pot lakes such as Leonard, the aboriginal fishing and hunting use, the offer of land to homesteaders in the 1800's, a sawmill, and the discovery of a meteorite that fell in the 1930s. The full letter written to his granddaughters can be found in Appendix C.

3.3.12 Existing Land Use (14.3 xi)

Leonard Lake is primarily used for residential purposes. Most of the shoreline properties (96%) are cottagers or year-round homes. Approximately 21% of the residences are year-round and 17 property owners live full time on the Lake. There are several waterfront properties around the Lake that are rented through various online services and the Lake has one backlot commercial property.

The Township owns approximately 14 Leonard Lake properties including five small island outcrops. *(Note source: TML assessment roll, 2019).*

The 2015 Watershed Council “Love Your Lake” Shoreline Assessment Summary Report indicated that Leonard Lake had no waterfront commercial or farming properties. That has been the case on the Lake for many decades and remains so, as at the writing of this report in 2020.

Table 5 of the 2017 Shoreline Land Use Survey (Appendix E) identifies land use within the “backlot” area which refers to the first 20 metres of land surrounding a waterbody.

Table 5: Leonard Lake Backlot Areas and Percentages (2017 Shoreline Land Use Survey)

Backlot	Type	Area (m^2)	Percent
NFC	Coniferous Forest	4,505.49	1.63
NFM	Mixed Forest	89,526.49	32.41
NFT	Thinned Forest	146,747.80	53.13
NO	Overgrowth	5,411.27	1.96
NR	Rock	3,974.29	1.44
NS	Shrub	1,571.02	0.57
OR	Road	612.19	0.22
OSSCO	Cottage	211.17	0.08
YL	Landscaped Yard	10,206.24	3.73
YLB	Buffered Lawn	5,696.29	2.06
YLU	Unbuffered Lawn	7,655.72	2.77
Total		276,217.97	100.00
Natural		251,736.36	91.14
Altered		24,481.61	8.86

3.3.13 Existing Built Form (14.3 xii)

Most of the residential buildings on Leonard Lake are original or upgraded cottages that have been in existence for many years.

Boathouses are not common built form on the shorelines of the Lake. According to the 2017 Shoreline Land Use Survey Structure Count Table (see Muskoka Water Web), boathouse totals included 2 - 1 slip, 1 - 2 slip and 8 "on-land" boathouses. There has been an additional build since the report. Due to the presence of many small lots, and high-density development on most of the Lake, the addition of boathouses to the shoreline of Leonard Lake is not recommended.

3.3.14 Development Trends (14.3 xiii)

The general trend has been from simple seasonal cottages to better built and year-round structures. In addition to one year-round residence built on an empty lot, there are approximately nineteen redeveloped lots and six major renovations - a total of approximately 17% of the residences on the Lake are newly build residences or substantial upgrades.

3.3.15 Boating Capacity (14.3 xiv)

Leonard Lake is a diverse lake from a boating perspective. Visual observation of residential properties indicates that virtually every property has a powerboat and one to several motorized watercraft. Over the years the number of inboard/outboard, personal watercraft and wake boats has increased. In addition to motorized vessels, the Lake has a significant number of kayaks, canoes, paddle boards, sailboats and swimmers that compete for Lake space, and property owners have identified that they are increasingly concerned about water safety and property damage from wake and ski boat activity.

3.3.16 Open Space, Recreational Areas, Trails (14.3 xv)

There is Open Space designation at various Lake points that includes: several small rock islands (OS4); a marshy area at the entrance to LL Road 2 (OS3); the central and north part of LL Road 1 abutted by Kirrie Glen Golf Course (OS2); and a central/north section of the west side of the Lake that is part of Brooklands Farm (OS2*). (See Schedule 38 Muskoka Web Map)*

There are no identified public spaces or public trails around the Lake.

3.3.17 Public Access Points (14.3 xvi)

There is one useable public access point at the southernmost end of the Lake, approximately 100 metres off Highway 118 West.

3.3.18 Development Potential and Capacity (14.3 xvii)

The development potential and capacity of lakes has not been universally defined or historically well researched. The tools available to guide planners are limited, however, the Provincial guidance on this includes the Ontario Lakeshore Capacity Assessment Handbook (May 2010), (the Lake-Cap Model) which is still used as core guidance in many Ontario Municipalities. The following is an excerpt from the handbook that summarizes the model and its limitations:

3.3.18.1 About Lakeshore Capacity Assessment

Lakeshore capacity assessment (a generic term, but herein used to describe the Province's recommended approach) is a planning tool that can be used to control the amount of one key pollutant — phosphorus — entering inland lakes on the Precambrian Shield by controlling shoreline development. High levels of phosphorus in lake water will promote eutrophication (excessive plant and algae growth), resulting in a loss of water clarity, depletion of dissolved oxygen and a loss of habitat for species of cold-water fish such as lake trout. While shoreline clearing, fertilizer use, erosion and overland runoff can all contribute phosphorus to an inland lake, the primary human sources of phosphorus are septic systems — from cottages, year-round residences, camps and other shoreline facilities. Lakeshore capacity assessment can be used to predict the level of development that can be sustained along the shoreline of an inland lake on the Precambrian Shield without exhibiting any adverse effects related to high phosphorus levels.

It should be emphasized that lakeshore capacity assessment addresses only some aspects of water quality — phosphorus, dissolved oxygen and lake trout habitat. Municipalities and lake planners also need to consider other pollutants (such as mercury, bacteria and petroleum products) and other sources of pollution (including industries, agriculture and boats). It must also be emphasized that water quality isn't the only factor that should be considered in determining the development capacity of lakes. Factors such as soils, topography, hazard lands (i.e. prone to flooding; steep slopes; and, narrow waterbodies), crowding and boating limits may be as, or more important than water quality. Finally, it's key to emphasize, that to be effective, the technical process of carrying out lakeshore capacity assessment must be followed by implementation — in other words, the information obtained must be incorporated into municipal official plans and policies. (Ontario Lakeshore Capacity Assessment Handbook, Executive Summary VIII, (May 2010)

The handbook clearly recognizes that the measurement of phosphorus should not be the sole factor used to guide municipal and lake planners when assessing the development potential and capacity of a lake. That said, there is little provincial guidance provided on how to assess other factors such as soils, topography, lake hydrology, climate change, cottage density, more year-round residences, boating limits, impact on wildlife and fish habitat, water biology and other lake specific elements. However, the lack of Provincial guidance on this does not prevent the use of other common capacity measures and concepts applied in other jurisdictions. While the handbook is still in use today and Leonard Lake is considered Over Threshold as per the Lake-Cap model, clearly there are many other factors to consider when planners assess the development potential and capacity of a lake.

The DMM Revised Water Quality and Lake Health Program (2016) ("the DMM Policy") deviates from the Lake-Cap Model guidance with respect to how phosphorus levels are employed to model the capacity of a lake. In particular, the DMM Policy increases the phosphorus limits (20 ug/l) that would classify a lake as "Over Threshold". This new measure of 20 ug/l of phosphorus set as a threshold to avoid nuisance algae blooms, has proven inappropriate in the case of Leonard Lake, because both severe golden brown and blue-green toxic algae blooms have been present at much lower levels of phosphorus.

The Policy further recommends implementing development best management practices to limit human activities that contribute to higher levels of phosphorus. Although not explicit, the underlying premise is that by effectively managing the inputs of human caused phosphorous into a lake, there is no limit to the amount of development a lake can sustain. Unlike the Lake-Cap Model, the DMM Policy does not reference other planning factors and lake characteristics that could impact development potential and capacity of a lake. It should be noted that the DMM Policy did not predict the Leonard Lake 2018 Blue Green Cyanobacteria algae bloom. A more holistic approach as articulated in the Lake-Cap Model is needed.

3.3.18.2 Recreational Carrying Capacity (RCC)

To better understand one aspect of the development potential and capacity of Leonard Lake, LLSA commissioned Jim Dyment of MHBC Planning Urban Design & Landscape Architecture in June of 2017 to conduct a Recreational Carrying Capacity study of the Lake based on the Ministry of Natural Resources RCC model developed by Mr. Reiner Jackson. Model results are one method of measuring the residential density and the associated recreational carrying capacity that a lake can accommodate.

Mr. Dyment calculated that the optimum RCC for Leonard Lake is 91 dwellings. The existing or permitted dwellings on the Lake is a total of 167, or 1.83x greater than the RCC model threshold. Given that the Lake has exceeded its recreational carrying capacity by a wide margin, it seems credible that there is no additional capacity for new lot creation on Leonard Lake, and the resulting development that would bring. (Leonard Lake Recreational Carrying Capacity Study, Dyment, 2017, produced with permission, is included as Appendix C.)

Summary

Determining the development capacity of a lake is critical to help prevent excessive shoreline development and encourage land-use decisions that maintain or enhance water quality. In the absence of a comprehensive model that looks at a range of development factors or a methodology that assesses and uses those factors to inform planning decisions, this Lake Plan will take guidance from the Lake-Cap Model and the Recreational Carrying Capacity model, to determine from a planning perspective, the development potential for Leonard Lake. It is believed that using this combined approach is prudent for our Lake, is consistent with the Ontario Provincial Policy Statement and provides a broader perspective with which to assess long term Lake health.

3.3.19 Specific Policies and Standards for Development (14.3 xviii)

Section 14.2 of the Township of Muskoka Lakes' Official Plan states that the land use aspects of a lake plan can be incorporated into their Plan by way of an Official Plan Amendment. Given that the Township is currently in the process of updating their present Official Plan, the integration of section 4.0 of this Lake Plan (Leonard Lake and the Township of Muskoka Lakes Official Plan), or part thereof, is timely without the need for a subsequent amendment to the Township's Official Plan.

4.0 Leonard Lake and the Township of Muskoka Lakes Official Plan, 2020

4.1 Jurisdiction

The Leonard Lake Plan was created and formulated by the Leonard Lake Stakeholders Association with input and support from a majority of the Lake's property owners. This 2020 Plan replaces an earlier version approved by the Association membership in 2008. The location of Leonard Lake in the context of the Township is shown in Appendix D. The scope of the Leonard Lake Plan includes the Lake, the watershed, islands and lands and backlots surrounding the Lake accessed by Leonard Lake Road #1, Leonard Lake Road # 2, Glen Gordon Road, and downstream property owners to Highway 118 West.

4.2 Goals

The goals of this Official Plan as it relates to Leonard Lake are as follows:

- To maintain, protect and preserve the three inter-related components of water quality, visual quality and recreational quality;
- To maintain the health of the Lake's ecosystem;
- To conserve the watershed's natural heritage features for their long-term protection;
- To protect, improve, or restore the quantity and quality of the Lake's surface and groundwater resources; and
- To ensure that all new development occurs in an environmentally sustainable fashion and respects the capacity and natural character of the Lake.

4.3 Objectives

The objectives of this Official Plan as it relates to Leonard Lake are as follows:

- To reduce impacts on the Lake's water quality through proper nutrient measurement, management and planning;
- To ensure development/redevelopment does not increase contaminant loads to the Lake, including phosphorus, chlorides and suspended sediments, by utilizing Low Impact Development (LID) principles;
- To promote a culture of water conservation including the use of high efficiency plumbing fixtures, water re-use and rainwater harvesting;
- To protect all wetlands within the Lake's watershed area from incompatible land uses and development;
- To maintain the existing forest cover within the watershed;
- To maintain, and where possible, restore the vegetation protection zone along the Lake to a minimum of 30 metres from the water's edge; and

→ To ensure that development decisions are made within the context of Lake capacity and the small size of the Lake.

4.4 Policies

1.0 Lot Creation	
1.1	The Recreational Carrying Capacity ("RCC") model is to be recognized and applied. As a result, in no case shall waterfront lots be created with the exception that the consolidation of lots, the donation of lands to a land conservancy, and the minor amendment of lot lines between adjoining lots would be permitted. This policy shall not restrict development on existing lots of record.
1.2	If the RCC model no longer applies, a minimum lot area of 1ha (2.5 acres) and minimum frontage of 120 metres (~400') are required.
2.0 General Development and Redevelopment Policies	
2.1	**a)** In all cases, maximum lot coverage shall not exceed 8%, calculated on the basis of that portion of the lot within 60 metres (200') from the high-water mark for all structures. **b)** A dwelling shall not exceed 325m^2 (~3,500 square feet) permitted on the lot. **c)** Access to a waterbody over privately owned lands by means of a right-of-way shall not be permitted for backlots. Easements or rights of way for backlots for the purpose of private water supply shall not be permitted. **d)** In keeping with the natural forested character, the many small lots and narrow bays of this small lake, and the significant adverse impact that boathouses have on open water and shoreline sightlines, no new attached-to-land, floating or over-the-lake boathouses will be permitted.
2.2	All vacant lot development applications shall be supported by the following studies in addition to those reports required by the Township or any applicable consent or other order: **a)** Planning Justification Report demonstrating consistency with the Provincial Policy Statement and conformity with the District of Muskoka Official Plan; **b)** Natural Heritage Evaluation; **c)** Environmental Impact Study; **d)** Species at Risk (SAR) assessment addressing the provisions of the *Endangered Species Act*; **e)** Functional Servicing Report; **f)** Tree Preservation and Edge Management Plan;

	g) Ecological Offsetting Plan for the loss of any natural heritage feature or part thereof; and **h)** Cumulative Environmental Impact Analysis (as per final TML OP Policy Directions - #5).
2.3	As a condition of approval of any development application affecting waterfront property on Leonard Lake, the applicant and the Township shall enter into an appropriate enforceable subdivision agreement; consent agreement; site plan agreement; as the case may be, with no fixed term containing financial security and other provisions to reasonably ensure that the tree preservation area and shoreline vegetation protection zone will be maintained by the landowner.
2.4	Development of dwellings and ancillary buildings including any wastewater systems and site alteration, where possible, shall be set back a minimum of 30 metres from the highwater mark of Leonard Lake. If this is not possible then an overall net improvement should be achieved through on-site planning management measures.
3.0 Wastewater Treatment	
3.1	To maintain and improve the health of the Lake through the resulting reduction of nutrient load on the Lake, it is recommended that: **a)** the development of new lots and vacant lots shall be serviced with a tertiary sewage disposal system; **b)** in general, the redevelopment of an existing dwelling, including additions, shall be serviced with a tertiary sewage disposal system where possible and where appropriate; and; **c)** tertiary systems shall be used, where possible and where appropriate, when wastewater treatment systems on existing lots are replaced.
4.0 Lake Vegetation Protection Zones	
4.1	The 30-metre setback area or vegetation protection zone shall consist of natural, self-sustaining trees, shrubs, and plants. Where necessary, the vegetation protection zone shall be enhanced with the introduction of native, non-invasive trees and shrubs as a condition of development and approval.

4.2	Where targets cannot be met, a net improvement over the existing situation is required, or at a minimum, must conform to any specific policies within the Official Plan designation.
4.3	Notwithstanding Policies 4.1 and 4.2, uses and development that by their nature are ancillary use of waterfront lot owners, including trails to access the Lake, docks and existing boathouses will be permitted subject to compliance with the Township By-law.
5.0 Wetlands	
5.1	Wetlands within the Lake's watershed shall be protected from any site alterations including, without limitation, all incompatible land uses and development of such wetlands, and such wetlands shall be maintained in a natural state.
6.0 Prohibited Use	
6.1	There will be no commercial use of any waterfront property including, without limitation, resorts (including fractional ownership), camps, not-for-profit institutions, marinas, tent and trailer parks, contractors and commercial nodes.
7.0 Construction Mitigation	
7.1	Construction mitigation measures, stormwater management, or other techniques must minimize negative impacts on the water quality of the Lake. At a minimum, this shall include: **a)** delineation of riparian setbacks and buffers, and provisions to adequately protect these areas during construction (including measures to protect against mechanical damage to trees, and compaction of their roots); **b)** plans to install and maintain sediment fencing, and other erosion and sedimentation controls as required, down gradient of all areas of site disturbance; **c)** plans to manage soils and other materials, so as to protect against sedimentation; and, **d)** plans to stabilize any disturbed areas as quickly as practical.

4.5 Proposed Leonard Lake Stakeholder Initiatives

During the 2020 Lake Plan consultation process, Leonard Lake property owners and residents identified challenges faced by the Lake and recommended a number of actions as essential to address those key Lake challenges.

The comments below were heard with the most frequency during the consultations and many of the ideas will help shape an action plan going forward, both for the Leonard Lake Stakeholders Association and Leonard Lake residents and volunteers:

1. **Aging septic systems** are seen as a major source of Lake pollution and of nutrient leaching into the Lake. We could have an initiative driven by Lake residents that would help property owners identify deficient septic systems. Education about new waste system technologies would be helpful. This approach has worked on other lakes. As a start, many agents during the provision of septic pumping services can be asked to provide a basic assessment of septic tank efficacy. We also need to apply pressure on the Township to upgrade its sewage disposal monitoring and inspection. This is imperative, if collectively, we are to improve Lake health.
2. **Water testing for septic breakdown.** Is it possible to design a water testing protocol that can help identify problem septic systems on the Lake?
3. **We need to stay abreast of new technologies that might help with anoxia and blue-green algae**. Are there technology applications that might help?
4. **Other Lake pollutants need attention.** Old 2-stroke engines for example, need to be retired. No one should be shampooing and bathing in the Lake or dumping bilge at the boat launch.
5. Sustaining the **"Eyes on the Lake" water team** volunteer program is important, both as an early warning system to residents when algal blooms occur and as a way of building Lake data that could not only track water quality events but also identify water quality trends. **Education** regarding behaviour and practices that affects Lake health should continue.
6. **Communication and engagement** with and between stakeholders is essential. Property owners need to be informed and consulted regarding decisions involving the Lake.
7. **The Lake's shoreline needs protecting, as does the boat lane in the shallow south bay** where blue-green algae has been identified in three different years. Residents need to know that there is a proven link between boat speed and sediment disturbance which releases phosphorus and nitrogen into the water causing algae growth. Bird nesting areas can also be wiped out by wakes. Where are the loons? We have a big bay that is perfect for water sports. The challenge is to help all stakeholders realize that together we can responsibly take care of the few vulnerable areas of the lake and still fully enjoy the land, water and water sports.
8. **Geese are ruining our Lake**. Docks, rafts and shorelines are targets for goose and duck droppings. As a result, the water used for swimming, showers and in some cases cooking and drinking could be contaminated with E-coli. The geese love our Lake because there

are more and more grassy waterfront beds that provide prime feeding areas. A robust shoreline buffer that blocks the view to the water could deter geese, but few grassy lots on the lake have such a buffer. Chemicals are also a concern. Grass cultivation often requires “weed and feed" treatment which naturally leaches into the lake due to the shallow root system of grass and encourages algae growth.

9. **Safe boating.** On the water there is disrespect shown by boaters at times for each other and for property owners. Silent crafts and swimmers are most vulnerable. **Everyone who is in, or on the water, including renters and guests, must show courtesy, play safely and use common sense.** The big bay is the place for personal watercraft to play, not the small bays. Swamping small crafts is not a game.
10. Where have the fish stock gone? **MNR is no longer stocking our Lake.** Why have they given up on Leonard Lake? What can stakeholders do to identify the best sport fish for the lake and work with MNR to develop a stocking plan for the future?
11. **We are not against renters but a code of conduct is needed**. There are a number of owners on the Lake that seem to do it right. How do we engage all owners who rent out their properties to reach a solution that is workable. Short term renting can result in an excessive number of renters/guests on undersized septic systems, who in some cases do not respect the land and neighbours.
12. **Blasting on the Lake needs to be monitored by owners**. The laws around blasting are lax. As a result, owners need to take responsibility so that neighbours are safe and the land and Lake water are protected.
13. It is suggested that road committees around the Lake monitor the amount of sodium chloride or salt alternative that is added to the **winter road sand.** Lake chloride levels are rising.
14. **Our Lake is dramatically over-built.** Will the Township recognize this issue in its pending Official Plan? We need our Lake Plan to limit new lot creation, to protect the environment and to mandate well managed lot development. We also need our plan to be supported and enforced by the Township in its Official Plan and bylaws.
15. **The 30m waterfront setback** is mandated in the current TML Official Plan for our Lake and all over threshold lakes, but is not practical for many lots on Leonard Lake. The Township must be strongly encouraged to retain reasonable grandfathering rules for existing Lake lots with structures within the setback zone.
16. **Leonard Lake is a deer wintering yard** and will remain so, as long as deer habitat remains. The Ministry of Natural Resources and Forestry should be pushed to formally designate the areas surrounding the Lake that are deer wintering areas.
17. **Respect for neighbours** includes stopping late night noise and excessive daytime music at the shoreline. Both the Township by-law officer and the Ontario Provincial Police should be asked to monitor persistent daytime gunfire in the immediate area of the Lake. Respect also includes cleaning up lot garbage and abandoned equipment that is visible to others.
18. There are some **old derelict docks on the Lake** that may belong to people that are no longer able to get rid of them. These abandoned docks can pose a safety hazard to other Lake residents during spring ice breakup. We could **lead a work team of volunteers** to

disassemble the docks and haul them to the dump. The property owner could cover the dumping fee.

4.6 Conclusion

The importance of Leonard Lake to the Stakeholder Association and landowners is well documented through the creation of a Lake Plan in 2008. This Lake Plan builds upon the previous version by providing an updated context, well defined goals, and policies to help achieve the environmental and social objectives that the stakeholders desire to achieve. The protection of the Lake including its ecosystem health, water quality, water quantity, and natural heritage features and values is paramount to the LLSA and inhabitants.

The implementation and monitoring of any environmental plan is critical to its success. The goals, objectives, and management actions of this Lake Plan can be implemented through a variety of methods. In general, the implementation of the Leonard Lake Plan can occur through:

- Ontario's land use planning system under the *Planning Act*;
- District and Township programs and guidelines;
- Land stewardship initiatives;
- Continued research and study;
- Local volunteerism;
- First Nations engagement.

It is important to note that the successful implementation of this Plan will occur through effective cooperation and collaboration between all stakeholders. It is also envisioned that Plan monitoring will occur on an ongoing basis in order to ensure its effectiveness over time. As a result, this Plan will be reviewed regularly and updated accordingly to reflect new science, information, and policy.

Appendix A

Values and Concerns, 2008 & 2020

A "Lake Values and Opinions Survey" was distributed to 150 Leonard Lake shoreline and backlot property owners. 86 surveys (57.3%) were completed and returned. Stakeholder input from the survey formed the basis of the first Leonard Lake Plan in **2008.** A summary of the values and concerns identified in the survey can be found in this Appendix.

The LLSA Lake Plan 2020 Survey was distributed primarily through electronic means to 248 Leonard Lake property owners and family members that represented 156 shoreline, island and backlot properties. 160 surveys were completed and returned, 62% of which were completed by property owners. A brief summary of survey results can be found in this Appendix.

LLSA 2020 SURVEY/EXECUTIVE SUMMARY

What we enjoy
(top 10)

Relaxing
Swimming
Paddle Sports
Reading
Appreciate Nature
Socializing
Walking/Hiking
Power Boating
Motorized Sports

What contributes
(top 5)

Water Quality (100%)
Scenery (99%)
Fish/Wildlife Habitat
Lake Level
Natural Shorelines

What detracts
(top 5)

Development
Light Pollution
Large Wakes
Nighttime Noise
Daytime Noise

Water Quality has gotten worse (66%)
Less than 50% state water quality is "good" or "excellent"

What we should do
(top 3)

Manage development
Protect water quality
Maintain septic systems

Values and Concerns (Leonard Lake Plan 2008)

This Plan started in earnest with a Lake Plan Residents Workshop on August 6, 2005. Every stakeholder was invited to attend. Approximately 40 Leonard Lake stakeholders actively participated. The workshop provided valuable input on several topics - important things, special places, memories, current and future issues and priority issues.

Using the input gained from the Workshop, a survey was distributed in the fall of 2006 to all Leonard Lake stakeholders. One hundred and fifty (150) surveys were distributed and a total of 86 surveys were returned, for a very respectable 57.3 % response rate. Survey respondents identified the following values and concerns:

Values

According to the information queried from the surveys (see table below), Leonard Lake stakeholders value highly (very important or moderately important) the following lake features:

- Water quality;
- Natural landscapes;
- Night skies;
- Peace and quiet;
- Natural shorelines and wildlife; and
- Water levels

Personal Values that Contribute to the Enjoyment of Leonard Lake Percentages				
Values	Very Important	Moderately Important	Not Important	Don't Know
Water Quality	99%	1%	0	0
Landscapes (Scenery/View)	81%	16%	3%	0
Night Skies (no light pollution)	75%	19%	6%	0
Peace & Quiet (Tranquility)	74%	23%	3%	0
Natural Shorelines	69%	31%	0	0
Fish and Wildlife Habitat	67%	28%	5%	0
Water Quantity/Level	64%	32%	3%	1%
Non-Power Boating	44%	36%	17%	3%
Power Boating	16%	39%	41%	4%

Issues and Concerns

Respondents identified several issues that may negatively impact their quality of life on Leonard Lake:

- Water pollution from septic systems and garbage, surface run-off and pollutants, shoreline alteration, and boating activity;
- Future development along the shoreline and back-lots, inappropriate structures and lot sizes, and commercial development;
- Inappropriate use and lack of consideration towards other lake users from boaters, PWCs, ATVs and dirt bikes;
- Water level fluctuations; and
- General concern of overcrowding, increasing development and conflicting uses causing an overuse of the Lake.

The following table lists the results of the survey question that asked respondents to indicate their feelings about the activities and issues that impact the enjoyment of Leonard Lake.

Activities and Issues that Impact the Enjoyment of Leonard Lake

Percentages

Activities and Issues	Significant Impact	Moderated Impact	No Impacts	Don't Know
Water Pollution	79%	15%	6%	0
Future Development	68%	25%	2%	5%
Personal Water Craft	55%	33%	9%	3%
Overuse of the Lake	51%	30%	15%	4%
Night-time Noise	50%	24%	25%	1%
ATV's/Dirt Bikes	45%	22%	27%	6%
Wakes from Powerboats	44%	34%	22%	0
Vegetation Removal Along the Shoreline	40%	35%	19%	6%
Boat Traffic	38%	50%	12%	0
Fluctuating Water Levels	27%	63%	8%	2%
Outdoor Light Pollution	27%	44%	27%	2%
Daytime Noise	21%	43%	34%	2%
Snowmobiles	15%	21%	48%	16%

Appendix B

Leonard Lake Recreational Carrying Capacity Study, Jim Dyment (2017)

MHBC
PLANNING
URBAN DESIGN
& LANDSCAPE
ARCHITECTURE

KITCHENER
WOODBRIDGE
LONDON
KINGSTON
BARRIE
BURLINGTON

To:	**Leonard Lake Stakeholders Association**
From:	**Jim Dyment**
Date:	**July 12, 2017**
File:	**17161A**
Subject:	**Leonard Lake Recreational Carrying Capacity Study**

I prepared this report for the Leonard Lake Stakeholders Association to provide information about how a recreational carrying capacity model would apply to Leonard Lake. I understand that the Association is concerned about potential future development on the lake and would like to consider how that development may affect the recreational carrying capacity of the lake.

I have discussed the matter with the Township of Muskoka Lakes (Rian Allen, Senior Planner). Mr. Allen has indicated that the Township is interested in the results of the report and would appreciate receiving a copy of same once it has been received by the Association.

MHBC (formerly Meridian Planning) implemented recreational carrying capacity provisions in Official Plans in many municipalities in the District of Parry Sound. The Township of Seguin Official Plan, which covers the north end of Lake Joseph and Lake Rosseau, implements a recreational carrying capacity model. The policies in the Official Plan recognize the recreational carrying capacity as a key criteria when considering development applications. Recently, the Seguin Township was successful in refusing an application to create one additional lot on Oastler Lake on the basis of recreational carrying capacity. I understand that the Association representatives may have read that decision (OMB File PL151021).

History

The concept of recreational carrying capacity in the Province of Ontario was first developed in the early 1970's by a gentleman named Reiner Jaakson. Mr. Jaakson was an employee of the Ministry of Natural Resources. At the time, the Ministry was in the process of developing Crown Lands for sale to residents for cottages and was actively involved in the development and sale of waterfront lands throughout Parry Sound and Haliburton. In particular, Mr. Jaakson's recreational carrying capacity model utilized a figure of 4.0 hectares of surface area per cottage on a lake. The model also subtracted the area of the lake that was within 30 metres (100 feet) of the shoreline. Mr. Jaakson's rationale was that this area was partly the littoral zone and may be utilized by small crafts, such as canoes, rowboats and kayaks, but would not be utilized for motorboat recreational use. I have never been able to find a rationale behind the application of a 4-hectare (10-acre) surface area for a dwelling. However, many models used during that period of time applied to that rationale.

When we prepared the first Official Plan for the entire Township of Seguin, following amalgamation of Humphrey, Foley, Rosseau and Christie Townships, a number of the municipalities had a recreational carrying capacity policy already in the Plan. I was personally responsible for preparing the Plans for the Township of Foley and the Township of Christie in the late 1970's and early 80's. Through the Official Plan process, we talked to cottage associations about the use of recreational carrying capacity and there was overwhelming support to apply such a consideration for the lakes in the Township. During that process, we established guidelines for different types of lakes, large lakes, medium-size lakes and small lakes. We utilized the Jaakson concept of eliminating the first 30 metres of lake surface area from the shoreline and then applied different ratios of surface area to number of dwellings based on the size of the lake. This was later changed to a consistent approach of using the lake surface area, minus the 30-metre buffer, divided by 1.6 hectares to establish lake carrying capacity. This model was fully vetted through a series of public meetings and subsequently inserted in the Official Plan for the Township of Seguin.

In the years to follow, Seguin Council questioned on a number of occasions whether or not they should change the policies with respect to recreational carrying capacity. Each time the issue came to the public, there was a consistent opposition to changing the policies to become guidelines rather than criteria. We had recommended that the policies become a guideline rather than an absolute criteria.

In the Oastler Lake decision, the OMB upheld the community standard of 1.6 hectares per unit and made reference to this being a standard not unlike parkland where 5 percent of the land of any development must be given to the municipality for public park purposes. We have argued previously before the Board that lakes in Muskoka, Parry Sound and Haliburton are, in fact, the parkland for the community and that, as communal lands, there needs to be sufficient land to accommodate proposed uses. Our use of 1.6 hectares per dwelling is based on the amount of area that would typically be used for a water activity, such as waterskiing, wakeboarding or tubing behind a power boat.

Leonard Lake

To apply the RCC model to Leonard Lake, we first acquired data from the District of Muskoka. The District provided us with the following statistics for Leonard Lake:

Number of Dwellings:	133	Seasonal
	18	Permanent
	151	Total

The District also advises that there are 16 vacant lots in excess of 0.2 hectares (0.5 acres). We consider these lots to be developable and therefore should be included in the existing density of development on Leonard Lake. Therefore, our model would include there being **167** existing or permitted dwellings on Leonard Lake.

The surface area of Leonard Lake is 195.1 hectares according to Ontario Geospatial Data available from the Ministry of Natural Resources. Through our Geographic Information Systems (GIS), we have calculated the area of the lake minus the 30-metre buffer described above to be 136.4 hectares.

Based on a lake surface area of 1.6 ha. per dwelling unit and considering the 30 metre buffer that is used in the model, the recreational carrying capacity for Leonard Lake would be **85** (85.25) units. As noted, at the present time, there are potentially **167** units on Leonard Lake.

The density of development that could occur without further planning approvals on Leonard Lake would result in a lake surface area to dwelling ratio of 0.81 as opposed to the 1.6 that we typically use in our model. This would indicate that the development on the lake would exceed the capacity provided in the model by 100 percent (there is one-half the surface area/unit than what would be ideal).

If the existing and potential lots were to achieve a density of 1.6 hectares per unit, it would be necessary for the lake to have a surface area minus the 30-metre buffer of 267.2 hectares. This is approximately 50 percent greater than the actual size of the lake surface area, again indicating that the capacity was already twice what the model would recommend.

The Township of Muskoka Lakes Official Plan does not contain policies about Recreational Carrying Capacity. However, the Plan supports the preparation of Lake Plans and consideration of those Lake Plans in the Township's planning. Including provisions for Recreational Carry Capacity in the Leonard Lake Plan may assist the Stakeholders Association future consideration of development proposals

I trust this information is of assistance to the Association. Should you have any questions regarding this matter, please do not hesitate to contact me.

Yours truly,

MHBC

Jim Dyment, BES, MCIP, RPP
Partner

Appendix C

Historical Letter by Robert Greenham

THE HISTORY OF LEONARD LAKE

MAY 2008

Dear Fiona and Ella:

Realizing the joy you experience when visiting the cottage, I am certain that learning of life in Muskoka in the past, would be exciting to you.

Items of history are lost forever unless one takes the opportunity to record them and that task has been asked of me. It seems that since we have enjoyed the distinct beauty of Leonard Lake since 1955, many facts since then have become either forgotten or have not been shared as yet. It is with this understanding, I will attempt to set forth some bits of information that may prove of interest.

In order to research facts of interest to the current lake population, it has been a real joy to contact neighbours (new and old), the Land Registry Office, and the fine staff at the Bracebridge Public Library. The reception was gratifying and encouraging. It is enlightening and encouraging to find persons being interviewed showing such interest in sharing stories about the lake. New friends develop this way. The more time spent on this project reveals how much is not known and will forever be a mystery.

As we gaze over the lake it is hard to believe that the last advance of the fourth glacier, about 50,000 years ago buried the area with ice up to 2 miles thick. As the ice melted, the resulting water filled in the pockets of land forming many lakes, large and small. Leonard Lake is one of the smaller Muskoka Lakes.

It is reasonable to expect that the lake and surrounding area were used for fishing and hunting by the Hurons, the Mohawks and the Iroquois who travelled extensively from the present Finger Lakes in the northern part of New York State. After some years of feuding among the tribes, the Iroquois stopped travelling this far north and left the land to the Hurons and Mohawks.

Many years later in 1837, the famous explorer David Thompson surveyed the Muskoka region when he was 67 years of age. Although the surveyors had helpers, travelling around the area this task was hard work. Much of the information for this letter was from conversations I had with Horace Edward Prowse whom I met in 1955. I was introduced to this Muskoka gentleman through my brother-in-law John Hincks whose grandfather was Mr.Prowse, one of the original pioneers in Muskoka. One of Horace Prowse's daughters was Alice whose name appears as a street name off Leonard Lake Road One. Mr. Prowse arrived in this country in 1873 at four years of age with his father, Edward (33) his mother, Mary Margaret Willmott Prowse (31) Fred (9) Lilian (3) and Charles (1). The trip from Berkinhead, England followed the sale of the Prowse Line of sailing vessels upon the invention of the first steam powered screw propelled ships.

Edward Prowse and John Willmott purchased Tonderrn Island at Beaumaris. The estate bought 1200 acres of land which included three miles of shoreline on Lake Muskoka at the end of Wyldewood Road off Highway 118 and five miles of shoreline on Leonard Lake. This combined territory was known as Wyldewoode.

LEONARD LAKE…HOW IT WAS NAMED.

There appears to be at least two possibilities. The staff at the Land Registry Office showed me the original map used to register lots on the lake bearing the date 1864 and the lake was described as THE LAKE. In1879 a map entitled MAP OF MONCK TOWNSHIP shows the lake as Leonard Lake. Edward and Mary Anne Margaret Prowse had a son Charles Leonard Prowse who died at age 15 in 1887 so it follows that they may have named the lake in his honour. As the name Leonard appears often as a secondary name in the Prowse family tree, it may be connected to a person of high standing in England. The mystery continues. This information was obtained from Alan Prowse, a nephew of Horace and a retired realtor in the Bracebridge area.

PIONEERS AT LEONARD LAKE IN 1879

Brooklands Farm which currently produces the best produce in Muskoka was established in 1878 by Charles William Riley. The township map referred to earlier shows that Robert Donally and William Donally owned property running to the east of Riley"s and south. The Monck Township Census of 1871 indicates that the Donnellys came from Ireland. The south section of the Lake and the part by what is known by many residents as Long Bay was owned by William Mason who arrived in the 1870's from the United States. Gord Roberts who provided much of the energy in establishing the Leonard Lake Stakeholders Association reported that a neighbour had found the remains of the foundation of the Mason Cabin east of his property.

This period of time was extraordinary in American history. To encourage settlement in Muskoka, an Act to Secure Free Grants and Homesteads was enacted in 1868. Any settler, 18 years of age and older, could select 100 acres in a surveyed township with the understanding that within five years was to clear and cultivate at least 15 acres of land and to have built a house fit for habitation of at least 16 feet by 20 feet and not being absent more than six months in any one year. Just think of the amount of work in clearing that land without chainsaws! It has been recorded that much of the trees were burned but some of the larger trees were harvested. In fact Horace Prowse showed me a site where the logs were loaded on wagons drawn by a team of horses. To discover this site you travel along Leonard Lake Road One a short distance and a trail appears on your right. As you walk along this route you will find a rock outcropping on your right. The logs were drawn to the top of this rock face by horses and then rolled on to the wagons which were brought alongside the rock face Bill McLean informed me that this trail that leads to Kirrie Glenn Golf Course was actually Highway 118 before the big hill by Touchstone was constructed. One wonders at the strength, courage and determination that these pioneers possessed at these times when medical doctors were scarce and utilities were not yet available. The 1871 census records William Mason as 65 years of age, his wife Ellen as 56 and his oldest son William Jr. as 22. Along this same route you may discover a spruce bog on your left. This bog was referred to as Lac Birnie by Mr. Prowse and contains pitcher plants and sundews. Care should be taken when exploring this area as moose and Black bear are frequently seen in this area. They are probably aware of the scrumptious food prepared at Kirrie Glenn.

Dates when things happen are sometimes hard to get your mind around. To help understand better what was occurring in the general area in 1871 compare this date to dates when the railroad was completed to Gravenhurst in1875, to Huntsville in 1885 and to North Bay in 1895.

SAWMILL NEAR THE FALLS

Lance Cochrane, who lived for many years as a summer resident on Leonard Lake Rd #2 and who passed away in the summer of 2007 spoke of the existence of a sawmill near the falls near Keith Veitch's cottage. It seems that Lance's brother Rick was snorkeling at the Lake with a friend and discovered on the bottom, a large sleigh with giant steel hooks holding a pile of logs. It seems that the team of horses went through the ice and the load sank to the bottom. I was told by Lillian Newbery that her grandfather, Horace Prowse had once reported that he had planned to set up a sawmill near the falls but his plan never materialized.

VISITORS FROM OUTER SPACE

When we gaze at the stars on those special nights in Muskoka we are tempted to wonder if we are not alone in sharing this wondrous universe. With binoculars we study the moon and with stronger telescopes we peer farther into space and are mesmerized by such beauty. Mr. Prowse reported seeing a meteorite fall just north of Leonard Lake in the 1930's. In 1955 I visited the site with him. The meteorite was blackish brown in colour rose three to four feet above the surrounding ground and extended about ten feet in diameter. Fragments responded strongly to a magnet. Efforts are currently being made to re-establish the site which is heavily overgrown. Ken Riley has confirmed the location. The search continues. This site is approximately 2.8 km. east of Highway 118 on the south side of the Butter and Egg Road. Across the road lies the bog known as the Billy Bob Pond (so-named after William and Robert Donally).

Gary Morrison, a former lake resident, reported witnessing a possible Unidentified Flying Object hovering over the lake displaying yellow and green lights rotating counter-clockwise in 1962. He found reference to another sighting the same night outside Sudbury and which was documented in Project Bluebook (1970-72). Currently the scientific community has looked more positively towards the growing evidence and reports from informed observers about such sightings. The future may reveal some exciting information. When we lie on the dock and wonder at the millions of stars before us, it is not hard to imagine the possibility of other forms of life. We must keep an open and enquiring mind.

CLIFFORD DOUGLAS LUMSDON Jr.

Cliff Lumsdon, the famous long-distance swimmer, trained in Leonard Lake before becoming the first swimmer to cross the Strait of Juan de Fuca in British Columbia in 1956. Art Luker, long-time cottager on the Glen Gordon Road at the Lake, billeted Cliff. Art's daughter, Linda paced Cliff while he trained at Leonard Lake and also represented Canada at the Junior Olympics in Cuba. When you swim in those wonderful lake waters, we should remember they have served other swimmers well and deserve our respect. The Lake does not deserve to be polluted by people washing their hair in the lake or otherwise abusing it. As Dr. Ursula Franklin once reminded us, the Lake is a living thing and as such should be respected as should all living creatures.

OLD PINE STUMPS

As you explore the area you may notice some old white pine stumps appearing on the south side of the lake. These are the remains of beautiful trees that were ravaged by a forest fire that passed through in the 1860"s. Fortunately the north and east sides of the lake were spared. The stumps remind us to be always careful with fires as they can spread so rapidly and create such tragedy.

ROGER CROZIER

Roger Crozier, born in Bracebridge on March 16, 1942 made his NHL debut when the Detroit Red Wings star netminder. Terry Sawchuk was felled by injury. He played for the Buffalo Sabres. In 1974-75 he recorded a 17-2 record to backstop the Sabres to the Stanley Cup Finals in just their 5th season. In 2000 the NHL unveiled the Roger Crozier Saving Grace Award given annually to the netminder who posts the best save percentage in each season. In his NHL career he played in 578 regular season games, earning 206 wins and 30 shutouts. His career goals against average was 3.04. He was one of the NHL's greatest goalies. Roger passed away at 53 on January 11th, 1996 from pancreatic cancer. He owned the cottage on Leonard Lake Road Two currently owned by the Grays. Muskoka is often referred to as the vacation choice of many professional hockey players and now we can say that Leonard Lake is no exception.

GORDON AIKEN,Q.C.

The Glen Gordon Road on the north-west part of the lake was named after this gentleman who was a distinguished county Court Justice who became the Member of Parliament for Parry-Sound Muskoka in 1957-72.

COFFEY ISLAND

It is my understanding that this island was one of the first on which a home was built in the 1930's. The rounded stones which comprise its walls came from the shores encircling the island. Leslie Simmonds, Mrs. Coffey's grand-daughter once showed me a magnificent pickerel that she caught in the lake while rowing.

Many fishermen from Pennsylvania used to travel to the Lake for pickerel. They stayed at the Leonard Lake Cabins owned originally by Horace Prowse, then later in the 50's by Chuck and Flo Gage who ran a small convenience store and a gas pump down near the present boat ramp.

A survey of the Lake was carried out by the Fish and Wildlife Branch of the former Ontario Department of Lands and Forests in September 1969. This survey reported in the Fish Planting History that since 1947, three million yellow- eyed Pickerel eggs, two hundred and fifty thousand yellow Pickerel Fry and twenty one thousand small mouth Bass fingerlings and Fry have been planted. The yellow pickerel plantings were discontinued in 1956 and the small mouth bass in 1964. An experimental planting of Rainbow Trout was made in 1968.

The survey also reported that the Lake was 462 Acres in area with a shoreline perimeter of 8.8 miles and was 600 feet above Sea Level. A dam was presently under construction at the time of the survey. As one would expect when any change occurs, such are met with mixed reaction. Anyone's property that may be a little low would be subject to a rising waterline that might interfere with the owner's activities. For a time it was interesting to find that overnight some of the logs used to raise or lower the level would mysteriously disappear. The following day the logs would be replaced and on and on the game continued. Many theories were advanced as to who the culprit was but the evidence was inconclusive.

LEONARD LAKE COTTAGER''S ASSOCIATION

In the 1960's Chuck Gage who operated Leonard Lake Cabins and store and Donald Chambers a lawyer from Dunnville formed the cottager's association. We met regularly and enjoyed the corn roasts and regattas. Chuck and Don represented the cottagers at the Department of Lands and Forest's Parry Sound office. The result was that 5000 young splake were placed in the Lake. The effects of DDT and acid rain have had a devastating effect on the fish and common loon populations. We must do all we can to encourage our neighbours to pay great care with the lake by making sure that septic tanks are maintained properly and refrain from using fertilizers, etc. If you are interested in learning more about the state of our lake you could speak with Heather Bowen who has been monitoring the water in the lake for many years. Each of us must remain vigilant to protect the Lake so that we don't experience any more man-made pollution as described in Rachel Carson's magnificent book, Silent Spring. We have already seen the effects of DDT on our Loon population. In the 1950's we often observed at least two loon nesting sites, each with several chicks but today our lonely loon family produces one chick. What a tragedy to wake up one morning and not hear the Loon's haunting call. We must be vigilant in our efforts to protect Loon's nests which are often destroyed by the wake of power boats. All boaters should exercise care and navigate their craft in a way that their wash and wake for which they are responsible does not erode the shoreline or damage wildlife habitat.

THE TORNADO OF 1963

In the summer of 1963 or 1964, according to Ms.Betty Isbister, the current owner, a waterspout which is basically a tornado that picks up water, moved across the Lake from west to east and picked up a cottage on a small island adjacent to Starhaven and completely flipped it over. Fortunately no-one was in the cottage at the time but the force of nature was remarkable. Around the same time a large old oak tree was toppled and crushed Mr. Secord's car near Copeland's cottage.(Rumour has it that Mr.Secord was distantly related to the famous Laura Secord who performed heroically to warn against the invasion of American forces in the Battle of 1812 but little proof is available to substantiate the connection.)

THE SPRUCE MOTH INVASION

Alex Tryon, a well-known resident on Leonard Lake Road Two, and who served with distinction in the Royal Canadian Air Force over Europe during World War Two as a wireless air gunner, recalled the time when the Ministry of Natural Resources sprayed the area to control a heavy infestation of Spruce Bud Worms. The result of the spraying was the destruction of all the pickerel in the lake. It seems that the pickerel fed on the poisoned moths and subsequently perished. It is felt by some birders that the DDT weakened the egg shells of the Loons and led to smaller numbers hatching. For greater understanding of the effects of such spraying you may find Rachel Carson's book Silent Spring of great help. Let us hope that we learn from our mistakes and consider carefully the general impact on our natural world when we find a possible solution to solve a specific problem. When we study and reflect on our beautiful planet we see how each living thing interacts in the web of life and we then stand in awe of such creation.

HAPPY ISLES

John Henry Warren Bradfield, a well-respected architect purchased the islands in 1942. With great difficulty, he moved a construction shack from a site at which he was working and after cutting it in sections, raised it on the islands by using a block and tackle. He also did his best to avoid interfering with the natural aspects of the islands. I recall in the 60's seeing his son, the current Dr. Leonard Bradfield, sailing the skiff back and forth across the lake, thoroughly enjoying the power of the wind. Imagine how dedicated a lover of nature Mrs. Bradfield was to spend the whole summer on those beautiful islands without hydro. Unfortunately, Leonard's father passed away on the island. I heard that the new owner of the property intends to erect a stone cairn in Mr. Bradfield's memory and to reclaim the natural beauty of the islands by encouraging the return of the native birds and other wildlife while making as little disturbance to the natural beauty of the islands as possible.

THE BAVARIAN VILLAGE

In the 1970's Leonard Lake Cabins property was purchased by Mr. Ted Grand of Grand and Toy who apparently planned to develop it. However other plans were made and the property was then purchased by someone who built a large restaurant called The Bavarian Village.

After a few years a fire started, apparently due possibly to an electrical problem and which resulted in the complete destruction of the restaurant and many gorgeous white pine trees. Many of the summer residents of long standing on the Lake will remember the large fish outline that hung from one of those pine trees and advertised the LEONARD LAKE CABINS.

EPILOGUE

As we review these bits of information, we are humbled by the small part we play in the scheme of things just as we are when we gaze at the millions of stars and feel so insignificant. We then remind ourselves of the great responsibility we carry to all those who have gone on before us, those who have worked so hard to preserve the wonderful beauty of the Lake for future generations to enjoy. We cannot expect others to respect us and our opinions unless we respect ourselves and the opinions of others. We must be ever vigilant in our efforts to preserve the Nature of the Lake. Before we support any changes within our control, we must carefully consider the initial impact as well as the scope of the long-term effects of what we do. Man has not managed the environment very well so far and Mother Nature is warning us through recent trends such as global warming that we must do better. As someone of great wisdom reported long ago…DON'T MESS WITH MOTHER NATURE! I have every confidence that over the years you will work hard to co-operate with our neighbours on Leonard Lake to ensure that the Lake and all who share it, are respected. It is with great appreciation that we see the tremendous efforts being made with considerable sacrifice of time to establish the Lake Plan. It proves that there are many neighbours who share our love of the Lake and are doing their part to protect it for years to come.

We thank all who have shown an interest in the lake and hope that this short history will answer a few questions and encourage others in the community to record their memories and stories. Remember, if we fail to write things down, they may be lost forever and that would be a shame.

This letter touches a small part of the history of the lake and I'm sure that many more bits of information could be added but what has been recorded is what I have experienced and I share these thoughts with you.

With love.

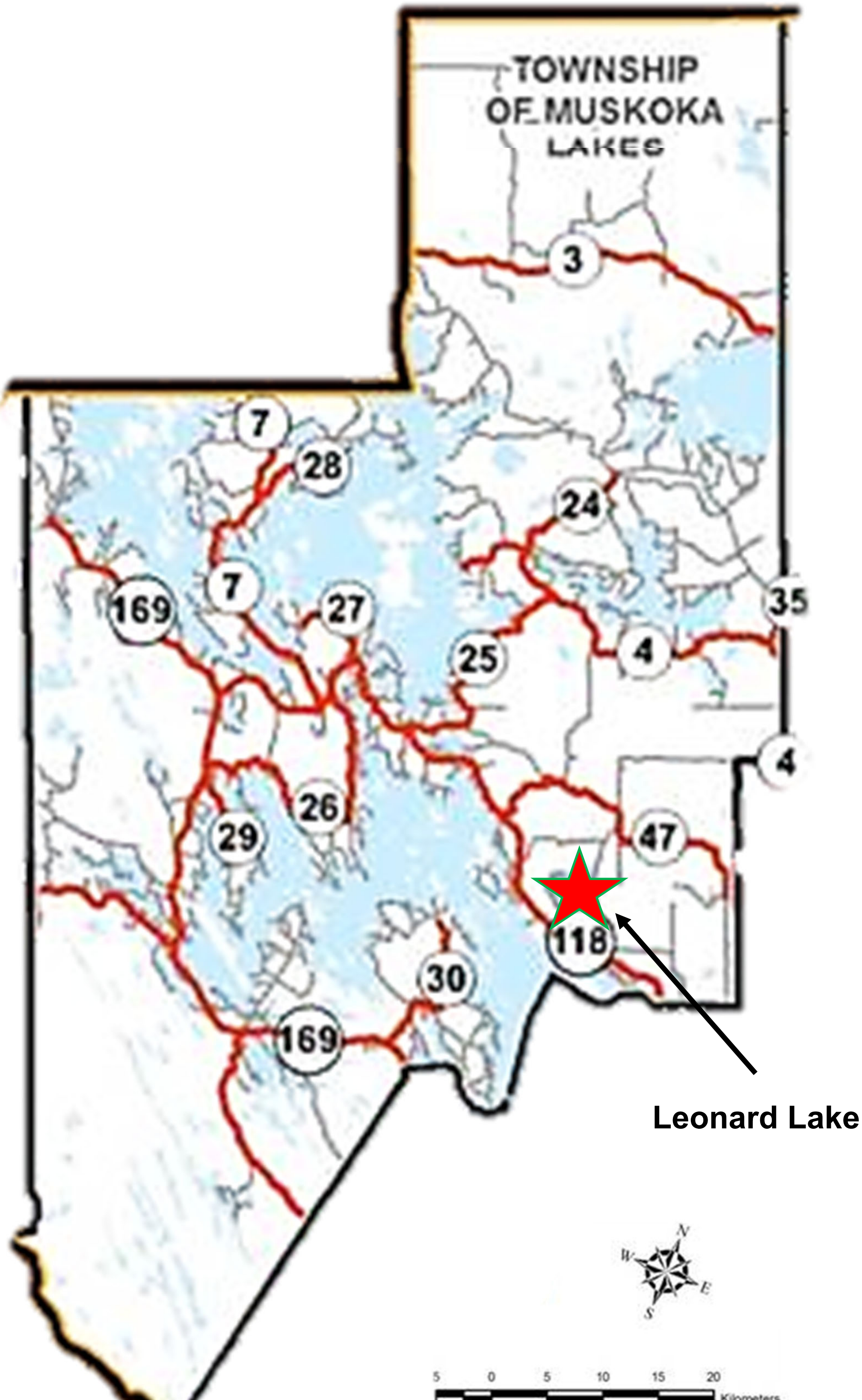
Papa (aka Robert Greenham)

P.S. It is with sadness that I recall my conversations with Horace Prowse to whom I was related through marriage. I also feel blessed that I spoke with him before he passed away while trudging through the snow on the frozen lake with some surveyors. Memories of him live on.

RCG.

Appendix D

Leonard Lake, in the Context of the Township


TOWNSHIP
OF MUSKOKA
LAKES
3
7
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118
30
169
Leonard Lake
N
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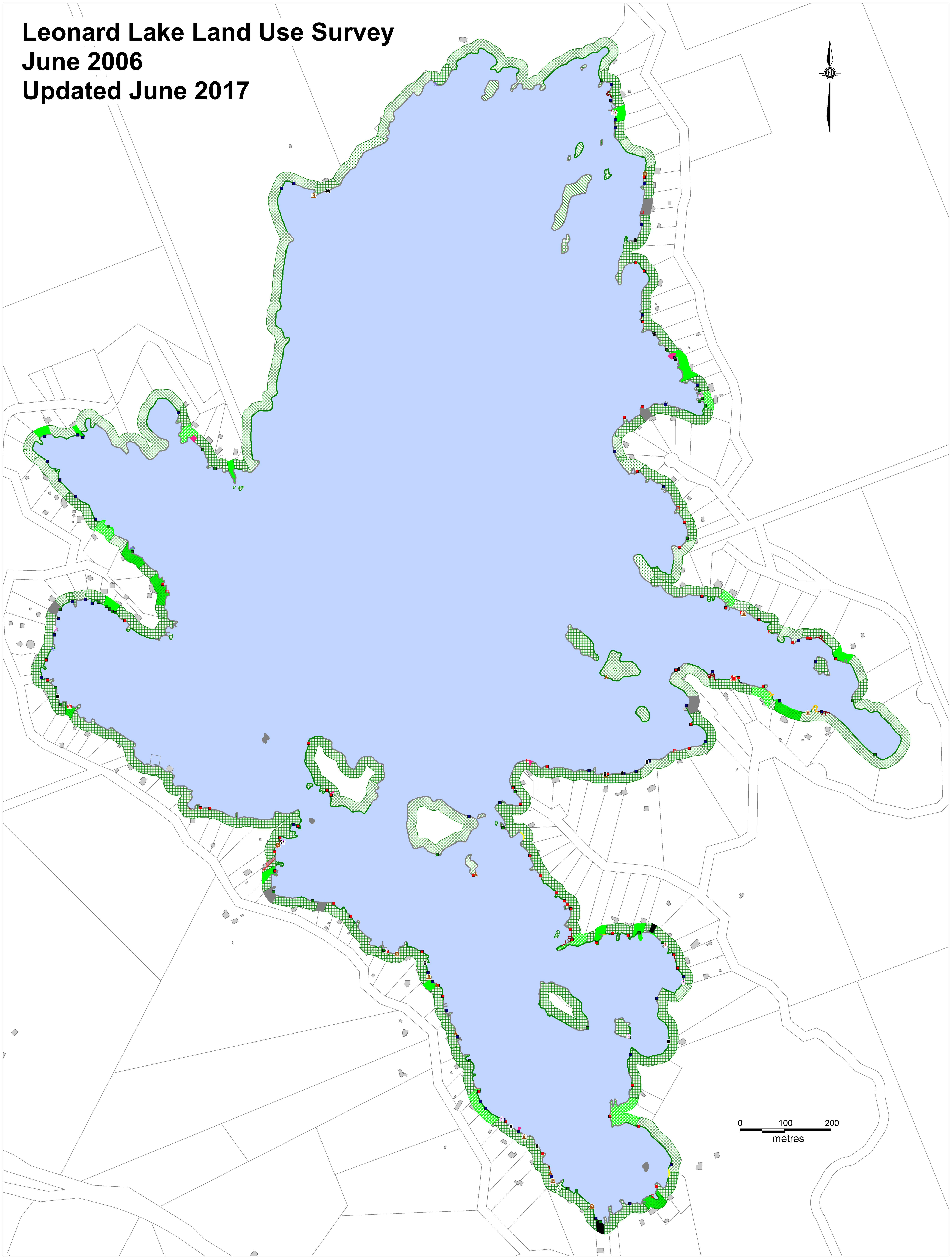
5 0 5 10 15 20
Kilometers

Appendix E

Leonard Lake Land Use Survey 2006, Updated 2017

Leonard Lake Land Use Survey
June 2006
Updated June 2017



THE DISTRICT MUNICIPALITY OF MUSKOKA

Managing Our Legacy Together

Legend

NB
NM
NR
NS
OMMB
OMR
OSD
RC
RN
RS
RW
SWS
SWW
YLU

Shoreline Lengths and Percentages

Shoreline	Type	Length_m	Percent
NB	Beach	43.75	0.25
NM	Mud	24.75	0.14
NR	Rock	9,835.34	56.18
NS	Shrub	6,396.53	36.54
OMMB	Man Made Beach	40.01	0.23
OMR	Marine Railway	33.60	0.19
OSD	Deck	103.14	0.59
RC	Concrete Ramp	45.80	0.26
RN	Natural Ramp	10.71	0.06
RS	Stone Ramp	25.72	0.15
RW	Wood Ramp	26.31	0.15
SWS	Stone Shore Wall	551.66	3.15
SWW	Wood Shore Wall	146.03	0.83
YLU	Unbuffered Lawn	222.59	1.27
	Total	17,505.94	100.00
	Natural	16,300.37	93.11
	Altered	1,295.57	7.40

Legend

NFC
NFM
NFT
NO
NR
NS
OR
OSCO
YL
YLB
YLU

Backlot Area and Percentages

Backlot	Type	Area_m2	Percent
NFC	Coniferous Forest	4,505.49	1.63
NFM	Mixed Forest	89,526.49	32.41
NFT	Thinned Forest	146,747.80	53.13
NO	Overgrowth	5,411.27	1.96
NR	Rock	3,974.29	1.44
NS	Shrub	1,571.02	0.57
OR	Road	612.19	0.22
OSCO	Cottage	211.17	0.08
YL	Lanscaped Yard	10,306.24	3.73
YLB	Buffered Lawn	5,696.29	2.06
YLU	Unbuffered Lawn	7,655.72	2.77
	Total	276,217.97	100.00
	Natual	251,736.36	91.14
	Altered	24,481.61	8.86

Legend

BHC1
BHC2
BHL
DC
DC1
DC2
DCA
DFL
DP
OSCO
OSD
OSDR
OSS
OSSC

Structure Count

Structure	Type	Count
BHC1	1 Slip Crib Boathouse	2
BHC2	2 Slip Crib Boathouse	1
BHL	Boathouse on Land	8
DC	Crib Dock	65
DC1	1 Slip Crib Dock	9
DC2	2 Slip Crib Dock	1
DCA	Cantilever Dock	3
DFL	Floating Dock	59
DP	Pole Dock	36
OSCO	Cottage	1
OSD	Deck	13
OSDR	Driveway	1
OSS	Shed	10
OSSC	Sleeping Cabin	6
	Total Count	215

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Appendix F

Glossary of Terms

Appendix F - GLOSSARY OF TERMS

Biodiversity - the variety of life found in a place on Earth or, often, the total variety of life on Earth.

Biota - the animal and plant life of a particular region, habitat, or geological period.

Biomass - The combined mass of all of the living organisms (micro-organisms, bacteria, fungi, plants, animals, etc.) in an environment.

Catchment Area - the area from which rainfall flows into a river, lake or reservoir.

Cyanobacteria - also called blue-green algae, are microscopic organisms found naturally in all types of water. Blooms form when cyanobacteria start to multiply quickly and in some cases can produce highly potent toxins.

Cumulative Impact Analysis - the process of monitoring, tracking and predicting accumulating environmental changes caused by both natural and man-made disturbances (e.g. development activities).

DOM or DMM – District Municipality of Muskoka

Ecological Function - the natural processes, products or services that living and non-living environments provide or perform within or between species, ecosystems and landscapes. These may include biological, physical and socio-economic interactions.

Ecological Offsetting – an approach to offset the adverse impacts of land use change on the natural heritage system through the creation or restoration of natural features.

Endangered Species - a species considered to be facing a very high risk of extinction in the wild. It is classified as "Endangered Species" on the Species at Risk in Ontario List, as updated and amended from time to time.

Environmental Impact Study (EIS) - used to provide a sufficient level of detail to demonstrate that a proposed development will have no negative impact on the natural features or ecological functions of the subject and surrounding ("adjacent") lands.

Environmental Monitoring - the processes and activities that need to take place to characterize and monitor the quality of the environment. The process of monitoring is an integral part of environmental impact assessments and is designed to help understand the natural environment and protect it from negative outcomes of human activity.

Eutrophication - excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which can cause a dense growth of plant life and death of animal life from lack of oxygen.

Fish Habitat - as defined in the *Fisheries Act*, means spawning grounds and any other areas, including nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

Functional Servicing Report (FSR) - demonstrates the adequacy of the existing and proposed water and sanitary sewer systems to satisfy the demands of a proposed development.

Hazard Lands - lands which may be prone to flooding, shoreline erosion or slope instability hazards, or any hazard that may result in life loss or injury, property damage, social and economic disruption or environmental degradation.

Hydrological Functions - catchments have four fundamental natural hydrological functions - collecting, storing and discharging (either contributing or transmitting) water.

Impacts of a Changing Climate - the present and future consequences from changes in weather patterns at local and regional levels including extreme weather events and increased climate variability.

Internal Loading of Nutrients - a process when phosphorus and nitrogen are released from an anoxic (oxygen deprived) sediment surface.

Invasive Species (IS) - animals or plants from another region of the world that do not belong in their new environment. IS can be introduced to an area by ship ballast water, accidental release, and most often, by people. Invasive species can lead to the extinction of native plants and animals, destroy biodiversity, and permanently alter habitats.

Lakeshore Capacity Model - quantifies the linkages between the natural contributions of phosphorus to a lake, the contributions of phosphorus to a lake from shoreline development, the water balance of a watershed, the size and shape of a lake and the resultant phosphorus concentration. The model allows the user to calculate how the water quality of a lake will be affected by the addition or removal of shoreline developments (such as permanent homes, seasonal cottages, resorts, campsites) and point source discharges (such as sewage treatment plants).

Lake System Health - a broad, watershed-wide approach to protecting Muskoka's waterbodies that includes recreational water quality monitoring, enhanced development policy, and a strong stewardship program. The goal of the Lake System Health Program is to protect lake ecosystems and the natural, social and economic value they provide.

Lake Vegetation Protection Zones - refers to forested or vegetated strips of land that border creeks, rivers and lakes. These buffers can help filter sediment and other pollutants (such as fertilizers and pesticides) from runoff that flows from the land into waterways, thus protecting these waters from various nearby land uses. A vegetative zone is different than a building setback from a waterbody, as defined through a zoning by-law. This zone or buffer is a vegetated or strip of land adjacent to a waterbody. A building setback does not include a specific requirement in a zoning bylaw to maintain vegetation. www.muskokawateshed.org

Limnology - the study of the biological, chemical, and physical features of lakes and other bodies of fresh water.

Low Impact Development (LID) - refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat.

Morphometry - the process of measuring the external shape and dimensions of landforms, living organisms or other objects, e.g. lake surface, volume, depth contours, mean depth, max depth, fetch, shoreline length, shoreline development, drainage basin sediment area, water strata, shoreline characteristics, nutrient supply, trophic status and lake productivity.

Natural Hazards - an extreme event that occurs naturally and causes harm to humans or to other things that are important to humans about (anthropocentric).

Natural Heritage Features and Areas - features and areas, including significant wetlands - coastal and other, fish habitat, significant woodlands and significant valley lands, habitat of endangered species and threatened species, significant wildlife habitat, and significant areas of natural and scientific interest, which are important for their environmental and social values as a legacy of the natural landscapes of an area.

Nitrogen - a naturally occurring element that is essential for growth and reproduction in both plants and animals, however, an excess, (e.g. nitrates from fertilizers, human and animal waste, etc.) in lake water causes algae to grow faster than ecosystems can handle.

OP – Official Plan

Phosphorus - an essential element for plant life, but excess phosphorus in a body of water causes extensive algal growth called "blooms" which are a classic symptom of eutrophication and lead to decreased oxygen levels.

PPS – Provincial Policy Statement

Quality and Quantity of Water - is measured by indicators associated with hydrologic function such as minimum base flow, depth to water table, aquifer pressure, oxygen levels, suspended solids, temperature, bacteria, nutrients and hazardous contaminants, and hydrologic regime.

Redevelopment - the creation of new units, uses or lots on previously developed land.

Species Composition - the identity of all the different organisms that make up a community. This is important when trying to discover how an ecosystem works, and how important different organisms are to an environment.

Species at Risk - any naturally-occurring type of plant or animal in danger of extinction or of disappearing from the area. Scientists and the Provincial and Federal Governments use terms such as Special Concern, Threatened, Endangered, Extirpated and Extinct to describe the category that best fits the condition of each species and their numbers.

Sustainable Development – development that meets the needs of the present without compromising the ability of future generations to do the same.

Tertiary Sewage Treatment System - a system that treats sewage to a higher level than traditional septic systems and typically includes removal of nutrients such as phosphorus and nitrogen and practically all suspended organic matter from waste water.

Watershed - an area of land that drains to a river, lake or stream. The watershed includes all the land, air, plants and animals within its borders. Land forms such as hills or heights of land largely determine the boundaries of watersheds and direct the speed and path of its rivers.

Wetlands - a distinct ecosystem that is flooded by water, either permanently or seasonally and may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favour the growth of specially adapted plants and promotes the development of characteristic wetland soils. In addition to fish and wildlife habitat, wetlands can filter and improve water quality and provide flood protection

Appendix G

Leonard Lake: Water Quality and Algal Blooms: Status, Monitoring and Management (2017), Dr. Sue Watson and Hedy Kling

Leonard Lake:
Water Quality, Biota and Algal Blooms

Status, Monitoring and Management

Prepared for the
Leonard Lake Stakeholders Association (LLSA)

S.B. Watson, University of Waterloo, ON
H. Kling, ATEI Winnipeg MN
2017

*cover photo of Leonard Lake, winter 2017, by Gordon Roberts, LLSA

EXECUTIVE SUMMARY

The Leonard Lake Stakeholders Association (LLSA) report *Leonard Lake Water Quality and Phytoplankton: Status, Monitoring and Management* was commissioned by the LLSA as part of their stewardship programme aimed to monitor and protect the integrity and quality of this lake. The report first provides a comprehensive synopsis of previous information on Leonard Lake (LL) generated by a number of earlier studies and monitoring programmes by different agencies, including lake morphometry, background information and historical monitoring data. The second section of the report describes the rationale, operation and results of an intensive LLSA water sampling study conducted between May and October 2017. This study was undertaken to assess current lake status and vulnerability to the effects of human activities and shoreline development, and develop more effective ongoing monitoring and stewardship programmes in partnership with regional and provincial agencies.

Leonard Lake is representative of many small lakes in Muskoka, with relatively clear water, low buffering capacity and low nutrient levels (oligotrophic). The lake's characteristics as a head-water lake with a small water catchment area, thin, acidic soils, and rocky, often steep shoreline serve to limit nutrient loadings from natural sources, but also make the lake more sensitive to degradation from shoreline changes and development.

Initial surveys and modelling dating back to 1971 by the Ontario Water Resources Commission (OWRC) describe LL as "*moderately enriched*" but also reported thick algal mats in the southwestern end where early cottage development had occurred. Since 1971, developed lots have more than doubled to 167, and based on the geology and topography of the shoreline and catchment, the OWRC concluded that the lake was "*largely unsuited for cottage development with subsurface septic systems*." In 2005, a review by Gartner Lee classified LL as "*above the threshold level of enrichment with a moderate sensitivity to development capacity…based on Total Phosphorus (TP) using the District of Muskoka Recreational Water Quality Model"*. This provided some level of protection from shoreline development. TP levels monitored by several agencies[a] at a central offshore site in LL indicate no significant long-term change in LL water quality, however, the District of Municipality of Muskoka (DMM) has recently proposed to initiate recommendations in the HESL (2016) report[b] which effectively remove this protection and reclassify Leonard Lake as warranting only "normal" protection from further lot development.

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[a] including the District Municipality of Muskoka (DMM), the Ontario Ministry of the Environment and Climate Change (MOECC) and Ministry of Natural Resources (OMNR), the provincial Lake Partnership Programme (LPP), and Muskoka Lakes Association (MLA).
[b] District of Muskoka Recreational Water Quality Model Review June 2016

Extensive monitoring by the MOECC between 1979 and 2016 revealed no overall change in TP measured at a single mid-lake location, but a gradual decline in water clarity and increase in dissolved organic carbon. During this period, chlorine and sodium levels almost quadrupled, possibly due to the use of road salt, demonstrating the vulnerability of Leonard Lake to runoff from roads. During late summer, dissolved oxygen levels near the lake bottom often declined to zero or very low levels ('anoxic' or 'hypoxic'), and Nurnberg (2017) recently highlighted the potential vulnerability of the lake to the release of nutrients from the bottom sediments due to depleted oxygen[c]. Internal loading is also generated by direct sediment resuspension from motor boats in shallow areas and exacerbated by the long residence time of water in Leonard Lake. Cyanobacteria (aka 'blue-green algae') were present in low abundance in historic MOECC samples but toxic producing species were not detected.

Leonard Lake has been monitored extensively by several agencies over the last half century and the availability of data spanning several decades provides an excellent opportunity for review and a useful base for interpreting the 2017 study results. However, comparison among data sets collected by these agencies is greatly hindered by differences in monitoring protocols, and future collaborative work should first work to institute common protocols and re-evaluate monitoring sites (see below) to improve the compatibility and value of water quality monitoring in Muskoka.

Anecdotal reports of increased algal blooms in Leonard Lake over the past few years indicated a potential decline in water quality and a need to expand lake monitoring, and with the identification of cyanobacteria-dominated surface and below surface blooms in neighbouring lakes in the region, there was concern and a sense of urgency for a detailed study of Leonard Lake. Between May and October 2017, members of LLSA carried out extensive water chemistry and phytoplankton sampling at several mid-lake and near-shore sites on LL.

The major results of this study showed that Leonard Lake has a low to moderate level of biomass growth and a diverse algal community dominated by lipid-rich diatoms and flagellates (high quality food for the upper food-web) and small cyanobacteria and green algae, indicative of an oligotrophic (nutrient poor) transitioning to a mesotrophic (moderately enriched) lake. A number of major concerns were identified:

- Nutrient[d] levels (total phosphorus (TP), total dissolved P, and dissolved inorganic nitrogen (N)) measured at different depths at four sites in the lake over the season were highly variable, and often exceeded the long-term averages measured by the provincial and regional agencies who have largely concentrated on spring samples collected over the entire water column at a single mid-lake location.

[c] This release from lake sediments is termed 'internal nutrient loading'.
[d] Essential nutrients for plant and algal growth (in most North American lakes these are usually P and N); a low supply means low algal growth.

- Low levels of noxious bloom-forming cyanobacteria such as *Dolichospermum* were present across much of the lake for most of the sampling period. While the background presence of these cyanobacteria is typical of low nutrient lakes, they are opportunistic and can develop localised blooms in response to nutrient influx e.g. from shoreline septic systems. Furthermore, some strains of these species can produce potent toxins that can have serious effects if ingested by pets, other animals and birds, or humans.
- In the summer of 2017, an LLSA "Eyes on the Lake" campaign resulted in 10 reports of possible near-shore bloom sightings. These were quickly sampled by LLSA volunteers and dispatched for species analysis. Four of the samples collected in mid-September from surface scums were composed largely of *Dolichospermum*, which has been reported as a toxin producer in other lakes.[e] Public awareness and reporting of algal blooms has escalated and can exceed laboratory and field capacity for timely sampling and analysis of these events, which can form and disperse rapidly. During September 2017, LLSA contacted the Spills Action Centre three times to report a scum. MOECC sampled a single site, but could not do so until after the bloom had disappeared.
- Sampling revealed significant vulnerability to low dissolved oxygen levels in bottom waters at several sites across the lake. This has implications for both internal loading and the degradation of fish/aquatic invertebrate habitat, particularly cold-living species which may migrate to these bottom sites.
- Appreciable seasonal and spatial variance in algal biomass and species composition, and a vulnerability to inshore blooms, is underrepresented by current agency monitoring programmes. In the current climate change scenario, this vulnerability is predicted to increase.

RECOMMENDATIONS

LOT DEVELOPMENT

Issue: Size, morphometry, low flushing rates, bottom oxygen depletion and cottage development mean that Leonard Lake is vulnerable to the impacts of current and further development, particularly with the current warming trends in climate. (Nurnberg 2017)

Actions: Consider a moratorium on further lot severances while continuing water chemistry and phytoplankton testing and monitoring for blooms. Restrict shoreline development to maintain a vegetated buffer strip and minimise runoff from lawns, roads etc. Maintain high vigilance on the capacity, age and status of septic and other wastewater systems.

MONITORING PROTOCOLS

Issue: Current protocols concentrate on spring samples collected as surface-bottom composites and fail to capture the significant spatial[f] and seasonal variance in water quality, nutrients

[e] Resources were not available for toxin analysis in 2017
[f] Inshore-offshore, surface scums, deep-living algal maxima

and algae exacerbated by activity, boat traffic, severe storms, etc. Seasonal averages are unlikely to provide a robust assessment of the full range in lake-wide nutrient and algal biomass levels.

Issue: The seasonal and spatially-resolved phytoplankton data represent a vital resource against which future change can be assessed, which if possible, should be continued along with an assessment of water quality and particularly, inshore and internal nutrient loading.

Action: LLSA should work with the DMM, MOECC and MLA to review testing protocols for Leonard Lake and other Muskoka lakes including site location, frequency and type. LLSA will continue to engage lake residents to report incidents of scum, blooms, etc. and to develop lake procedures regarding incident reports, collection and dispatch of samples.

ANOXIA AND HESL "39 CANDIDATE ANOXIC LAKES"

Issue: Oxygen profiles show a significant decrease towards the sediment surface which in many years are anoxic or hypoxic; however, Leonard Lake was not included in the 39 Candidate Anoxic Lakes identified in the recent HESL (2016) report and further sampled for internal loading. Lakes in the '*above-threshold*, *moderately to highly sensitive'* categories (e.g. Leonard Lake) should be further assessed for soil composition, depth and P retention.

Action: The DMM should add Leonard Lake to the 39 Candidate Anoxic Lakes and further sample LL for internal loading.

Action: The LLSA board consider ways of increasing awareness among stakeholders concerning the impacts of motor boats on lake health.

DATA COMPATABILITY

Issue: At present, Leonard Lake is monitored by five agencies or government departments, often using different protocols, resulting in redundancy and incompatible data. This greatly impedes the interpretation of these data and represents a waste of scarce resources.

Action: That LLSA should request the key agencies (e.g. DMM, MOECC) to evaluate discrepancies in site locations, redundant sampling efforts and differences between agencies in sampling and analysis, and work with the LLSA to develop common protocols to maximise the valued outcome of these efforts.

SEPTIC SYSTEMS

Issue: The efficacy of current septic wastewater systems on Leonard Lake is unknown. Septic loading can represent a significant proportion of the total external load to a lake.

Action: That LLSA should continue to maintain close liaison with the DMM regarding lake septic and wastewater testing and evaluation to ensure that systems on LL meet municipal and provincial specifications and are monitored to insure full compliance.

CYANOBACTERIA (‘BLUE-GREEN ALGAE’)

Issue: The revised Muskoka Lake Health System Update stipulates *“Blue-green algal cyanobacteria blooms as documented by public complaints to the MOECC or the Simcoe-Muskoka District Health Unit,”* as one of three metrics identifying “special status” lakes.

Issue: Cyanobacteria blooms were identified in LL at several shoreline sites in 2017, but the LLSA was unable to test these for toxicity. In addition, the MOECC and Simcoe Muskoka Health Unit could not mobilise quickly enough to confirm the presence of these blooms.

Action: A bloom response protocol with speed of service standards should be established collaboratively between provincial (MOECC), District and local (Simcoe/ Muskoka Health Unit), and Lake Associations (including MLA) to ensure a rapid, timely response and rigorous assessment of toxins and other risk factors. The protocol could include training at the lake or lake association level in sampling and dispatch protocols, to address the need for timely sampling. In addition, a toxin analysis protocol should be established.

Expertise and taxonomic analysis and was provided by the authors of this report, Dr. Sue Watson, University of Waterloo, Department of Biology and Hedy J. Kling, MSc., Algal Taxonomy and Ecology Inc., Winnipeg. Field and lab support were provided by Mark Verschoor, MSc., York University, Department of Biology and Dr. Mingsheng Ma, Laboratory Manager, Biogeochemical Analytical Service Laboratory, University of Alberta.

Leonard Lake

Background

Leonard Lake (45.0751, -79.4496) is a headwater lake in a small catchment area (4.19 km^2) in the Algonquin-Lake Nipissing ecoregion of the Boreal Shield Ecozone (CCME 2006; DMM 2015). The catchment is composed of Precambrian bedrock covered by a thin (< 1.5 m deep) layer of granitic loam sandy till with rocky outcrops. Surface water inputs occur largely from precipitation, direct runoff and small streams; the contribution of groundwater is unknown. It has a shallow south

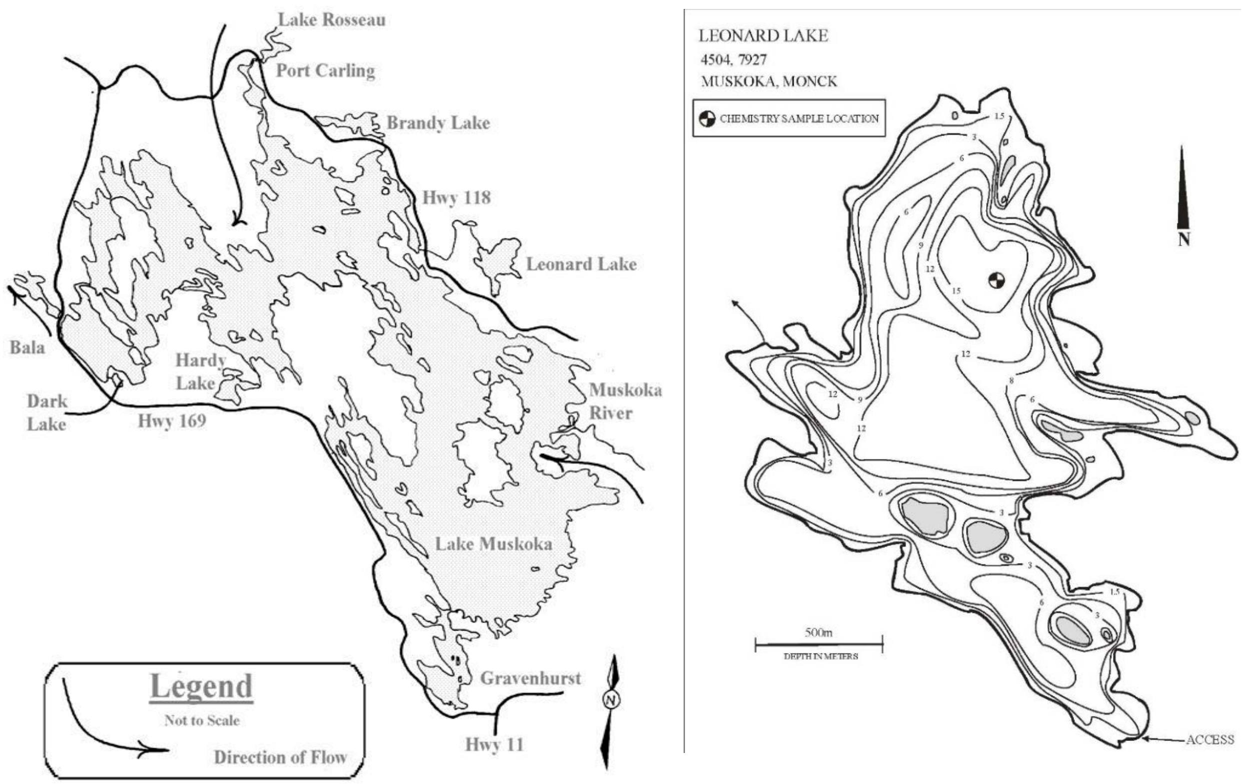

Fig 1. Location (left) and bathymetry (right) of Leonard Lake

basin which is generally < 6m deep, and a deeper northern segment (maximum depth 16-17.5 m; DMM 2015; Ingram and Paterson 2015; Table 1; Fig 1) which develops seasonal bottom oxygen depletion (detailed below). A single small outflow at the western side has a discontinuous flow into Milford Bay, Lake Muskoka, and the lake has a long turnover rate with ~ 20% of the total volume renewed each year and an estimated residence time of 5.4 years (Nurnberg 2017). Leonard Lake has a complex shoreline morphometry, largely composed of exposed bedrock or stones with a few proximal or shoreline wetland areas (Table 1; Fig S-1).

Leonard Lake has a low buffering capacity, typical of softwater shield lakes, as shown by the impacts of the acid precipitation of the mid-late 1900s on the pH, which reached a low of 5.5 in the early 1980s and have shown a very slow recovery to current levels around 6.5. This important characteristic affects the abundance, composition, and productivity of the aquatic biota. During the recovery, there has been a gradual concomitant decrease in sulphate and increase in dissolved organic carbon (DOC) from ~3 mg/L to ~4.5 mg/L, within the range typical of this Ecozone (3.9-4.7 mg/L; Fig. 2; CCME 2006). This increase was attributed by the Ontario Ministry of the Environment and Climate Change (MOECC) to climate-related increased basin inputs from soil and detrital turnover (Ingram and Paterson 2015), and likely resulted in a change in the penetration and spectrum of light in the water column.

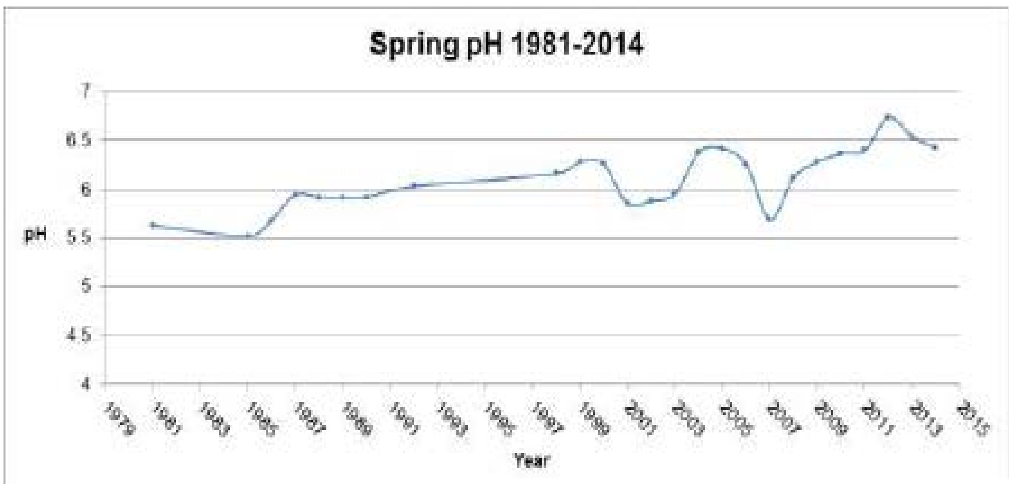

Fig 2. Long term trend in pH measured at the central monitoring site in Leonard Lake; from Ingram and Peterson (2015)

Water clarity is generally high in Leonard Lake, with spring secchi depth (SD) between 3 – 4.5m. This would support photosynthetic activity down to a depth of approximately 7.5-9m[1], and provide an extensive littoral area for the growth of aquatic plants and benthic algae, particularly in the south basin. These areas are also important habitat for invertebrates, fish and other aquatic and terrestrial organisms and can often represent the predominant fraction of the lake productivity (Vadeboncoeur et al. 2002).

The vulnerability of Leonard Lake to runoff from roads is demonstrated in the significant rise in chloride levels from road salt over the past few decades, increasing dramatically since the late 1970s. Proximity to roads can have major impacts on water quality, aquatic food-webs, and the ecological services provided by lakes as a result of pollution (heavy metals, sediment, organic

[1] assuming the commonly used measure of the photic zone as 2.5 x secchi depth

pollutants), habitat disruption, erosion etc. (e.g. Transportation Research Board and National Research Council 2005, Reeves et al. 2008; Denoël et al. 2010).

Early surveys of water clarity and total phosphorus (TP) levels indicated generally oligotrophic[2] conditions but showed some indications of shoreline deterioration (e.g. thick algal mats), notably in the more developed southern end of the lake. Initial modelling categorised Leonard Lake as '*above the threshold[3] level of enrichment with a moderate sensitivity to development capacit*y, and over the past few decades, the lake has been monitored by several agencies (mostly at one or a few offshore sites), the Ontario Ministry of Environment and Climate Change (MOECC), the Muskoka Lakes Association (MLA), the District Municipality of Muskoka (DMM) and the Leonard Lake Stakeholders Association (LLSA). These have generated several datasets, based on different sampling regimes and analytical labs. Overall, these data show generally similar levels of TP and water quality, but the effectiveness of this multi-agency effort and compatibility of these data has not been rigorously assessed.

Since 1971, developed lots on Leonard Lake have more than doubled to 167. Most of these (91%) are located on thin soils, the majority (85%) are 30 m or less from the shore, and a third are built on moderate to steep slopes (Fig. S-2; MWC 2015; Nurnberg 2017). The highest density of properties occurs in the southwest region of the lake. A detailed shoreline survey in 2015 reported that approximately 30% of these properties were 'ornamental' and/or showed erosion, shoreline development (e.g. retaining walls, docks etc.) and lawns. The majority of properties had shorelines with emergent, floating, or submergent aquatic vegetation (MWC 2015).

Based on the geology and topography of the shoreline and catchment, an early study concluded that the lake was largely unsuited for cottage development with subsurface septic systems (OWRC 1971). Nevertheless, all shoreline properties rely on septic wastewater systems of varying age and construction. A 2008 survey conducted by The Township of Muskoka Lakes was unable to determine whether these systems were working properly - hence their contribution to nutrient loads is unknown and are rarely detected by typical monitoring methods (such are currently used by DMM, MOECC and other agencies in Leonard Lake). Localised seepage of (highly bioavailable) nutrients from septic systems can occur throughout the season into the shallow warmer inshore areas. Typically, the nutrients are taken up rapidly by shoreline aquatic plants or algae and decline significantly with distance away from the shore, becoming undetectable at sites a few meters or more offshore. Septic loading can represent a significant proportion of the total nutrient input to a lake and because it is difficult to detect using conventional methods, recent studies have used chemical tracers such as caffeine, sweeteners etc. (Robertson et al. 2013; Spoelstra et al. 2017).
It has been estimated, for example, that septic systems account for 30% or more of the total phosphorus inputs into some of the northern basins of Lake of the Woods (HESL 2011).

[2] i.e. low level of productivity, high water quality and clarity
[3] modelled baseline Phosphorus (P) levels+50%

Septic influx can promote prolific algal or cyanobacterial[4] growth on the bottom, or as biofilms on stones and aquatic plants in the shallow areas along the shoreline, which can dislodge and form surface scums or remain as bottom growth, often invisible to the casual observer. In some cases, these shoreline algal communities can include toxin producing species (Quiblier et al. 2013). It is of note that thick shoreline growth is often reported in areas of Leonard Lake (see below).

Overall, the combination of its size, morphometry, low flushing rates, bottom O_2 depletion and cottage development mean that Leonard Lake is considered vulnerable to the impacts of current and further development, particularly with the current warming trends in climate (LeBlanc et al. 2008, Callieri et al. 2014, Nurnberg 2017).

Biota

There have been several assessments of the biological communities of the lake over the past few decades. A survey by the Ontario Water Resources Commission (1971) conducted in spring, mid-summer, and fall) reported '*large gelatinous masses of the filamentous green algae Zygnema...in nearshore areas of the southern bay, and to a much lesser extent in shallow areas of the main body of the lake...evidence that conditions of accelerated eutrophy*[5] *are developing in the lake*'. A later report similarly described mats of the related species *Spirogyra*[6] Proliferations of these green algae are often indicative of localised inputs of nutrients with a high ratio of nitrogen (N) to phosphorus (P) - typical, for example, of wastewater inputs. The phytoplankton have been sampled for composition and biomass by the MOECC intermittently between 1970 and 2004, particularly in the late 1980s[7]. Analyses were carried out on composite samples from a depth-integrated sample or combined from individual samples collected over the season in each year and were generally not resolved to species level; nevertheless, they provide a valuable baseline series for comparison with more recent years.

Overall, the MOECC phytoplankton samples showed a predominance of colony- and chain-forming chrysophyte flagellates ('golden brown algae'; *Chrysophaerella longispina, Synura, Dinobryon, Uroglena, Mallomonas*), diatoms (*Asterionella formosa*, *Tabellaria fenestrata*,

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[4] Traditionally named '**blue-green algae'**, cyanobacteria are bacteria (not *algae*, which evolved from cyanobacteria and have more complex cell structure and reproduction). They are widely distributed in aquatic and terrestrial systems and in many cases, are important and beneficial components of the foodweb; however, some Cyanobacteria can produce noxious and sometimes toxic **Harmful Algal Blooms (HABs),** which are increasingly a concern. The term 'blue-green' is derived from their pigment, **phycocyanin** (PC) which is commonly used in monitoring to detect their presence in water but is not necessarily diagnostic. PC is often masked by other cell pigments and these species range in colour e.g. blue-green, grass green, yellow-green, pink, black.

[5] **Eutrophy:** advanced productivity (e.g. manifested by algal blooms) as a result of high nutrient inputs

[6] 10 Both of these non-toxic algae belong to the order **Zygnematales** along with other related filamentous 'green' algae and the desmids, reclassified recently under the phylum **Charophyta**, which are closely related to the **Chlorophyta** ('green algae') and land plants; see Guiry (2013). For simplicity, in this report the Charophyta are included in the **Chlorophyta** (i.e. their original taxonomic grouping) in the discussion and graphs.

[7] Raw spreadsheet data obtained from Claire Holeton, MOECC, 2017

Cyclotella sp., *Synedra* sp.) and unicellular dinoflagellates (*Peridinium*). Other groups were present at low abundance and consisted of green algae and desmids (*Botryococcus, Staurastrum, Chlamydomonas, Quadrigula, Gloeocystis, Kirchneriella*; *Dictyosphaerium pulchellum*, Haptophytes (*Chrysochromulina parva*) and small-celled cryptophyte nanoflagellates (*Cryptomonas*, *Plagioselmis* (formerly called *Rhodomonas), Chroomonas*, *Katablepharis*, *Cryptaulax*). A number of these taxa (notably *Chrysophaerella*, *Dinobryon, Uroglena, Chrysochromulina, Katablepharis*, *Cryptaulax)* are mixotrophs or heterotrophs (i.e. lack chlorophyll a), and capable of using organic material or ingesting bacteria as a supplemental source energy and nutrients, allowing them to grow at low nutrient or light levels and exploit deep layers of bacteria associated with degrading organic detritus settling out from the surface. This serves to recycle nutrients directly back into the foodweb as part of the 'microbial loop', an important mechanism which facilitates productivity in oligotrophic lakes. It can also provide these algae with a competitive advantage when inorganic nutrient supplies, on which most algae depend, are in low supply, and can enable the development of deep chlorophyll maxima (DCMs), or even dense blooms of these mixotrophic taxa (many of which have a strong fishy-rancid odour; (Watson et al. 2001).

Cyanobacteria were present in low abundance in all MOECC samples, largely represented by Chroococcales and colonial Synechococcales (*Aphanothece*, *Chroococcus*, *Dactylococcopsis*, *Rhabdoderma*, *Coelosphaerium*, *Gomphosphaeria* and *Merismopedia*). The toxin-producing genus *Microcystis* was not detected. 'Nuisance' filamentous cyanobacteria were rare, but it is of note that the bloom forming N_2-fixer *Anabaena* (now reclassified as *Dolichospermum*) was not reported until the late 1980s, when it was present in very low abundance.

Zooplankton were surveyed in the 1980s by the MOECC, which reported a community dominated by species of *Daphnia* (*D. ambigua*, *D. catawba*, *D. pulex*), *Eubosmina tubicen*, *Leptodaphnia minutus*, calanoid copepods and *Holopedium glacialis* (Table S-3). The invasive spiny waterflea (*Bythotrephes longimanus*) was first recorded in Leonard Lake in 2001 (MNR 2010); this species has invaded many North American lakes including the Great Lakes where it has had serious impacts on the aquatic foodweb. It is inedible to many natural predators due to its long abdominal barbed spine, and preys on smaller keystone zooplankton (Barbiero and Tuchman 2004).

Aquatic benthic invertebrate surveys between 2004 and 2014 show little evidence of environmental impacts on these organisms; long term data indicate a diverse, stable community composition aligned well with the Muskoka average, with a high species richness and percentage of gatherers/shredders and low fractions of chironomids and predators (DMM 2015 datasheet; Table S-4)

A provincial (MNR) survey in 2001 reported that the fish community was dominated by lake whitefish in the deeper areas, and supports a 'marginal' walleye population (stocked between

1940-1960s); other species include burbot, smallmouth bass (introduced in 1939), brown bullhead, yellow perch, lake whitefish, pearl dace, golden shiner and pumpkinseed. The lake is stocked every two years with rainbow trout, which are not well supported by the low levels of productivity of the lake and are targeted by sports fishermen (MNR 2010).

Long-term monitoring programmes

Leonard Lake is one of the 26 lakes monitored at spring overturn and in early fall under the MOECC Lakeshore Capacity and Acid Precipitation programmes, and has been sampled intermittently between 1979 – 1998, and on a yearly basis since 1998. Spring profiles for dissolved oxygen (DO) and water clarity (secchi disk depth, SD) and a single depth-composite water sample[8] are collected at the deepest site as '*representative the entire lake*',[9] although the complex morphometry of the lake can produce significant local differences in water quality, particularly in sheltered inshore areas (below). The water sample is filtered through an 80µm mesh "*to remove plankton and particulate matter*" - which likely also removes large phytoplankton typically present in this lake in spring, such as chain-forming diatoms and colonial chrysophytes (see below). This sample is analysed for major water quality parameters and chlorophyll a (chl-a)[10].

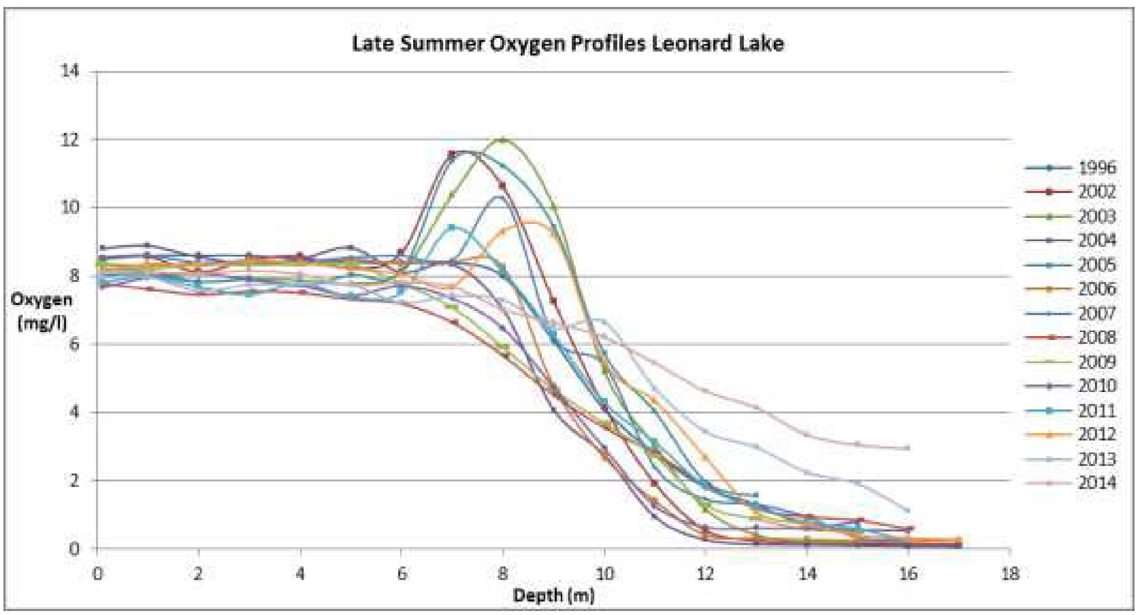

Fig 3. Late summer DO profiles measured at the central monitoring site in Leonard Lake showing deep maxima in some years; from Ingram and Peterson (2015)

While the status of the lake has been largely assessed from the single spring water samples, DO and temperature profiles were taken at this site up to seven times during the open water season in

[8] from odd-numbered depths, through a hose, using a peristaltic pump
[9] MOECC 2015
[10] **chl-a** is a common measure of the **total** abundance of the algal community; it includes all chlorophyll-containing species of algae and cyanobacteria

the 1980-90s, more recently, this has been reduced to a bi-annual frequency (Fig S-3). These data show that thermal stratification is established at the deep site each year, often by early summer, with midsummer surface temperatures between ~16-24^{o}C. No long-term trends in surface temperatures are apparent.

DO profiles collected at this site often show a peak at variable depths below the surface layer, indicative of deep chlorophyll maxima, associated with aggregations of depth-regulating algae at the 'thermal plate' between the upper and lower lake strata where light and nutrient levels are optimal. Historical data indicate that these DCMs are formed at different times during the season and migrate vertically; in some years they are more pronounced than others (e.g. Fig. 3).

Oxygen profiles also show a significant decrease towards the sediment surface which in some years approaches anoxic or hypoxic levels i.e. 0-2 mg/L.[11] The severity and depth coverage of the O_2 depleted zone varies among years, but generally increases over the season (Fig. 3). This has potential implications for internal loading i.e. nutrient (P, N) release from anoxic sediment surface (e.g. Nurnberg 2017). Despite this, however, Leonard Lake was not included in the 39 'Candidate Anoxic Lakes' that were identified in the recent HESL (2016) report and sampled for internal loading.

Internal loading is often difficult to assess using conventional sampling efforts. In many waterbodies which develop anoxic or hypoxic zones, this process is not necessarily manifested as massive increases in hypolimnetic P and N such as is seen annually, for example, in Sturgeon Bay (Georgian Bay). Nutrients released by anoxic sediment are often dissipated with distance above the bottom, and not detected by sampling efforts which typically collect water at least 1m above the bottom to minimise sediment disturbance. Nutrients are released from anoxic sediments in a highly available form (as phosphate, and ammonia) and are rapidly taken up by bacteria and algae, in some cases stimulating surface blooms, DCMs or thick layers of benthic algae. Two-thirds of the 39 anoxic Muskoka lakes identified in the HESL (2016) report, for example, showed no significant increase in bottom P samples compared to surface levels, and further sampling and assessment was recommended.

Other processes that can directly or indirectly affect the way in which internal loading is manifested include:

- Bottom anoxia and nutrient release can occur on an intermittent, diurnal basis – peaking at night when benthic photosynthetic O_2 generation is absent.
- direct resuspension of oxic or anoxic sediments in shallow basins, releasing interstitial or particle-bound P and N. In large windswept shallow lakes (e.g. Lake Erie, Lake Winnipeg)

[11] **Anoxia** is defined as 0 mg/L DO; **hypoxia** (< 2 mg/L DO) is considered stressful for all aquatic fauna, while concentrations <4 mg/L are stressful for fish (Hawley et al. 2006)

sediment resuspension by wind, waves etc. can result in a significant internal loading (e.g. Matisoff et al. 2017).

- Recreational boats cause sediment resuspension, increasing nutrients and suspended particles in the water, and also have numerous other negative impacts, from exhaust, fuel spillage and hydrocarbon pollutants, propeller contact, induced turbulence and waves, noise, sediment resuspension, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion (Yousef et al. 1980, Asplund 2000, Anthony and Downing 2003, White 2007).
- Nutrients can be recycled into the open water from sediments through bioturbation by aquatic organisms (including bottom dwelling fish like carp), or by uprooting/harvesting aquatic plants which can also uptake nutrients though their roots and release these into the open water during fall/winter die back (Breukelaar et. al. 1994, Søndergaard et al. 2003).
- Nutrients can be translocated by algae, which uptake P directly from the sediment or from nutrient-rich lower water column layers and then transport it in their cells to the surface (e.g. the bottom-growing cyanobacteria *Gloeotrichia*, or vertically migrating /buoyancy regulating

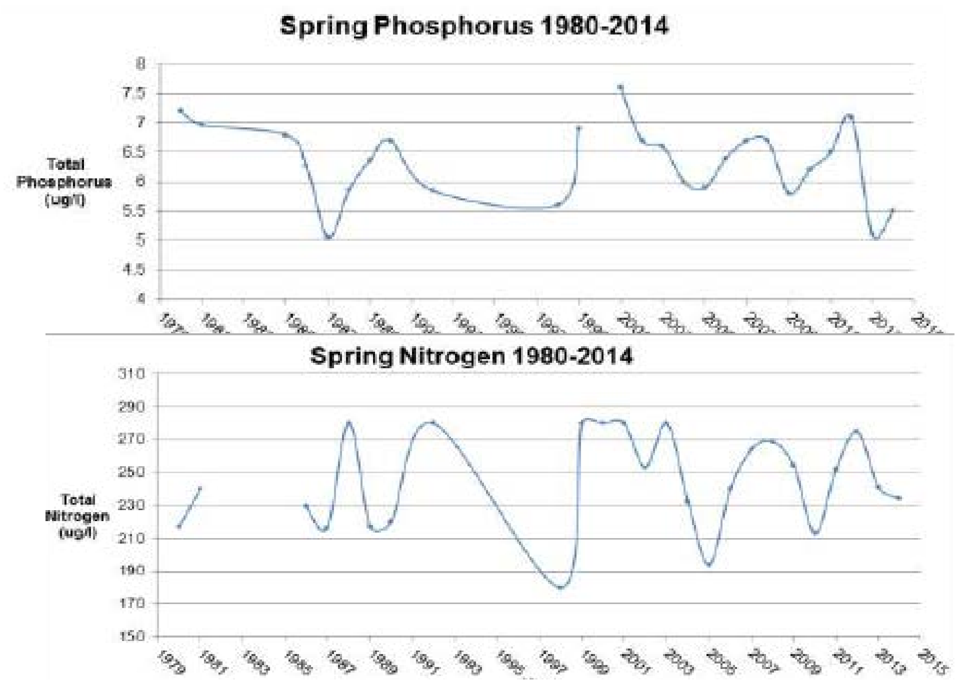

Fig 4. Long term trend in spring total P and total N in depth composite samples at the central monitoring site in Leonard Lake; from Ingram and Peterson 2015

flagellates (e.g. *Dinobryon*, *Uroglena*) and HAB forming cyanobacteria such as *Dolichospermum*, *Aphanizomenon*, *Planktothrix*).

Recent work using more advanced methods (peepers, geochemical modelling, stable isotopes) has demonstrated that these processes can account for a significant fraction of the nutrient budget of a lake (Dittrich et al. 2013, Paytan et al. 2017, Matisoff et al. 2017). It is of note that with increasing eutrophy, the capacity of the sediments to ‘sink’ P appears to be permanently diminished as a result of geochemical changes in the sediments (Rothe 2015).

The MOECC report a gradual decrease in spring TP in Shield lakes, but data for Leonard Lake show variable levels and no significant long-term trend, as was verified by a recent analysis of the Muskoka lake data (HESL 2016). Between 1979 and 2015, TP ranged between ~ 5 - 7.5 µg/L (Fig 4), characteristic of oligotrophic conditions in this ecoregion (CCME 2006) and of median TP concentrations across the 1421 lakes monitored under the Lake Partnership Programme (LPP)[12]. However, it is important to note that after 2002, LPP samples were analysed at the Dorset Environmental Science Centre and these more recent data are ~10x more precise; samples analysed prior to this have a high associated error and should not be used to assess long term trends (A. DeSellas, LPP coordinator, personal communication 2017). This highlights the issue with data compatibility and the potential error introduced by differences in analytical protocols.

Spring total Nitrogen (TN) has been similarly low and variable, ranging between ~180-280 µg/L (Fig 4; Tables S-1, S-2) and showing no clear long-term trend. The data indicate an average spring TN:TP of ~16 (molar ratio), indicating that P, not N, is the primary nutrient limiting productivity at ice out.

Management and development capacity

A series of reports assessed nutrient levels across a range of Muskoka and Ontario lakes and developed management targets, models and strategies (CCME 2006, Gartner Lee 2005, HESL 2016). The CCME study identified distinct spatial patterns in TP in lakes in the three Ontario Ecozones[13] and assessed the primary factors contributing to these patterns (CCME 2006). These included

- Catchment bedrock and surficial geology.
- Lake and catchment size, shape and topography, vegetation
- Lake residence time (flushing rate)
- Susceptibility to bottom anoxia
- Density, type of dwellings (cottages, camp grounds, hotels etc.)
- Wetland coverage in catchment
- Wastewater and septic systems (design, drainage bed composition, distance from shore, age, usage / capacity and nutrient contribution)

Given the unique nature of every lake it was recommended that they are evaluated for these characteristics on an individual basis to assess development capacity and develop management

[12] the LPP data represent a separate sampling programme based on volunteer collection of subsurface (‘dip’) samples where there was often high sampling error involved. See Supplementary material for 2002-2015 LPP data for Leonard Lake

[13] Mixed Wood Plains, Boreal Shield, and Hudson Plains; see the following link: https://www.ccme.ca/files/Resources/water/water_quality/phosphorous_ecoregion_rpt_1.0_e.pdf

strategies, particularly lakes that are in the above-threshold[14], moderate-to-highly sensitive[15] categories; the latter group should be assessed further for soil composition, depth and P adsorption ratio (CCME 2006, HESL 2016).

Risk analysis should consider these factors, and the criteria and thresholds used to define risk and management targets. The quality of the data used to define and validate management decisions should be examined critically, and collection/analytical methods optimised. With the current scenario of climate change, for example, sampling protocols (timing, frequency, sampling/analytical methods, spatial and depth coverage) should be adaptively managed; with earlier spring thaw, rigid field schedules are often out of sync with loading, runoff and ice-free seasonal lake events.

TP measures are simple and cost effective, but taken alone they do not provide an adequate gauge of lake status, which is best assessed using several indicators (e.g. Carlson 1977; 1981, Eimers et al. 2009). Traditionally, P has been shown as the primary limiting nutrient in most North temperate lakes. It is present in a variety of organic and inorganic forms which undergo complex transformations, affecting its bioavailability (e.g. Bostrom et al. 1988, Wetzel 2001). These processes are affected by the chemistry and temporal-spatial patterns of P loading (external and internal) and the physiochemical and biological characteristics of individual waterbodies. Total P thus represents a variety of dissolved and particulate forms, which vary seasonally and spatially and are affected by basin morphometry, climate and catchment size/development/ and biological activity (e.g. Clarke et al. 2010 and many others). Seasonal averages of intermittently spaced TP measures are thus unlikely to provide a robust assessment of lake-wide nutrient levels and availability across the season.

TP data alone cannot adequately capture potential issues in water quality related to harmful algal blooms (HABs) and/or those dominated by cyanobacteria (cHABs). Many of these blooms occur in shoreline areas where there is greatest risk of public exposure. As noted above, TP does not measure bioavailability - the degree to which it will stimulate biological activity and risk of noxious and/or toxic HABs/cHABs. For example, the recent and dramatic increase in toxic cHABs in the west basin of Lake Erie have occurred during a period where there was no significant change in <u>total</u> P loading or in-lake concentrations, and is attributed to an increase in the %bioavailable P in this loading, and changes in the timing of these loads, which are often decoupled in time from the apex of the bloom events (Stumpf et al. 2016, Watson et al. 2016a). Increasing evidence is also pointing to the important role of other factors in controlling bloom development – notably nitrogen (N) and mixing (water column stability) (O'Neil et al. 2012, Orihel at al. 2013, Watson et al. 2016b).

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[14] **Threshold defined as modelled baseline P levels+50%,** as determined for each lake
[15] Sensitivity defined by **capacity to accommodate further development** (i.e. P influx)

TP measures can often lack precision and/or accuracy, due to sampling and analytical errors. This is important, since small changes in P supply (e.g. in the order of µMol) can have significant effects on algal growth. Differences in analytical methods can produce significant discrepancies among data generated by different labs, and inter-lab comparisons should be conducted if multiple labs are used for analysis of the same parameters. Similarly, sample collection can introduce error through contamination of equipment, collection bottles, surface debris, sediment disturbance etc. As a result, measures of TP often have large coefficients of variation – in Muskoka lakes, this error ranges between 30-60% (e.g. Gartner Lee 2005, 2008). Mid-lake TP levels can differ significantly from those in inshore areas due to currents, wind and wave action, reduced flushing, warmer temperatures, shoreline inputs of nutrients and other material (anthropogenic and natural), groundwater influx, sediment exchange and bioturbation [16]. This heterogeneity in nutrient distribution is particularly an issue in lakes with low flushing rates, complex morphometry – e.g. multiple basins, islands, wetlands, embayments, deep and shallow areas - and a vulnerability to bottom anoxia. It is also of concern for those lakes with shoreline properties with septic systems that are improperly installed or maintained, or under capacity (e.g. properties that have been enlarged and converted into year-round residences). This introduces considerable uncertainty into modelling predictions and the interpretation of long term trends.

TP is not a reliable predictor of chl-a; in many cases there is a poor and/or highly variable and non-linear relationship between these measures (e.g. Carlson 1984, Watson et al. 1992); for example, a poor correlation between TP and chl-a is reported for Muskoka and other regions of Ontario (Gartner Lee 2005). Despite this, long-term monitoring programmes have relied largely on TP as the primary measure of lake status in Muskoka, and other indicators have been overlooked, particularly over the past few decades. The routine measurement of chl-a in Muskoka lakes was discontinued several decades ago, although it is an important indicator of eutrophication and trophic status (e.g. Carlson 1981) which is widely used in many national, international and local lake management programmes (e.g. SOLEC 2016; USEPA, 2017).

Climate change and other stressors related to human activity can profoundly alter a lake's nutrient balance and resilience to development, affecting seasonal ice coverage, runoff, stratification patterns, nutrient input and retention, water chemistry and extent of noxious algal growth (e.g., Hadley et al. 2013, Persaud et al. 2014, Winter et al. 2011, Watson et al. 2016a,b). This can increase the number, geographical range and diversity of lakes that are at risk - and the monitoring efforts required - and necessitate a re-evaluation of earlier management criteria and targets focussed on TP. Climate-related changes in water levels and runoff, for example, are key factors in the recent increases in cHABs in nutrient-poor (oligotrophic) lakes (e.g. LeBlanc et al. 2008, Callieri et al. 2014).

[16] sediment disturbance by living organisms.

The DMM has traditionally managed the water quality and recreational development of lakes using a model based on the provincial Lakeshore Capacity Model (LCM). This model was developed and validated using data not necessarily representative of the Muskoka region, and defined a lake's capacity for recreational development using catchment characteristics, modelled TP levels and lake morphometrics (Gartner Lee 2005). This approach defined a single ("Over Threshold") category to calculate development capacity and "Low", "Moderate" and "High" Sensitivity ratings to P loads to manage future development and protect water quality. Using this approach, Leonard Lake was classified as *above the threshold*[17] *level of enrichment with a moderate sensitivity to development capacit*y i.e. having some capacity to accommodate increased P inputs "without a significant decrease in water quality". Monitoring data, however, showed considerable variance between observed and modelled P levels, which thus could not be reliably used to describe development capacity.

The DMM has recently proposed the OP 45 Amendment, based on a Revised Water Quality Model and Lake System Health Program (HESL 2016). This Amendment proposes to revise the earlier lake classifications and development criteria and claims to thereby address some of the limitations of this TP-based model, which did not consider the multiple other stressors on these systems. Based on a more 'holistic' approach, it re-defines water quality management targets and commercial development criteria to remove some of the focus on TP. Yet although a multi-year study in the Muskoka watershed concluded that multiple indicators should be used (Eimers 2016), the OP 45 Amendment proposes three simple metrics to assess a lake's sensitivity to development and risk of 'blue-green algal' blooms (aka cHABs), two of which are based on TP data:

- A long-term statistically significant increasing trend in TP concentration demonstrated by at least five (5) sample measurements starting in 2001 or thereabouts;
- A long-term TP concentration > 20 µg/L[18], demonstrated by the average of five (5) most recent spring overturn TP sample measurements taken within the last ten (10) years
- A blue-green algal (cyanobacteria) bloom *confirmed by the province or health unit* and comprised of cyanobacteria species.

These criteria risk excluding lakes with an elevated sensitivity to development and associated impacts (e.g. increased inputs of nutrients, suspended solids, shoreline degradation, habitat disturbance etc.) for a number of reasons:

- As noted in HESL (2016) "*The estimate of total phosphorus loading to a lake becomes increasingly uncertain as development increases because of the uncertainty associated with the mobility of phosphorus from septic systems"*
- Significant water quality degradation and algal blooms can accompany TP levels below 20µg/L, a trend that is increasing with climate change-induced fluctuations in flushing and lake levels (e.g. LeBlanc et al. 2008, Callieri et al. 2014, Salmaso et al. 2015).

[17] modelled baseline P levels+50%

[18] interim provincial water quality objectives for TP to protect against algal/cyanobacterial blooms

- The target TP level is assessed using DMM data largely collected at ice-out, isothermal[19] conditions, when the impacts of cottages, recreational activities, boats, severe storms etc. are low. During the summer period, these activities increase, and have a very different effect on the lake; the response to nutrient inputs of nuisance algae/ cyanobacteria is enhanced by warm temperatures, increased daylength and water column stability.
- The low frequency and seasonal/spatial coverage represented in the current monitoring programme is, in many cases, too course-grained to detect long term trends in TP, particularly in morphometrically complex lakes.
- The third criterion is focussed on cyanobacteria, some of which can produce toxins. However:
  - -Toxicity cannot be determined from field inspection or microscope examination, and should be verified by lab tests, although commercial kits can be used to screen for toxicity on site (Watson et al. 2017);
  - -Public awareness and reporting of algal blooms has escalated in the past decade, and often exceeds the lab and field capacity for timely sampling and analysis of these events - which can form and disperse rapidly[20];
  - -Many cyanobacteria blooms are non-toxic, but can nevertheless cause significant socioeconomic harm (taste-odour, shoreline fouling, impaired recreational areas, impacts to food-webs and fisheries etc.);
  - -Surface blooms are often formed from inconspicuous or 'hidden' populations dispersed through the water column or present as DCMs during calm conditions. These can persist undetected in the water column for some time and may or may not aggregate at the surface; thus are often not detected or reported. It is important to monitor the species and their abundances during the mid-late summer;
  - -Benthic [21] mats of algae and cyanobacteria are rarely sampled in most monitoring programmes, but are also a potential 'hidden' source of toxins, and/or noxious odours and shoreline fouling and can significantly impair habitat and spawning areas for fish and other organisms (Quiblier et al. 2013).
  - -Other non-cyanobacterial species can also develop HABs. These include *Cladophora*, *Spirogyra* and other attached algae, which foul beaches and shorelines with rotting material, increasing bacterial levels and putrid odours in these areas and decreasing property value. Golden-brown algae (Chrysophyta), dinoflagellates and diatoms can produce noxious

[19] Fully mixed water column

[20] e.g. Leonard Lake Association (LLSA) made 3 calls between Sept 14-26 2017 to the Spills Action Centre to report a scum at several inshore sites. At the same time, LLA collected samples of this material which were preserved with Lugols and sent for microscopic analysis by ATEI, Winnipeg (H. Kling). This showed that one site in particular was dominated by cyanobacteria (>99% *Dolichospermum (Anabaena) lemmermannii* (see Fig S-), a known toxin producer in other lakes). MOECC sampled a single site on Sept 15 (when the bloom had disappeared); this sample was not found to contain a bloom.

[21] Bottom-dwelling

blooms and taste-odour, impacting recreational and drinking water quality (e.g. Watson and Molot 2013; Watson et al. 2001, 2016b).

Leonard Lake Association study, 2017

Rationale

Anecdotal reports of increased surface algal blooms in Leonard Lake over the past few years indicated a decline in water quality and a need to continue to monitor the lake and restrict further development. None of the blooms was sampled or identified and there was increasing concern with the risk of cyanobacteria. Long-term data at the offshore monitoring sites show generally low nutrient and chl-a levels, but no detailed survey of inshore sites had been made. Furthermore, there is serious concern with the revised classification of Leonard Lake and proposed OP 45 Amendment, which would allow less constraint on lot development. A recent in-depth evaluation of the catchment and lake morphometrics and hydrology and the (DO, temperature) profile data from the deep monitoring site highlighted the potential for internal loading and need to more fully characterise this issue (Nurnberg 2017). As noted earlier, DO profiles show a high vulnerability to bottom oxygen depletion and indicate the intermittent presence of deep-living algal maxima of unknown species composition. In many lakes these deep maxima are composed of chrysophytes and other flagellates which are of high nutritional value to zooplankton, but some lakes in the region (spanning a range of nutrient levels) show annual development of cyanobacteria-dominated deep maxima (e.g. Lake Ontario, Lake 227 in ELA, Twelve Mile Bay; M. Verschoor, S. Watson, unpublished data).

Methods

To address these issues, during 2017, the Leonard Lake Stakeholders Association undertook a three-pronged investigation of the lake, with a focus on the present and possible future occurrence of algae blooms in the lake. Samples were collected at sites in offshore and inshore areas (Figs. S-4, S-5; Table S-5), some on several occasions during the open water period. The purpose of this work was to:

- i) characterise spatial and temporal range in water quality, major nutrients (P, N) and algae/cyanobacteria
- ii) assess bottom anoxia across the lake and evidence of internal loading
- iii) sample and analyse water quality and algal species composition in any deep chlorophyll maxima detected during sampling
- iv) sample and characterize the prevalence of cyanobacteria in any algal blooms reported around the lake.

At each site, a depth profile for temperature, dissolved oxygen and chl-a fluorescence was collected at 1m increments from the surface down to 1 m above the bottom using a YSI© EXO1 Sonde. Secchi depth and surface temperature were also recorded. Individual samples were collected at specific depths for water chemistry using a horizontal sampler at 1m, 1m above the bottom, and based on the profile data, at the depth of any DCM, or if none was present, at 0.5 m above the thermocline[22]. Subsamples were filtered directly in the field into sample tubes using a syringe filter and 0.45µm membrane filters for dissolved metals and inorganic N analysis (nitrate/nitrite, ammonia); N samples were frozen until analysis. Subsamples were also processed for other water quality measures (TP, total dissolved P, chl-a) at the shore-based lab. These were shipped overnight to the Biogeochemical Analytical Service Laboratory (BASL), Edmonton AB or stored until analysis at Trent University Water Quality Centre (total dissolved metals). Method descriptions and minimum detection and quantification levels for the analyses are given in Table S-6.

Depth-integrated (composite) samples were collected over the season at several offshore monitoring sites, mainly stations 36 and NDH (Fig. S-4). On most occasions, this was carried out using the horizontal sampler at 1m intervals down to a depth corresponding to the approximate photic zone[23] (estimated as twice the Secchi depth). These individual samples were then combined into a composite sample which was preserved for phytoplankton analysis at ATEI, Winnipeg Manitoba using the standard Utermöhl technique (Findlay and Kling 1998). As the horizontal sampler was not available until mid-season (July), earlier samples were collected using different protocols: in May, a surface sample was collected manually as an 'elbow' depth dip (~0.5m), while in June, a tube sampler was used to collect the integrated sample.

At selected sites, plankton was concentrated using replicate (4) hauls with a 20 µm 'Student' Nitex© plankton net over a depth of ~5m. These samples were sent as both unpreserved and Lugol's preserved samples to ATEI for quantitative analysis of the major species present (Fig. S-4; Table S-5). In response to several reports of surface blooms in shoreline areas in mid September, unpreserved and preserved net samples were also collected between September 14-17th at five sites (QL 6,7,8,9,10; Fig. S-4), together with a composite sample at the central monitoring site (station 36), to assess the species composition of these blooms and any potential risk to the residents.

Results and Discussion

Profiles

Depth profiles taken between Aug 21-23, 2017 showed stratification at all 4 offshore sites. Surface temperatures were similar at all sites (22.6 ^{o}C) except station 36, where it was marginally cooler (21.5 ^{o}C) (Figs S-4, S-5). The depth of the mixed layer (epilimnion) extended past the Secchi depth (which showed good water transparency across the lake, ranging between 3.2-3.7 m), down to a depth of ~4.5-5 m.

Dissolved oxygen profiles showed significant declines with depth at all four sites, with concentrations decreasing to <4 mg/L at the bottom of the water column (1m above the sediment

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[22] Where the water column is thermally stratified; the **thermocline** is defined as the depth range covering the abrupt decline in water temperature, marking boundary between the warmer mixed surface layer (**epilimnion**) and cooler deep water **(hypolimnion**)

[23] [Theoretical] water column depth with sufficient light to support photosynthesis

surface) and reaching anoxic conditions at the deep site in the north basin (NDH) and site 2 in the south (Figs S-4, S-5). MDL: minimum detection level; QL: quantification level

Table 1 Dissolved and total P and N, and extracted chl-a at the four sampling sites, August 2017

Site	Depth (m)	Date	Secchi (m)	NH_3 (µg/L)	NO_2+ NO_3 (µg/L)	TDN (µg/L)	TN (µg/L)	TP (µg/L)	TDP (µg/L)	Chl-a (µg/L)
NDH	1	21-Aug-17	3.5	53	<MDL	246	248	29	17	2.2
	3.5			20	8	220	266	16	7	2.7
	15			595	130	320	339	8	7	1.0
32	1	22-Aug-17	3.7	5	3	223	247	17	5	3.7
	4.5			<MDL	129	240	262	7	11	3.7
	7			37	20	203	227	7	5	3.0
2	1	22-Aug-17	3.2	39	15	215	273	8	5	4.3
	3.5			51	4	218	240	8	8	4.2
	7			62	7	242	319	16	11	28.7
36	1	23-Aug-17	3.2	17	120	254	236	17	5	4.8
	4.5			66	8	225	247	7	4	5.1
	11.5			68	71	283	286	6	3	1.5
MDL				3	2	7	7	1.4	1.8	0.2
QL				8.2	5.9	7	23	3.1	4.9	N/A

The bottom anoxia at the shallow south site 2 was unexpected, and did not appear to reflect sediment disturbance by the probe as the decline in DO began at 4m, well above the sediment surface. This was the only site where dissolved and total P and ammonia increased in the B-1m sample (Table 1), suggesting internal loading[24]. This site also showed a significant increase in conductivity with depth, possibly suggesting an intrusion of groundwater or shoreline seepage. However, as noted above, anoxic sediment release is difficult to detect from a boat, particularly where conditions are choppy and sampling close to the sediments is necessarily conservative.

[24] However, inconsistencies between low chl-a (2.2 µg/L) and high total and dissolved nutrient data (e.g. TP, TDP=29, 17 µg/L respectively) in surface samples from NDH suggest a mix-up between 1m and B-1m nutrient samples at this site but this cannot be verified.

Unlike earlier studies, there was no clear evidence of a DCM in the DO profiles (Fig. S-5), although there was a slight increase in chl-a fluorescence towards the middle of the water column at most sites, with no consistent alignment with the temperature or DO profiles. There was, however, no corresponding peak in nutrient levels at these depths. Phycocyanin (PC) fluorescence was very low and increased slightly towards the bottom at all sites. This could be interpreted as an increase in cyanobacteria with depth; however, it is more likely that these profiles reflect an increase in DOC towards the bottom, as this material produces background fluorescence which can interfere with PC readings.

Nutrients and chl-a

Summer (August)

TP ranged between 6-29 µg/L across all samples and were higher in the surface than the deeper samples (except at site 2, as noted; Table 1). The data showed considerable spatial variance, which was unrelated to the maximum depth or chl-a at each site. Overall, TP levels were significantly higher than those measured in other monitoring programmes (e.g. Tables 1, S-1, S-2), which may reflect sampling/analytical methods or genuine differences, possibly related to season (most long-term monitoring programmes are based on spring, mixed conditions). This discrepancy should be followed up with further sampling and rigorous interlab and interagency comparisons.

Total dissolved P accounted for 30-100% of the TP, with the %dissolved fraction generally lower at the surface where most P was present in plankton cells and other particles (Table 1). With the exception of the bottom anoxic layer at the deep northern site (NDH), dissolved inorganic N (i.e. NO_3, NH_4) was low and most of the dissolved fraction present as organic N. This may represent a variety of different organic compounds including urea, amino acids, peptides etc., some of which are readily assimilated by some algae and cyanobacteria (Donald et al. 2013). TN:TP (molar) ratios were almost consistently >16, as also seen with previous monitoring data (discussed above), indicating that N is not the primary nutrient limiting algal growth and productivity in Leonard Lake.

Extracted chl-a ranged between 2.2 - 4.8 µg/L in the surface waters, with higher levels at the south and central stations (sites 2 and 36). It is of particular note that the lowest chl-a levels were measured at the deep site in the northern end of the lake (Table 1), which serves as the basis for much of the long-term monitoring by the provincial and district agencies. This suggests that these long-term data underrepresent the level of productivity in the lake, and demonstrates that future monitoring sites should be carefully selected. The shallowest site (site 2) also showed significantly higher chl-a (28.7 µg/L) in the bottom sample (not evidenced in the fluorescence profile or plankton sample collected at 7m depth; see below), suggesting a layer of live algal cells settled out from the plankton, or an actively growing benthic population. Given the shallow nature of this area of the lake, benthic algal growth is highly probable, and could represent a significant contribution to the overall productivity of the lake.

Table 2. Dissolved and total P and N, and extracted chl-a in the north and south basin sites NDH and station 2, October 17th, 2017

Statistic*	site	depth (m)	NH_3 (µg/L)	NO_2+ NO_3 (µg/L)	TDN (µg/L)	TN (µg/L)	TKN (µg/L)	TP (µg/L)	TDP (µg/L)	Chl-a (µg/L)
average	NDH	1	<MDL	<MDL	231	280	280	6	2	6.9
STD					*1*	*46*	*46*	*1*	*0*	*0*
average		15	189	2.5	364	365	363	12	3	1.2
STD			*6*	*2*	*9*	*8*	*11*	*1*	*0*	*0*
average	STN 2	1	<MDL	2	245	293	292	6	2	6.0
STD				*1*	*7*	*40*	*41*	*1*	*0*	*0.2*
average		8	178	<MDL	456	447	447	8	3	6.7
STD			*1*		*29*	*22*	*22*	*0*	*0*	*0.30*
MDL			3	2	7	7	7	1.4	1.8	0.2
QL			0.2	5.9	7	23	23	3.1	4.9	N/A

* based on the analysis of duplicate subsamples from the same sample

October

Phosphorus levels were generally lower in the mid- October samples, and close to the long-term averages for this lake (Table 3). At both north and south basin sites, bottom samples showed higher TP levels than surface, particularly at the deeper NDH site. TDP showed little depth-related change, suggesting that the increase was largely in the form of particles, possibly representing settled phytoplankton cells and other organic material. This is consistent with the elevated bottom levels of NH_4 and low concurrent nitrate concentrations at both sites, suggesting mineralization of organic material. DO and temperature profiles were not collected, so the presence of any anoxia or hypoxia and associated internal loading could not be assessed.

Metals

Dissolved metals were generally representative of average levels seen across a range of 28 Canadian lakes (Table 3; M. Verschoor, in prep.) and below Canadian and Ontario Guidelines for the Protection of Aquatic Life, with a few anomalies. The one high aluminium (Al) measure at 3m at site NDH may represent clay contamination at the thermocline, while the high hypolimnetic iron (Fe) values at both sites likely reflect anoxic sediment reduction processes. Copper and cadmium (Cu, Cd) were slightly elevated, particularly in the hypolimnion which may reflect the metal deposits in the local geology. Zinc levels were significantly elevated relative to

Table 3. Total dissolved metals (mean ±%RSD) at north and south sites in Leonard Lake (LL), August 2017; values highlighted where they exceed Canadian Water Quality Guidelines for the Protection of Aquatic Life (CWQG) or Provincial Water Quality Objectives (PWQO) for the range of alkalinity seen in LL (<75 mg/L $CaCO_3$)

date	21-Aug-17			22-Aug-17				
Station	LLNDH			STN2				
depth	1	3.5	15	1	3.5	7	CWQG	PWQO
	ppb							
Be	0.01	0.01	0.01	0.01	0.01	0.01		11
%RSD	*5.7*	*12.3*	*16.8*	*20.5*	*5.9*	*12.2*		
B	30.4	15.3	9.1	9.7	10.9	9.4		
%RSD	*1.0*	*3.0*	*4.7*	*0.8*	*1.6*	*4.0*		
Al	17.4	**156.7**	49.9	14.7	18.6	85.9	100	75
%RSD	*2.3*	*5.1*	*0.7*	*1.0*	*1.5*	*2.4*		
Ti	0.3	2.8	0.8	0.3	0.3	1.1		
%RSD	*11.6*	*6.4*	*6.2*	*22.4*	*2.3*	*11.0*		
V	0.1	0.8	0.1	0.1	0.1	0.2		6
%RSD	*3.9*	*2.5*	*2.5*	*6.3*	*5.5*	*4.8*		
Cr	1.4	1.5	1.4	1.3	1.2	1.6	8.9	8.9
%RSD	*5.4*	*2.9*	*1.0*	*1.3*	*1.5*	*1.5*		
Mn	11.5	2.3	446.1	2.7	4.4	910.5		
%RSD	*4.7*	*3.9*	*1.6*	*2.2*	*1.4*	*2.8*		
Fe	21.2	17.2	317.8	22.5	28.0	**1291.1**	300	300
%RSD	*2.2*	*4.2*	*1.1*	*3.3*	*1.1*	*2.1*		
Co	0.1	0.1	0.8	0.0	0.1	**1.2**		0.9
%RSD	*8.9*	*5.9*	*2.3*	*8.9*	*2.0*	*3.6*		
Ni	1.2	1.3	1.4	1.2	1.1	1.6	25	
%RSD	*4.7*	*4.8*	*4.1*	*3.1*	*0.4*	*7.2*		
Cu	0.9	**1.3**	**1.7**	**1.2**	1.0	**1.3**	2	1
%RSD	*6.0*	*6.5*	*0.5*	*7.5*	*3.1*	*5.3*		
Zn	**186.6**	**1584.4**	**52.4**	**37.6**	**154.7**	**132.9**	30	20
%RSD	*2.4*	*2.9*	*1.1*	*2.0*	*3.8*	*3.2*		
As	0.4	0.3	0.4	0.4	0.4	0.7	5	5
%RSD	*12.3*	*3.4*	*9.2*	*14.9*	*11.9*	*7.3*		
Se	0.1	0.1	0.2	0.2	0.1	0.1	100	100
%RSD	*11.4*	*8.7*	*18.7*	*27.6*	*18.0*	*17.2*		
Sr	15.7	17.7	15.5	14.2	14.8	18.9		
%RSD	*2.6*	*5.0*	*2.0*	*2.4*	*1.1*	*2.5*		
Mo	1.5	2.6	1.3	1.1	0.8	0.7	73	40
%RSD	*3.1*	*8.8*	*6.9*	*4.3*	*6.3*	*1.9*		
Ag	0	0.01	0	0	0	0.01	0.25	
%RSD	*29.44*	*4.52*	*9.45*	*38.99*	*29.06*	*26.91*		
Cd	0.01	**0.03**	**0.06**	0.01	0.01	**0.07**	0.017	0.1
%RSD	*13.2*	*14.2*	*8.8*	*26.5*	*2.7*	*4.5*		
Sn	0.1	0.1	0.1	0.1	0.1	0.1		
%RSD	*8.8*	*3.9*	*4.9*	*3.0*	*5.3*	*5.5*		
Sb	0.1	0.1	0.1	0.1	0.1	0.1		
%RSD	*2.2*	*7.8*	*5.8*	*0.6*	*5.6*	*7.6*		
Ba	154.9	116.0	97.3	112.8	126.8	86.3		
%RSD	*1.0*	*4.4*	*1.3*	*1.2*	*2.4*	*2.0*		
Tl	0.0	0.0	0.0	0.0	0.0	0.0	0.8	
%RSD	*14.6*	*10.5*	*15.7*	*27.4*	*41.0*	*18.0*		
Pb	0.1	0.1	0.3	0.1	0.1	0.5	1	1
%RSD	*3.1*	*2.0*	*1.4*	*1.9*	*7.2*	*1.4*		
U	0.0	0.0	0.0	0.0	0.0	0.0	15	
%RSD	*4.8*	*7.7*	*4.4*	*7.9*	*11.6*	*8.7*		

the guidelines, which again is not uncommon in this region where lakes often show Zn levels far exceeding the 30 ppb[25] level with a hypolimnetic gradient in Zn similar to iron and manganese.

Zinc also seems to form a pattern of concentration in the metalimnion towards the end of the season in some lakes, which could represent settling material or bio-accumulation (M. Verschoor, in prep).

Algae

May-June Plankton assemblages

Spring plankton samples from the central site (station 36) showed a mixed community in surface samples, with a marginal increase in Total Algal Biomass (TB) and the abundance of flagellates - chrysophytes and dinoflagellates- between May 28th and June 28th. Overall there was little change between the May and June surface water assemblages, which showed comparably low total biomass (360, 380 μg/L respectively; Fig. 5).

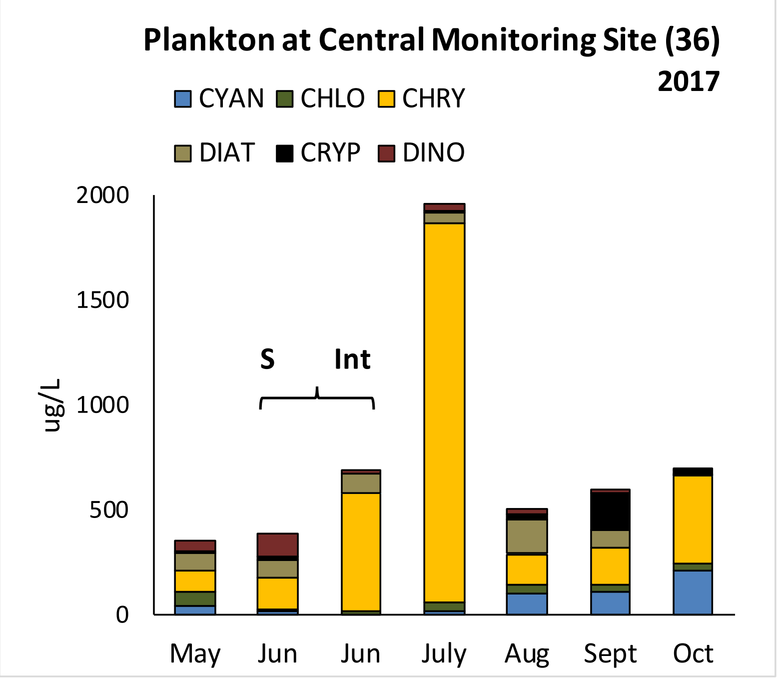

Fig. 5. Seasonal changes in phytoplankton biomass and composition in depth-integrated samples at the central monitoring site (36), Leonard Lake. CYAN=Cyanobacteria; CHLO=Chlorophyta (green algae), CHRY=Chrysophyta, DIAT=diatoms, CRYP=Cryptophyta, DINO=Dinophyta; Surface (S) and Integrated (Int) samples from June included

In May, surface algal biomass showed a fairly even distribution among several taxonomic groups. There was a predominance of diatoms (esp. *Tabellaria fenestrata*, *Lindivia* (formerly called *Cyclotella*) *bodanica* complex), mixotrophic and scaled chrysophytes (notably the mixotroph

[25] i.e. milligrams per litre (mg/L) of water

Uroglena spp., which have been shown to have a high ability to use bacterial grazing as an alternative resource under low light and inorganic nutrient levels; Watson 1999) and other flagellates (e.g. dinoflagellates; *Gymnodinium mirable*) and cryptophytes, *Cryptomonas reflexa*, *C. marssonii*, *Plagioselmis nanoplanktica* formerly called *Rhodomonas lacustris*), typical of spring algal assemblages in oligotrophic lakes (e.g. Watson and Kling 2017). The surface June biomass was fairly evenly distributed among three major algal groups that are typical of spring assemblages in softwater oligotrophic lakes, dinoflagellates (*Gymnodinium mirable*), diatoms (*Tabellaria fenestrata*, *Cyclotella bodanica* complex) and large colonial chrysophytes with a reduced prevalence of mixotrophs (*Synura* sp., *Dinobryon sertularia* and *Chrysosphaerella multispina/ longispina*). The depth-integrated sample collected in June showed a much higher (~2x) biomass than the corresponding 1m surface sample (total algal biomass of 389, 695 µg/L respectively), which likely reflects a deep-living population captured in the composite sample (this was not collected in May). In particular, the integrated sample showed a much higher biomass of large colonial chrysophyte flagellates (*Synura* sp., *Dinobryon sertularia* and *Chrysosphaerella multispina / longispina*).

Cyanobacteria were very minor constituents of both the May and June samples, largely represented by small celled colonial or filamentous picocyanobacteria[26] (*Aphanocapsa delicatissima*, *Aphanothece minutissima (Syn Anathece minutissima)*, *Cyanodictyon planktonica*, *Planktolyngbya* sp., *Radiocystis geminate*) that are common in plankton assemblages, particularly in oligotrophic lakes (e.g. Watson and Kling 2017). A very small population of filamentous nitrogen fixers was present in the May surface sample (9 µg/L; *Dolichospermum lemmermanii*, *D. planktonicum*), but no heterocysts[27] were observed, indicating that N was not limiting at this time. These cyanobacteria were not observed in June, when they may have been present at insufficient abundance to be detected.

July plankton

The composite sample from July (station 36) contained a significantly higher total biomass than the spring samples (1966 µg/L; Fig 5), and was overwhelmingly dominated by colonial chrysophytes (91%TB), notably *Dinobryon sertularia* (70% TB), along with other mixotrophic and scaled chrysophytes *(Dinobryon bavaricum, Synura* cf *splendida*, *Ochromonas* sp., *Mallomonas caudata, M. tonsurata*). Again, this may have reflected the presence of a significant DCM. The large colonial scaled chrysophyte *Chrysosphaerella* was low in abundance or absent from this and later samples, consistent with its preference for cooler spring conditions. Other algal groups were minor components of the sample biomass, and included green algae (i.e. Chlorophyta; 2%TB; notably colonies of *Botryococcus braunii*), diatoms (2% TB; *Cyclotella. bodanica*,

[26] **Picocyanobacteria** are small celled cyanobacteria (typically <2um in cell diameter) which are abundant in many oligotrophic systems where they are an essential part of the foodweb. They occur singly or in colonies or filaments
[27] **Heterocysts** are specialised cells are produced by these species which have the capacity to fix atmospheric N_2 i.e. convert this to a usable form; this capacity is lacking in algae and most other organisms (except certain bacteria), and provides these species with a competitive advantage when supplies of more bioavailable N are low

Fragilaria sp.) and dinoflagellates (2% TB; *Parvodinium cf pusillum*; *Gymnodinium* sp. *Peridinium* sp.). A similar assemblage of small filamentous and colonial picocyanobacteria was again present at very low abundance (<2% TB); bloom-forming species like *Dolichospermum* were not observed.

Net hauls collected at three inshore sites (QL3, QL4, QL5) showed similar distributions of species richness among the major groups (Fig. 6; see also Table S- 7). This does not reflect their dominance or biomass, and represents simply a species listing; note also that these taxa vary considerably in cell size. No single species or group was found to predominate the samples. Higher numbers of species were seen in the Chrysophytes (*Dinobryon* spp., *Mallomonas* spp., *Chrysosphaerella*, *Chrysostephanosphaera*), green algae (*Botryococcus*, *Planktosphaeria*, desmids) and

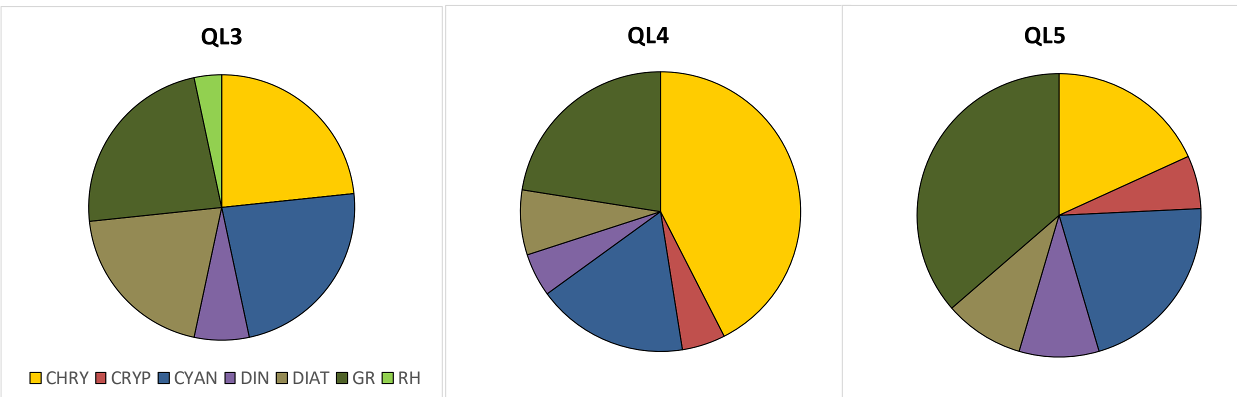

Fig 6. Species numbers in each major taxonomic group in net samples collected at nearshore stations QL3, QL4 and QL5, mid July, Leonard Lake; GR=Chlorophyta (Green algae), CHRY=Chrysophyta , DIAT=diatoms, CRYP=Cryptophyta, DIN = Dinophyta; RH=Rhaphidiophyte

Cyanobacteria (*Planktolyngbya*, *Synechococcus*, *Cyanodictyon*, *Woronichinia elorantae*). It is of note that the cyanobacteria *Dolichospermum* (*D. lemmermanii*, *D. planctonicum*) were present at all three sites, demonstrating a wide distribution (at low population levels) at this time across the inshore areas not observed at the offshore site. In addition, *Gonyostomum semen* was present at station QL3 at low levels of abundance. This species has developed highly problematic slime-producing blooms in acid-impacted lakes with high DOC and low abundances of large grazers (Trigal et al. 2013). It has been recorded in other lakes in this region (e.g. Findlay et al 2005, S. Watson unpublished data), but was not observed in any other samples in Leonard Lake.

August plankton

The algal and cyanobacterial assemblage of the lake was assessed in far greater detail in August from composite, discreet depth and net samples collected at several sites across Leonard Lake for quantitative and qualitative analysis of dominant taxa present at offshore and inshore sites. (Figs 7,8,9, S-4; Table S-7).

The depth-composite sample from the central site (station 36) collected in early August had a total algal biomass of 512 µg/L, which was significantly lower (~75%) than seen at this site in July and

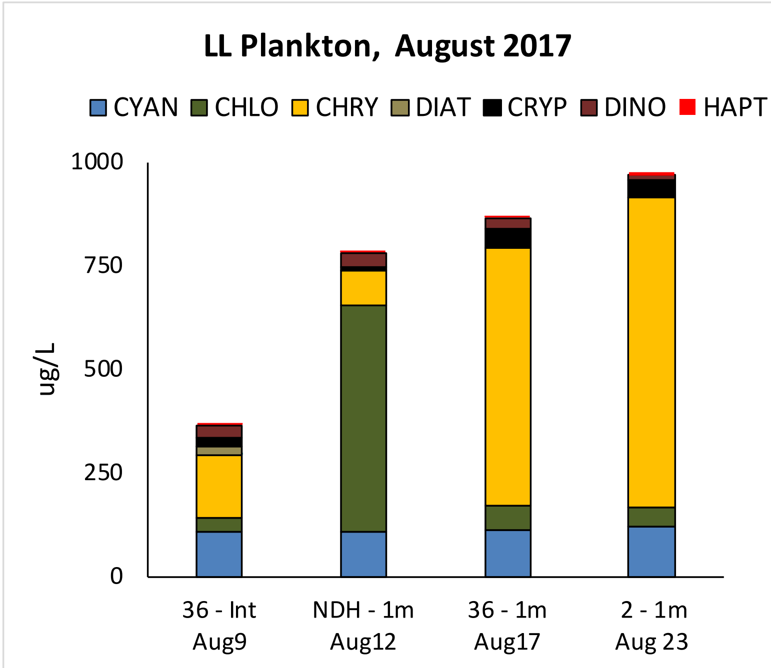

Fig 7. Phytoplankton biomass and composition at stations 2, 36 and NDH in 1m and integrated samples collected during August, Leonard Lake. CYAN=Cyanobacteria, CHLO=Chlorophyta (Green algae), CHRY=Chrysophyta , DIAT=diatoms, CRYP=Cryptophyta, DINO = Dinophyta; HAPT=Haptophyta

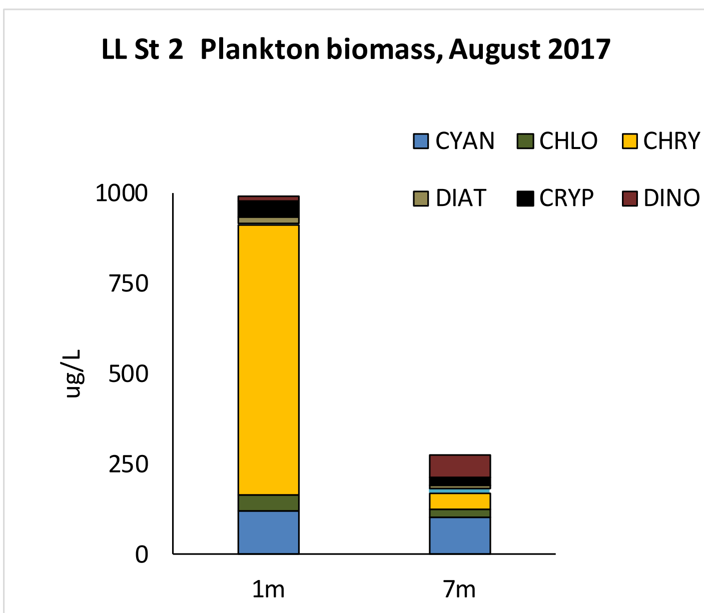

Fig 8. Phytoplankton biomass and composition in 1m and 7m samples, station 2, Leonard Lake August 23, 2017. CYAN=Cyanobacteria, CHLO=Chlorophyta (Green algae), CHRY=Chrysophyta , DIAT=diatoms, CRYP=Cryptophyta, DINO = Dinophyta

more evenly divided among different taxonomic groups (Fig. 7), with a lower abundance of mixotrophic species. Diatoms and chrysophytes were again major constituents (32%, 29% TB respectively), dominated by the chain-forming pennate diatom *Tabellaria fenestrata* (30%TB), *Synura* spp. (15%) and a variety of mixotropic chrysoflagellates (*Uroglena* sp. and small-celled ochromonads; 5%TB). Cyanobacteria showed a modest increase from July (from 24 µg/L to 106 µg/L), again dominated by small filamentous and colonial picocyanobacteria; *Dolichospermum lemmermannii* was present but at very low abundance (14µg/L or 3%TB).

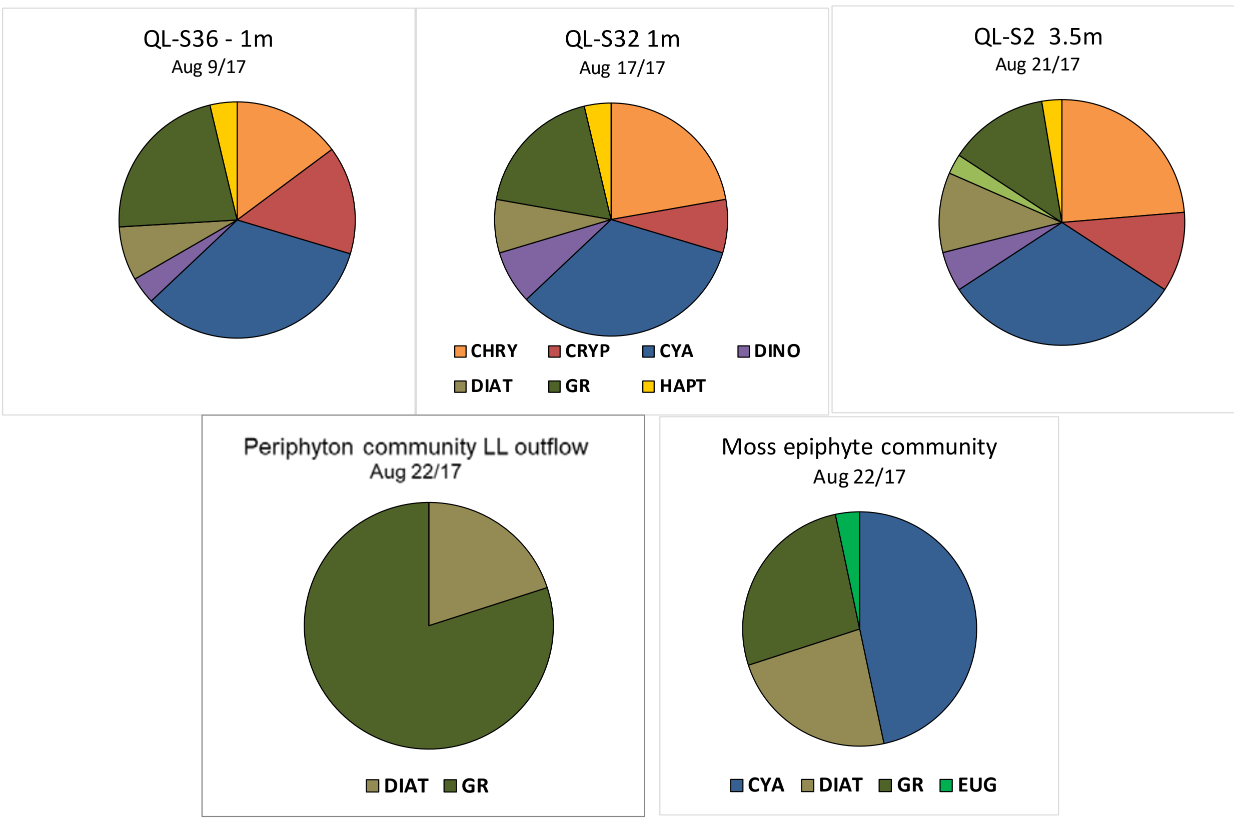

Fig 9. Species numbers in each major taxonomic group, mid August, Leonard Lake. in (Top row) net samples from stations QL S36, QL S32 and QL S2 (3.5m); (Bottom row) periphyton at shoreline site near outflow to lake; on rocks (left) and moss (right); CHLO=Chlorophyta (Green algae), CHRY=Chrysophyta, DIAT=diatoms, CRYP=Cryptophyta, DINO = Dinophyta; HAPT=Haptophyta

There was a marked difference in community composition in the surface (1m) sample collected from the north end of the lake (station NDH) which was something of an anomaly (Fig.7). The total biomass was moderately higher (800µg/L) but dominated by small celled green algae *Koliella* cf *corcontica* which are not commonly seen at high densities in the open water. This species is usually most abundant in terrestrial habitats, and the population may have originated on the shoreline and been introduced to this site by local runoff. Other species present were generally representative of the central site community composition. *Dolichospermum lemmermanni* was present in low abundance (~3%TB), together with trace levels of the potentially toxic cyanobacterium *Aphanizomenon gracile* (<1%TB).

The 1 m samples from the central and south monitoring stations collected later in August showed much higher biomass than the earlier samples (Fig. 7), mainly due to large populations of colonial scaled chrysophyte flagellates (*Synura cf. splendida, S.* cf. *peterseni*i., *Chrysosphaerella longispina*) which accounted for ~61% of the total biomass both sites (Fig.8.). These and other chrysophytes can produce strong cucumber-fishy-rancid taste and odour (Watson 2010), and may have been the source of fishy odours reported recently (in early spring) near the outlet to the lake (K. Riley, personal communication, 2017). Cyanobacteria were present but not significant, and mainly composed of small picocyanobacteria (*Cyanodictyon planktonica, C. reticulatum, Merismopedia tenuissima, Radiocystis geminata, Aphanocapsa delicatissima, Chroococcus minutus*) and fine filaments of *Planktolyngbya limnetica*. *Dolichospermum lemmermannii* was also present at both sites, but at very low abundance (1-5µg/L).

Comparison of samples collected near the surface (1m) and bottom (7m) at the southern site 2 showed marked differences in community composition (Fig. 8), demonstrating clearly that the water column was not well mixed, but contained a heterogeneous plankton population even at this shallow offshore site. This was consistent with the temperature and DO profiles which showed a strong stratification, a thermocline at ~4m and an anoxic bottom layer (Fig S-5). Compared to the surface, the plankton biomass at 7m was significantly lower (280 µg/L); *Synura* spp. were rare (only ~6µg/L) and the community was composed largely of small-celled cyanobacteria (notably *Romeria*), mixotrophic/ heterotrophic flagellates and degrading algal material. Cyanobacteria biomass was low and remarkably similar in surface and bottom samples and in both cases, dominated by a variety of picocyanobacteria and small, non N_2 fixing filamentous forms

(*Planktolyngbya, Pseudanabaena*). The erratic chl-a florescence profile peaked between 5-6 m depth (Fig S-5), but was not correlated with the dramatic change in biomass between 1m and 7m. Similarly, the PC profile suggested an increase in cyanobacteria with depth, which more likely reflected increases in dissolved organic material which fluoresces at similar wavelengths and can interfere with these readings.

Unlike the variance seen among the quantitative samples, the qualitative analysis of August net material (stations 36, 32) and a depth sample (station S2, at 3.5 m) showed very similar species representation, with no clear dominance by any one species or group (Fig. 9). Large bloom-forming cyanobacteria taxa were rare but a few cells of *D. lemmermanni* were recorded in the net hauls taken at two of the three sites (stations 2 and 36).

August periphyton

In response to a property owner's report of thick littoral[28] growth near the outflow to the lake, two samples were collected and sent to ATEI for analysis (Station 38; plate S-1; Table S-7). One was composed largely of metaphytic[29] filamentous green algae belonging to the order Zygnematales (Charophyta), and of similar composition to those reported in earlier years, dominated by species of *Spirogyra, Mougeotia* and to a lesser extent, *Zygnema* and *Oedogonium*. None of these taxa was exhibiting reproductive stages and hence they could not be identified to species level, but this kind of green algal growth is typical of inshore areas in many small ponds and lakes, and usually flourishes where there is local nutrient enhancement e.g. from groundwater influx or shoreline inputs. A few diatoms were also present, largely dominated by the cosmopolitan chain-forming species *Tabellaria flocculosa*, which is distributed widely across surface waters but most commonly found in low alkalinity, slightly acidic waterbodies.

Tabellaria flocculosa and other benthic diatoms (*Gomphonema cf acuminatum, G. cf truncatum, Enyconema cf gracilis, Navicula cf cryptocephela, Fragilaria cf rumpens, Achnanthidium minutissimum, Eunotia cf bilunaris*) were also present in the moss sample, collected from the same area. The moss epiphytes also included a diversity of benthic cyanobacteria (notably non N_2-fixing filaments *of Leptolyngbya* (dominant), *Borzia or Hormogonia, Tychonema cf rhodonema Pseudanabaena limnetica* and *Heteroleibleinia cf kuetzingii;* N_2 fixers *(Calothrix* sp ;small colonies of *Nostoc cf paludosum),* together with a colonial chroococcales *(Aphanocapsa sp, Aphanothece cf stagnina, Snowella septentrionalis, Gloeocapsa cf sanguinae, Coelosphaerium kuetzingiana*). *Dolichospermum* spp. (filaments of akinetes[30]) were not observed. Green algae were present as filaments (*Mougeotia, Bulbochaete*),and small unicells (*Pediastrum tetras*, desmids *Cosmarium* spp., *Xanthidium antilopeum*). As is typical of benthic and epiphytic communities, mixotrophic taxa were common, including the euglenophyte *Astasia*[31], thecate amoeba (e.g. *Difflugia globosa*) and rotifers. Aquatic moss is common in oligotrophic lakes and forms mats at depths down to 30 m, providing a substrate for a diverse community of small epiphytic cyanobacteria and algae.

September plankton assemblages and inshore blooms

The depth composite sample at the central site (36) showed only a slight increase from the August biomass recorded at this site (604 µg/L TB; Fig. 5), and some small shifts in species composition. In particular, there was a significant increase in the abundance of small flagellates, notably *Cryptomonas reflexa* (26%TB), which is ubiquitous to many lakes and a high quality, lipid rich food source for zooplankton. It is of note that while cyanobacteria accounted for ~20%TB, they

[28] Epiphyton: growing in the littoral or nearshore zone attached to the bottom or to rocks and other surfaces
[29] Metaphyton: growing attached or free-floating among or in near shore plants, rocks, debris etc. sometime floating in mats; some species e.g. filamentous Conjugales, often have the appearance of 'green cotton candy'
[30] Akinete: vegetative resting cell produced under adverse conditions, often over winters on sediments after the decline of a population
[31] See web video for an entertaining illustration of this taxon https://www.youtube.com/watch?v=UJfc3BTz1tE

were predominantly small-celled filamentous, colonial, and unicellular forms, while large bloom-forming species - notably *Dolichospermum* - were not observed at this site.

In contrast, all bloom samples collected at the inshore sites Q6-Q10 (see plate S-1) contained high numbers of live or decaying *Dolichospermum lemmermannii.* Most of these blooms were located on the south or east shorelines, where they may have formed as a result of wind or surface currents transporting cells inshore; however, as noted above, there was no evidence of the presence of any significant offshore population in the central site sample. Alternatively, they may reflect localised inputs of nutrients. These surface blooms degraded after less than a week, forming milky-like scums of decaying material and clusters of akinetes, resilient, thick-walled resting 'spores' produced by these cyanobacteria at the end of a population cycle and which act as 'seed beds' on sediment surfaces, germinating under favourable conditions. Nevertheless, the presence of these blooms in these shoreline areas, where there is an enhanced risk of human and animal exposure, represents a potential issue in Leonard Lake that needs further investigation. No toxin analyses were carried out on these samples.

October plankton assemblage, central site

The mid-October plankton sample again showed a moderate increase in total biomass from the previous month (700 µg/L), and a shift in species composition towards an assemblage resembling the spring community (Fig. 5). Phytoplankton biomass was dominated by chrysophytes (60%TB), notably the large colonial taxa *Chrysosphaerella longispina* (14%TB), *Dinobryon* spp. (*D. divergens, D. bavaricum*) and *Synura*, while small celled cryptophytes (C. *reflexa*, *Plagioselmis nanoplanktica (*formerly called *Rhodomonas*) were minor constituents. Cyanobacteria accounted for ~30%TB and were again dominated by small celled taxa, notably *Chroococcus minutus* (9%TB), but *D. lemmermannii* and other large bloom-forming taxa were not observed.

Conclusions

Overall, the LLSA data from Leonard Lake 2017 show distinct seasonal and spatial patterns in phytoplankton biomass and community composition, that are poorly correlated with nutrients (TP, etc.), chl-a and other measures. This clearly illustrates the importance of basing any assessments of the trophic status of the lake on multiple parameters. It also demonstrates a need to evaluate site selection, sampling frequency and depth(s) carefully in order to fully capture the range of variance in these measures and optimise the efficiency of future long-term monitoring programmes.

Summary of major results

The collective data from 2017 indicate that Leonard Lake has a low-to-moderate level of productivity and a generally robust and diverse algal community, dominated by lipid-rich diatoms and flagellates (representing high quality food for the upper food web) and small celled picocyanobacteria and green algae. However, the water quality data show nutrient levels that periodically exceed those measured by the provincial and regional agencies, who have largely concentrated their efforts on spring samples collected as depth composites.

The 2017 data show several important results:

- A significant vulnerability to low DO levels at several sites across the lake (not just the long term, central monitoring site), which develop bottom hypoxia or anoxia. This has implications for both internal nutrient loading and fish/aquatic invertebrate habitat (particularly cold-living species which may migrate to these bottom sites during warm summer months)
- Appreciable seasonal and spatial variance in the phytoplankton abundance and community composition, which at times reaches mesotrophic levels of productivity which may be underestimated by current monitoring programmes.
- Low abundances of bloom-forming taxa *Dolichospermum* spp. across much of the lake, typical of oligotrophic systems where these potentially nuisance algae are present at background levels (but can exploit localised or gradual increases in response to increased nutrient supplies).
- Brief but visibly dense cyanobacteria surface blooms at several inshore sites in late summer, possibly reflecting localised enrichment from the shoreline, or as a result of wind and wave activity concentrating the cells in these inshore areas. Such blooms may contain toxins, an issue that should be further assessed. These toxins can have serious effects if ingested by pets or humans (e.g. during recreational activity). Climate change is likely to increase the frequency of these blooms, as a result of increased open water periods, severe storms with flash runoff, altered lake circulation patterns and increased surface water temperatures, all of which favour nuisance blooms.
- The seasonal and spatially-resolved phytoplankton data represent a vital resource against which future change can be assessed, which if possible, should be continued along with an assessment of water quality and particularly, inshore and internal nutrient loading.

Ongoing stewardship and monitoring - recommendations

- Above all, discrepancies in site locations, redundant sampling efforts and differences between agencies in sampling and analytical protocols (interlab comparisons) need to be rigorously evaluated.
- The resiliency of current wastewater systems and potential impacts on Leonard Lake should be evaluated and acted on
- The extent and level of internal loading should be investigated
- A bloom response protocol should be established in collaboration with provincial and district agencies to ensure a rapid, timely response and rigorous assessment of toxins and other risk factors.

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Supplemental material

Fig. S-1

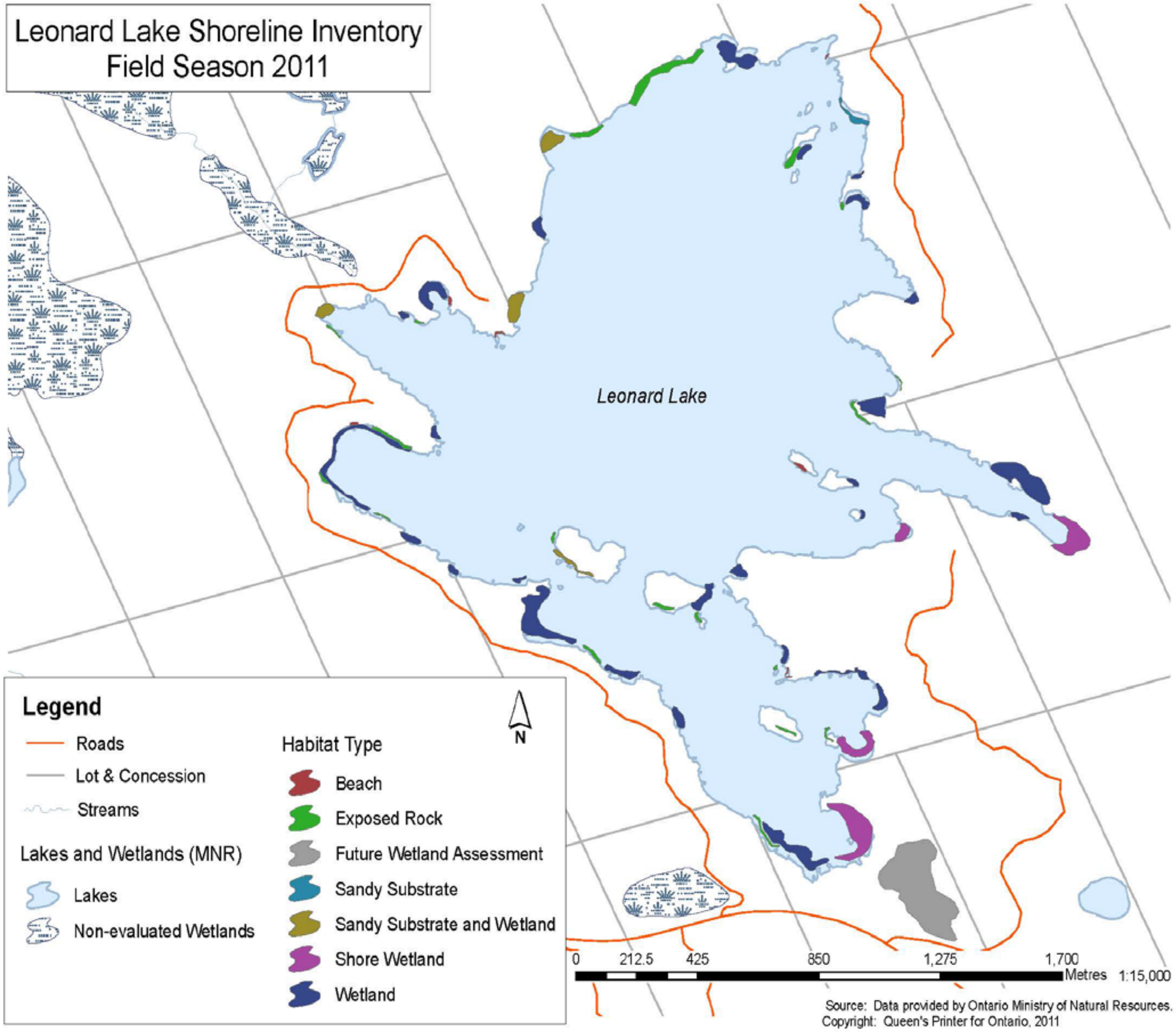
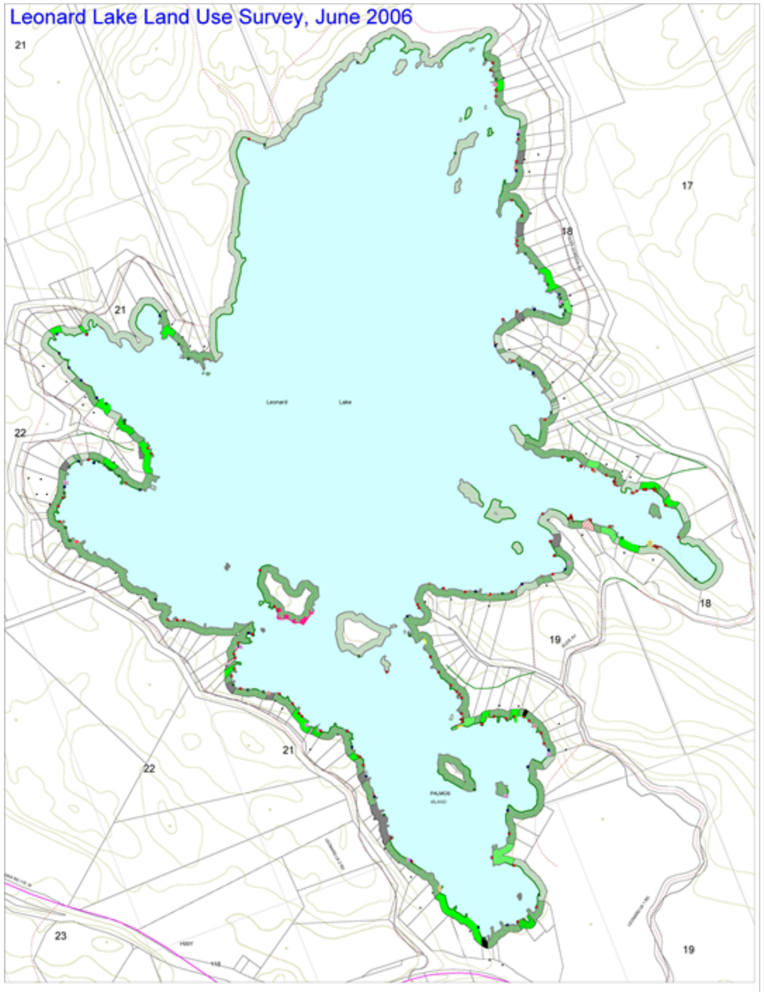

Leonard Lake Shoreline Inventory
Field Season 2011
Leonard Lake
Legend
Roads
Lot & Concession
Streams
Lakes and Wetlands (MNR)
Lakes
Non-evaluated Wetlands
Habitat Type
Beach
Exposed Rock
Future Wetland Assessment
Sandy Substrate
Sandy Substrate and Wetland
Shore Wetland
Wetland
N
0 212.5 425 850 1,275 1,700
Metres 1:15,000
Source: Data provided by Ontario Ministry of Natural Resources.
Copyright: Queen's Printer for Ontario, 2011

Fig. S-2: Leonard Lake Shoreline Use survey 2006 (source: District Municipality of Muskoka)



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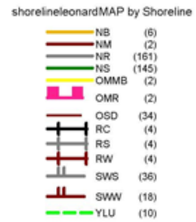
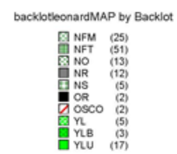


Shoreline Length and Percentages

Shoreline	Type	Length_m	Percent
NB	Natural Beach	127.06	0.36
NM	Natural Mud	49.49	0.14
NR	Natural Rock	18,866.87	54.07
NS	Natural Shrub	12,709.43	36.43
OMMB	Man Made Beach	38.41	0.11
OMR	Marine Railway	325.58	0.93
OSD	Deck	349.01	1.00
RC	Cement Ramp	81.00	0.23
RS	Stone Ramp	72.85	0.21
RW	Wood Ramp	35.04	0.10
SWS	Stone Shore Wall	1,262.32	3.62
SWW	Wooden Shore Wall	390.51	1.12
YLU	Unbuffered Lawn	583.28	1.67
	Total	34,890.85	100.00
	Natural	31,752.85	91.01
	Altered	3,138.00	8.99

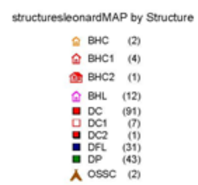
Legend



Backlot Area and Percentages

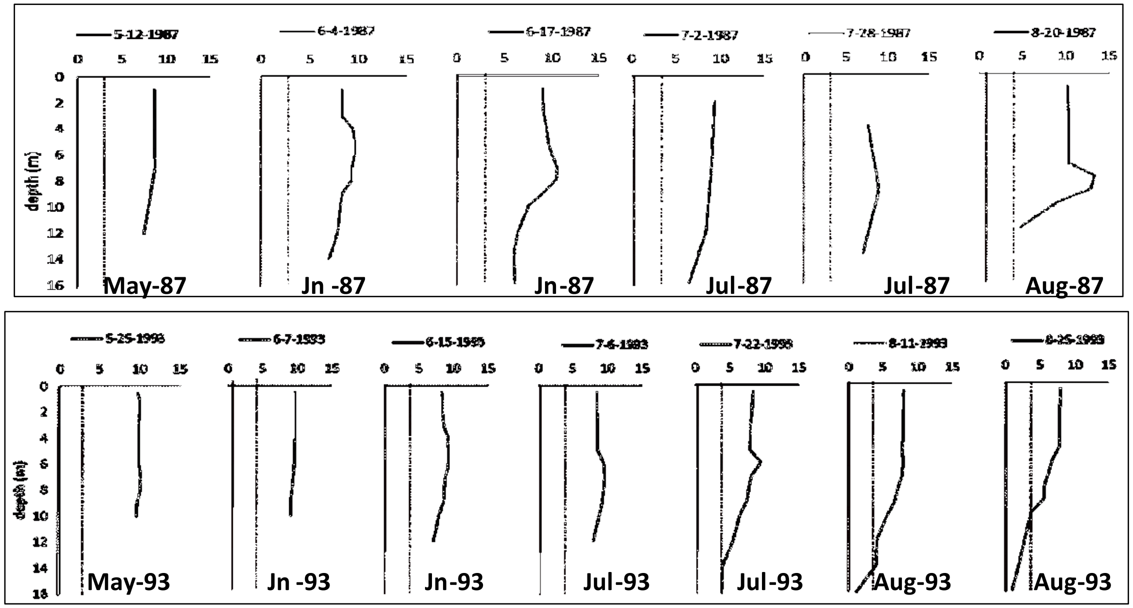
Backlot	Type	Area_m2	Percent
NFM	Mixed Forest	463.12	3.23
NFT	Thinned Forest	4,528.54	31.61
NO	Overgrowth	515.95	3.60
NR	Rocks	2,666.15	18.61
NS	Shrubs	110.92	0.77
OR	Road	403.27	2.82
OSCO	Cottage	211.17	1.47
YL	Landscaping	820.97	5.73
YLB	Buffered Lawn	542.89	3.79
YLU	Un-buffered Lawn	4,061.48	28.35
	Total	14,324.46	100.00
	Natural	3,240.19	22.62
	Altered	11,084.27	77.38

Legend



Structure Count

Structure	Type	Count
BHC	Crib Boathouse	2
BHC1	1 Slip Crib Boathouse	4
BHC2	2 Slip Crib Boathouse	1
BHL	Boathouse on Land	12
DC	Crib Dock	91
DC1	1 Slip Crib Dock	7
DC2	2 Slip Crib Dock	1
DFL	Floating Dock	31
DP	Pillar Dock	43
OSSC	Sleep Cabin	2
	Total	194



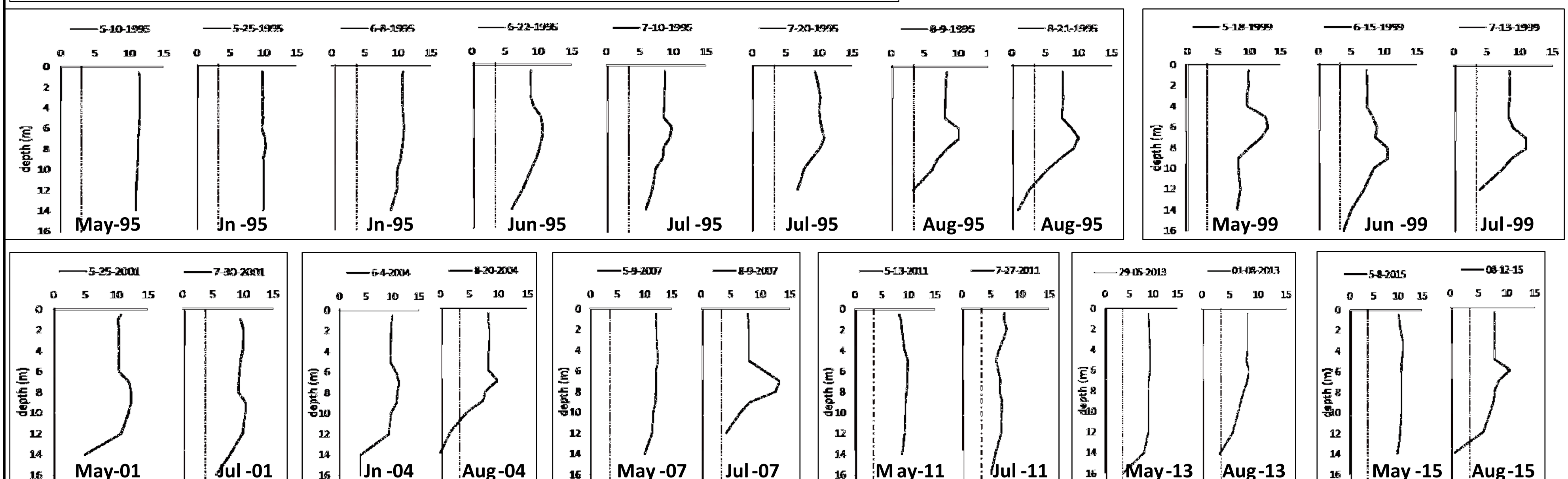


Fig S- 3. Dissolved O_2 profiles at site 36 (central long-term monitoring site, depth 16m) in Leonard Lake, 1987 - 2015. Drawn from historical MOEE data; note reduced sample frequency after 1995. Vertical dotted line at 4mg/L where conditions are adverse for fish.

Fig. S-4. Leonard Lake sampling sites, LLSA 2017

Fig S-5: Leonard Lake August profiles, Sites 2, 32, 36 and NDH

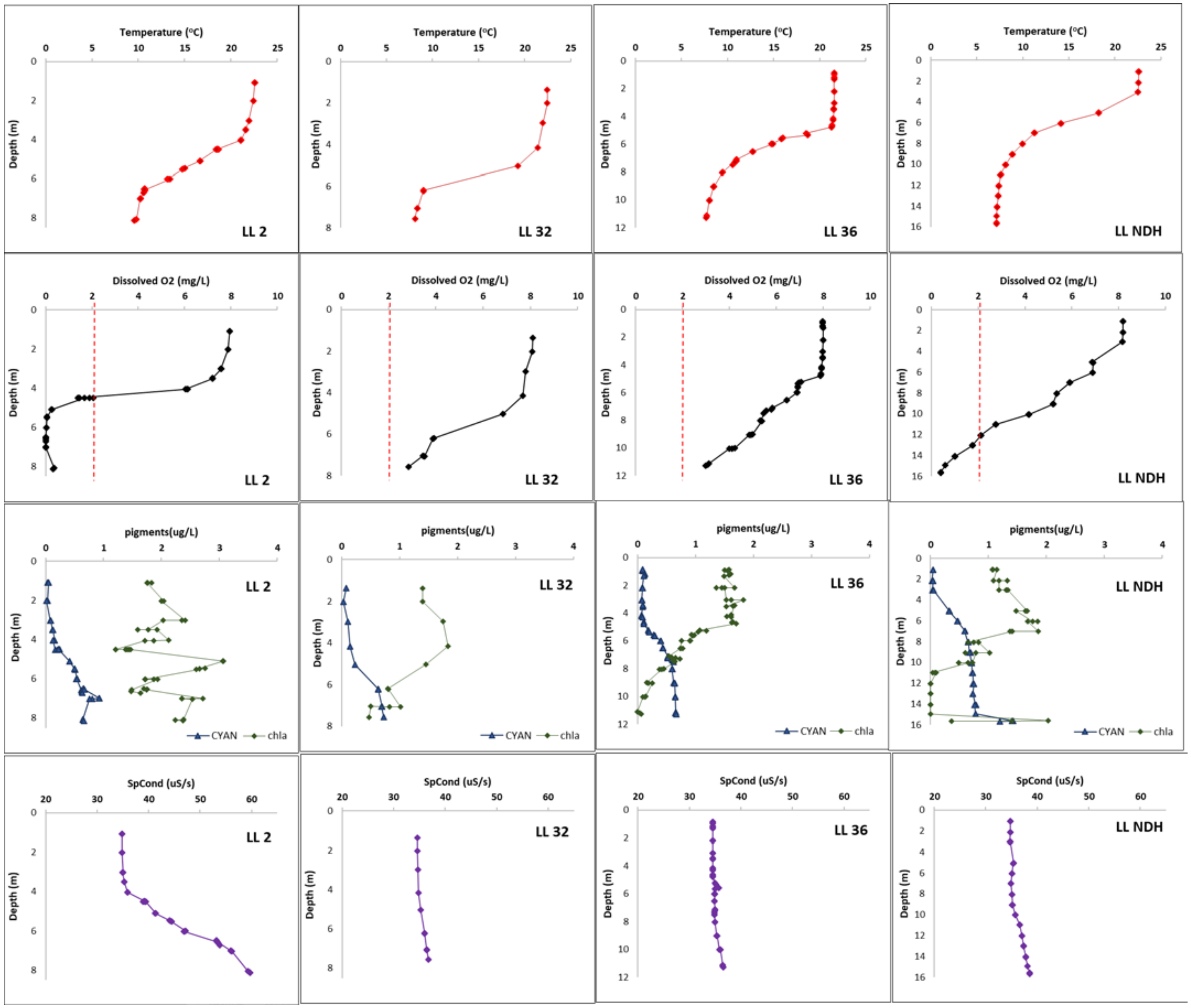


Table S-1: Summary of Leonard Lake major morphometric and average water quality parameters

Parameter	Range or average (1980-2015)	Reference
Location (lat, long)	45.0751 N, -79.4496 W	MNR 2017
Elevation (m asl)	275	MNR 2017
Surface Area (SA) (km^2)	1.95	Ingram & Paterson 2015
Catchment area (km^2)	4.19	Ingram & Paterson 2015
Shoreline (km)	13.9	MNR 2017
Island shoreline (km)	3.7	MNR 2017
Shoreline Development Index	1.4	Calculated, this report
Volume (m^3)	1.33×10^7	MNR 2017
Max depth (m)	18	MNR 2017
Mean depth (m)	6.8	Ingram & Paterson 2015
Residence time (yr)	5.4	Nurnberg 2017
pH	5.5 – 6.7	Ingram & Paterson 2015
Secchi depth (m)	4.1	MNR 2017
Dissolved Organic Carbon (mg/L)	2 – 4.5	Ingram & Paterson 2015
Dissolved O_2 (mg/L), epilimnion	7.5 – 8.8	Ingram & Paterson 2015
Alkalinity (mg/L $CaCO_3$)****	2.8	MOEE, raw data
Conductivity (µS/S)	33-35**	OWRC 1971
Calcium (mg/L)	1-2.5	Ingram & Paterson 2015
Sodium (mg/L)	0.75-3.5	Ingram & Paterson 2015

Chloride (mg/L)	0.5 – 5.4	Ingram & Paterson 2015
Total P (µg/L)	6 – 8*	Ingram & Paterson 2015
Total N (µg/L)	160-280*	Ingram & Paterson 2015
NO_3 (N, µg/L) ****	45.3	MOEE, raw data
NH4 (N, µg/L) ****	24.6	MOEE, raw data
TKN (µg/L)****	245.2	MOEE, raw data
Chlorophyll-a (µg/L) ****	2.4****	MOEE, raw data
Algal biomass (µg/L)	350 - 1966	This study
E. coli (cfu/100 mL)***	1-30	MLA 2016
Total coliform (cfu/100 mL)***	27-129	MLA 2016

*spring data
**1971 data
*** Inshore sites; see report
**** 2001-2015 yearly average

Table S-2: summary of long-term data from Leonard Lake spring samples collected at the central monitoring site, DMM

Lake	Site ID	Site Description	(DMS)	(DMS)	Date	(µg/L)	(µg/L)	%RSD	Collector
LEONARD	1	Stn 1, N end	450453	792641	19-May-02	7.1	11.4	33.3	LPP Volunteer
LEONARD	1	Stn 1, N end	450453	792641	19-May-03	7.8	6.8	9.9	LPP Volunteer
LEONARD	1	Stn 1, N end	450453	792641	02-Jul-04	5.4	5.5	1.4	LPP Volunteer
LEONARD	1	Stn 1, N end	450453	792641	08-May-05	6.3	5.6	8.5	LPP Volunteer
LEONARD	1	Stn 1, N end	450453	792641	03-Jul-06	7.3	6.5	8.4	LPP Volunteer
LEONARD	3	Mid Lake, deep spot	450430	792646	07-Jun-04	7.1			District Municipality of Muskoka
LEONARD	4	Mid Lake, Deep Spot	450428	792637	12-May-09	4.7	4.3	6.3	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	02-May-10	4.8	8.2	37.0	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	08-May-11	6.6	6.2	4.4	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	20-May-12	4.8	5.0	2.9	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	19-May-13	6.2	4.0	30.5	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	18-May-14	7.6	12.6	35.0	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	11-May-15	5.4	5.6	2.6	LPP Volunteer
LEONARD	4	Mid Lake, Deep Spot	450428	792637	22-May-16	4.2	3.6	10.9	LPP Volunteer
overall average							**6.3**		
	stdev						**2.1**		
	%RSD						**14.7**		

Table S-3: Major taxa reported in MOECC survey of Leonard Lake zooplankton (1984)

Calanoid copepodid
Calanoid nauplius
Chaoborus flavicans
Chaoborus punctipennis
Cyclops scutifer
Daphnia ambigua
Daphnia catawba
Daphnia longiremis
Diacyclops bicuspidatus thomasi
Diaphanosoma birgei
Diaphanosoma brachyurum
Epischura lacustris
Epischura lacustris copepodid
Eubosmina longispina
Holopedium glacialis
Leptodiaptomus minutus
Leptodiaptomus sicilis
Mesocyclops edax
Tropocyclops prasinus mexicanus

Table **S-4**: Aquatic Invertebrate Surveys, Leonard Lake Site 1**

	2005	2006	2010	2014	2011	2014	Leonard L. avg.	Muskoka avg**
Richness	14	16	14	14	14	19	15.17	14
% EOT	22	17	20	24	25	29	22.83	22
% Chironimids	12	11	9	19	16	15	13.67	12
% Predators	23	27	21	22	29	30	25.33	23
% Shredders	3	3	3	6	4	8	4.5	3
% Collectors/ Gatherers	70	60	69	69	66	58	65.33	70
Hilsenhoff Index***	6.10	5.68	5.98	5.96	6.09	5.87	5.95	6.1

*Reference site
**147 samples from 76 reference sites (2004 – 2011) from 9 mesotrophic, 26 oligotrophic lakes
***indicative of organic pollution; low scores indicate good water quality

Table **S-5** Leonard Lake qualitative sampling 2017: site location, collection information and reporting

Station	Date	Location	GPS Coordinates	Collection Observations & Notes	Secchi (m)	Temperature (oC)									CSI Volunteer
						0m	8 m	7 m	6m	5m	4m	3m	2m	1m	
QL 1a	28-May-17	Mid Lake (approx)	N45 04.741, W079 27.210 Waypoint 312	Surface, elbow depth, arm sweep; Near 1971 map Central station 36	4.5	18	no temperature taken ===>								G.Roberts, B. Isbister
QT	28-May-17	Mid Lake (approx.)	N45 04.741, W079 27.210 Waypoint 312	Integrated live and lugols net haul (borrowed net) down to 7.0m. Surface elbow sweep.	4.5	18	no temperature taken ===>								G. Roberts, B. Isbister
QL 1b	28-Jun-17	Mid Lake (approx)	N45 04.559, W079 26.778 Waypoint Algae Deep	Surface, elbow depth sweep	4.5	24	no temperature taken ===>								G. Roberts, K. Riley
QT	28-Jun-17	Mid Lake (approx.)	N45 04.559, W079 26.778 Waypoint Algae Deep	Integrated live and lugols; Pump/hose pull down to 7.0m (2x secchi)	4.5	24	no temperature taken ===>								G.Roberts, K.Riley
QL 2	9-Jul-17	Beaver Bay	N45 04.740, W079 27.210 Waypoint 313	Lime green, slimy, cotton candy scum; reported by M. Scarrow. Found in Beaver Bay; E of property 1294 and W of 1304 LL Road 2; Pail used to skim water; Near 1971 map Nearshore Beaver Bay. E of Stn. 32	n/a	22	no temperature taken ===>								G.Roberts, M. Scarrow
QT	18-Jul-17	Mid Lake (approx.)	N45 04.548, W079 26.822 Waypoint	Vertical Sampler; integrated whole water	3.5	20	-	8	12	14	18	18	19	20	G.Roberts, B.Isbister
QL 1c	18-Jul-17	Mid Lake (approx)	N45 04.548, W079 26.822 Waypoint		n/a	20	no temperature taken ===>								G.Roberts, B. Isbister

QL 3	25-Jul-17	Outlet Bay Off Shore	N45 04.679, W079 27.337 Waypoint 315	Outlet Bay out from Scarrow's (1250 LL Road 2) and Riley's dock (1166 1250 LL Road 2); net haul x4 & integrated sample; K.Riley reported. Secchi 4.2m. Near 1971 map Nearshore Outlet Bay Stn. 32	4.2	18	no temperature taken ===>								G. Roberts, K. Riley
QL 4	25-Jul-17	1126 LL Road 2	N45 04.260, W079 27.075 Waypoint 316	Between Greenham's docks 1126 LL Road 2; Net haul x4 & integrated sample; Mark G reported. Too shallow for secchi Near 1971 map Nearshore.Mid way Stn. 31and 40	n/a	18	no temperature taken ===>								G. Roberts, K.Riley
QL 5	25-Jul-17	1163.8 LL Road 1	N45 04.105, W079 26.467 Waypoint 317	Beside McNeely's dock 1163.8 LL Road 1. Net haul x4 & integrated sample. Reported Floating algal mass Too shallow for secchi. Near 1971 map Nearshore N of Stn. 42	n/a	18	no temperature taken ===>								G.Roberts, K. Riley
QL 1d	9-Aug-17	Mid Lake (approx)	N45 04.510, W079 27.906 Waypoint	Surface, elbow depth, arm sweep.	n/a	24	no temperature taken ===>								G.Roberts, K. Riley, M.Green-ham
QT	9-Aug-17	Mid Lake (approx.)	N45 04.510, W079 27.906 Waypoint	Vertical Sampler, Sunny, partially cloudy. No waves; calm. water depth 14.2 m.	3.5	24	-	17	17	21	22	22.5	23	24	G.Roberts, K.Riley, M. Green-ham
QL n/a	22-Aug-17	1186 LL Road 1	N45 04.318, W079 26.597 Waypoint 363	John Riffel reported **Periphyton.** Sample scraped from rocks; Near 1971 map Nearshore SW Stn. 38	n/a	no temperature taken ===>									G. Roberts M. Greenham

QL	6	14-Sep-17	1208 LL Road 2	N45 04.458, W079 27.386 Waypoint 348	Significant bloom b/w Wilde's and Caravaggio's; sample collected at Caravaggio's who reported green shore scum. Whitish collected vertical sampler 3pm; reported Sept 14th to MOE Spill Action Centre ref no. 8716-AR7PTB; Near 1971 map SW Stn. 31. East Bay	n/a		n/a ===>								G. Roberts
QL	7	19-Sep-17	LL Boat Launch	N45 03.769, W079 26.495 Waypoint 349	2010 Highway Woods; Reported by Hans Heeneman; Skimmed sample off lake surface; along shoreline, not water column; reported Sept 19th to MOE Spill Action Centre ref no. 4531-ARCQ3M; Oily scum near boat launch collected. 1971 map Nearshore Stn. 43 Boat Launch South Bay	n/a	21	n/a ===>								G. Roberts, K. Riley, M. Greenham
QT		19-Sep-17	Mid Lake (approx.)	N45 04.543, W079 27.909 Waypoint	Vertical Sampler	3.5m	21	-	18 C	18 C	18. 5C	19. 5C	20C	21 C	22C	G. Roberts, M. Greenham
QL	8	25-Sep-17	1250 LL Road 2	N45 04.672, W079 27.377 Waypoint 357	1250 LL Road 2 Scarrow; sample skimmed near dock 2 feet of water; water very calm, sunny; shoreline stream, approx. 3' -4', of whitish substance approx. 3”x48”; Skimmed water sample off surface. M Scarrow/ K. reported Green ribbons in floating needles. Near 1971 map Nearshore SW Stn. 32 Outlet Bay	n/a	24	n/a ===>								K. Riley

QL 9	26-Sep-17	1250 LL Road 2	N45 04.681, W079 27.388 Waypoint 354	Scarrow 1250 LL Rd 2 over to neighbours; sample skimmed from water surface; Whitish thin mat /ribbons; very calm and sunny, Near 1971 map Nearshore, W of Stn. 32	n/a	22	n/a ===>	K. Riley
QL 10	26-Sep-17	1217 Butter & Egg	N45 05.002, W079 26.975 Waypoint 356	Bright's collected in bay just to the west of cottage, near shore; sample skimmed from water surface; 4m alongshore. Whitish ribbons; very calm and sunny; Near 1971 map Near shore W of Stn. 34	n/a	n/a	n/a ===>	K. Riley
QT	22-Oct-17	Mid Lake (approx.)	N45 04.546, W079 26.906 Waypoint	Sunny, partial cloud, light chop, wind light; It appears lake turned over	3.5	14	14ºC ===> lake has turned over	

Table S-6: Method description and MDL, DESC, Trent University Water Quality Centre (metals) and the Biogeochemical Analytical Service Laboratory (BASL), University of Alberta, Edmonton AB (all other listed analyses)

Method ID	Abbrev.	MDL	Method Name	Reference	Method	Instrument
TM-IOG-003	NH_4	0.2 μg/L	Determination of Ammonia in Surface and Wastewaters by Flow Injection Analysis	Standard methods for the examination of water and wastewater (Modified)	Standard methods for the examination of water and wastewater, 22nd Ed, 4500-NH_3-B,H, AWWA 2004.	Lachat QuickChem QC8500 FIA Automated Ion Analyzer
TM-IOG-004	NO_2+NO_3	2 μg/L	Determination of Nitrate/Nitrite in Surface and Wastewaters by Flow Injection Analysis	US EPA 353.2 (Modified)	Determination of Nitrate Nitrite Nitrogen by Automated Colorimetry	Lachat QuickChem QC8500 FIA Automated Ion Analyzer
TM-IOG-005	TDN	7 μg/L	Automated Determination of Total Nitrogen and Total Dissolved Nitrogen by Flow Injection Analysis	Standard methods for the examination of water and wastewater (Modified)	Standard methods for the examination of water and wastewater, 22nd Ed, 4500-N-B, AWWA 2004.	Lachat QuickChem QC8500 FIA Automated Ion Analyzer
TM-IOG-007	TP; TDP	1.4; 1.8 μg/L	Determination of Total Phosphorus and Total Dissolved Phosphorus in Waters by Flow Injection Analysis	Standard methods for the examination of water and wastewater (Modified)	Standard methods for the examination of water and wastewater, 22nd Ed, 4500-P-B, G, AWWA 2004.	Lachat QuickChem QC8500 FIA Automated Ion Analyzer
TM-IOG-013	Chl-a-F	0.2 μg/L	Determination of Chlorophyll a in Water by Fluorometry	Welschmeyer, N.A. 1994. Limnol. Oceanogr., 39(8), 1994, 1985-1992. (Modified)		Shimadzu RF-1501 Spectro -fluorophotometer
	Total Dissolved Metals	See Table 1B	Trace Metals Analysis by ICP-MS https://www.trentu.ca/wqc/	Standard methods for the examination of water and wastewater, 22nd Ed, 3125, AWWA 2004.	Sample run 3 times, 25 instrument reads per run (0.1 s dwell time). Values calculated as mean ± RSD of 75 reads	Inductively coupled plasma mass spectrometry (ICP-MS)

Table S-7: Listing of plankton and benthic algal, cyanobacteria and microzooplankton taxa recorded in samples collected from Leonard Lake, May-October 2017. Sites 36, NDH, 2, 32 – offshore monitoring sites; QL3-QL10 – inshore net sample sites; Peri – periphyton collected near outflow; Moss – epiphyte community associated with aquatic moss sample collected near outflow. Numbers in columns represent month number(s) when species recorded at that site

	Site, month(s) recorded													
Taxon	**36**	**NDH**	**2**	**32**	**QL3**	**QL4**	**QL5**	**QL6**	**QL7**	**QL8**	**QL9**	**QL10**	**Peri**	**Moss**
Cyanobacteria														
Anathece minutissima	5,3,7,8,10													
Anathece sp.	6,8													
Aphanizomenon cf. gracile		8	8											
Aphanocapsa delicatissima	6,8			8										
Aphanocapsa incerta			8											
Aphanocapsa sp.	5,6,8,9,10	8												8
Aphanothece cf. planctonica	5													
Aphanothece cf. stagnina														8
Aphanothece clathrata	5		8											
Aphanothece sp.	8	8	8											
Calothrix sp.														8
cf. Borzia sp. or Hormogonia														8
Chroococcus cf. aphanocapsoides			8											
Chroococcus cf. minimus	6,7,8	8												
Chroococcus microscopicus	10													
Chroococcus minutus	7,8,9,10		8	8										
Chroococcus sp.	10			8										
Clastidium sp.														8
Coelosphaerium kuetzingiana														8
Cyanodictyon filiformis	7,9			8										
Cyanodictyon planktonica	5,6,7,8	8	8			7	7							
Cyanodictyon reticulatum	6,8,9	8	8											
Dolichospermum (=Anabaena) lemmermannii	5,8	8	8		7	7	7	9	9	9	9	9		
Dolichospermum (=Anabaena) planctonicum	5				7					9				

Taxon	Site, month(s) recorded													
	36	NDH	2	32	QL3	QL4	QL5	QL6	QL7	QL8	QL9	QL10	Peri	Moss
Eucapsa starmachii														8
Gloeocapsa cf. sanguinae														8
Heteroleibleinia cf. kuetzingii														8
Lemmermaniella palida	8													
Leptolyngbya sp.														8
Limnothrix					7									
Limnothrix cf. redekei	8													
Merismopedia tenuissima	6,7,8,9	8	8			7								
Nostoc cf. paludosum														8
Planktolyngbya limnetica	8		8	8						8				
Planktolyngbya sp.	6,7,8,9,10	8	8	8	7	7	7			9	9			
Pseudanabaena limnetica	6,9													8
Pseudanabaena mucicola	6													
Pseudanabaena sp.	8,9		8											
Radiocystis geminata	6,7,8,9,10	8	8		7	7	7							
Rhabdoderma sp.	8													
Rhabdogloea smithii	8,9				7	7	7							
Rhabdogloea sp.	10		8											
Romeria cf. leopoliensis			8											
Snowella septentrionalis														8
Spirulina major				8										
Synechococcus lineare							7							
Synechococcus sp.	6,8		8											
Tychonema cf. rhodonema														8
Woronichinia sp.	6													
Woronichinia eloranta	8					7								
Chlorophyta and **Charophyta***														
Ankistrodesmus falcatus/fusiformis	8,10	8	8											

	Site, month(s) recorded													
Taxon	**36**	**NDH**	**2**	**32**	**QL3**	**QL4**	**QL5**	**QL6**	**QL7**	**QL8**	**QL9**	**QL10**	**Peri**	**Moss**
Ankistrodesmus fusiformis						7	7							
Aphanochaeta flagellates														8
Binuclearia														8
Botryococcus braunii	6,8,10				7	7	7			9	9	9		
Botryococcus cf. pila	7													
Botryococcus protruberans	9						7							
Bulbochaeta														8
Chlamydomonas sp.			8											8
Closterium kuetzingii									9					
Coenococcus planctonica (=Eutetramorus planktonica)	6	8	8											
Collodictyon triciliatum	10		8											
**Cosmarium cf. laeve*		8												
**Cosmarium abbreviatum*														8
**Cosmarium cf. depressum*	5,8,10													
**Cosmarium sp.*	5,8					7	7							8
**Cosmocladium sp.*					7	7	7							
Crucigeniella quadrata	5													
Crucigeniella tetrapedia	5,8,9													
Desmodesmus cf. braziliensis			8											
Didymocystis sp.	8													
Elakatothrix biplex	9													
Elakatothrix gelatinosa	5													
Elakatothrix genevensis	5,6,8,10		8	8		7	7							
Elakatothrix spirochroma	7,8													
Gloeothece linearis			8											
Keratococcus	5,8,9						7			9				
Koliella cf. corcontica		8												
Koliella longiseta	8,9	8	8											

Taxon	36	NDH	2	32	QL3	QL4	QL5	QL6	QL7	QL8	QL9	QL10	Peri	Moss
	Site, month(s) recorded													
Koliella spiculiforme			8											
Merismopedia punctata			8											
Monomastix sp.			8											
Monoraphidium contortum	8,9,10		8											
Monoraphidium griffithii	6,7													
**Mougeotia sp.*													8	8
Nephrochlamys subsolitaria			7											
Oedogonium													8	
Oocystis cf. submarina	8,10	8	8											
Oocystis lacustris			8											
Oocystis nephrocytium	5				7									
Oocystis sp.	8													
Oocystis submarina	8,9		8											
Oocystis submarina v. variabilis	6,8													
Pediastrum tetras	6													8
Pedinomonas sp.	8		8	8										
Planctosphaeria gelatinosa		8		8										
Planktonema lauterbornii	5													
Planktosphaeria gelatinosa	5													
Quadrigula pfitzeri	8,9		8	8										
Quadrigula sp.	6,8			8		7	7							
Scenedesmus cf. disciformis	6	8	8											
Scenedesmus ecornis		8												
Scenedesmus sp.	8	8												
**Spirogyra sp.*	5,8												8	
**Spondylosium planum*	7													
**Staurastrum bullardii*										9				
**Staurodesmus dejectus*				8										
**Staurodesmus incus*	7				7	7	7			9				

	Site, month(s) recorded													
Taxon	**36**	**NDH**	**2**	**32**	**QL3**	**QL4**	**QL5**	**QL6**	**QL7**	**QL8**	**QL9**	**QL10**	**Peri**	**Moss**
**Staurodesmus sp.*	8		8											
**Staurodesmus triangulare*							7							
Stichococcus sp.					7									
**Teilingia granulatum*	5,6						7							
Tetraedron caudataum	5,8,9		8											
Tetraedron minimum	8						7							
**Xanthidium antilopeum*	8,10	8	8											8
**Zygnema sp.*	6,8		8										8	
Chrysophyta														
Bicoeca sp.									9					
Bitrichia chodatii											9			
Chroococcus limneticus						7								
Chrysococcus sp.	8													
Chrysolykos planktonicus	5,8		8											
Chrysosphaerella longispina	5,6	8	8			7	7							
Chrysosphaerella multispina/ longispina	6													
Chrysostephanosphaera gobulifera	6,8,10		8	8	7	7								
Dinobryon bavaricum	6,7,8,10		8		7	7	7							
Dinobryon bavaricum v. vanhoffnii						7								
Dinobryon borgei						7	7							
Dinobryon divergens	6,7,8,10		8		7	7	7							
Dinobryon mucronatum						7								
Dinobryon pediforme	8	8				7								
Dinobryon sertularia	5,6,10													
Dinobryon suecicum	7	8		8		8								
Epiphyxis sp.	6													
Kephyrion boreale	5,6,7,8													
Mallomonas acaroides	6													

Taxon	Site, month(s) recorded													
	36	NDH	2	32	QL3	QL4	QL5	QL6	QL7	QL8	QL9	QL10	Peri	Moss
Mallomonas akrokomos	7,8					7								
Mallomonas caudata	6													
Mallomonas cf. punctifera			8											
Mallomonas crassisquama	8													
Mallomonas duerrschmidtae	5,7					7	7							
Mallomonas elongata	7													
Mallomonas lychenenis/ allorgei						7								
Mallomonas sp.						7								
Mallomonas tonsurata	5													
Ochromonas sp.	6,8,9													
Pseudokephyrion boreale	5,7				7	7	7							
Pseudokephyrion sp.	7,8,10		8	8										
Pseudopedinella cf. pyriformis, P. erkensis		8												
Pseudopedinella sp.	9													
Rhizochrysis limnetica	8		8	8										
Spiniferomonas sp.	10													
Stichogloea doederlenii	9					7								
Stichogloea olivaceae	5,8,10		8		7	7	7							
*Synura cf. splendida***	7													
*Synura petersenii***	5,7,8,9		8			7	7							
*Synura sp.***	9													
*Synura sp.. (S. petersenii, S. spinosa)***	5,6,8,10		8	8	7									
Uroglena sp.				8										
Cryptophyta														
Cryptomonas cf. playturis	5,7,8		8											
Cryptomonas marssonii			8											
Cryptomonas obovata	5,8	8	8	8										
Cryptomonas reflexa							7							

Taxon	Site, month(s) recorded													
	36	NDH	2	32	QL3	QL4	QL5	QL6	QL7	QL8	QL9	QL10	Peri	Moss
Katablepharis ovalis	5,6,7,8,9,10	8		8		7	7							
Rhodomonas lacustris (= Plagioselmis nanoplanktica)	5,7,8,9,10	8	8	8	7	7								
Diatoms (Bacillariophyta)														
Achnanthidium minutissimum														8
Asterionella formosa	5,6,7,8,9,10	8	8		7									
Lindivia bodanica (=Cyclotella bodanica) complex	5,6,7,8			8	7	7-	7							
Enyconema cf. gracilis														8
Eunotia cf. bilunaris														8
Fragilaria cf. rumpens														8
Fragilaria sp.	7													
Gomphonema cf. acuminatum														8
Gomphonema cf. truncatum														8
Navicula cf. radiosa	8													
Navicula cf. cryptocephela														8
Synedra acus v. radians					7									
Synedra nanana (=Fragilaria nanana)	6,8,9													
Synedra sp.	7	8												
Synedra tenera (=S.acus)						7								
Tabellaria fenestrata	5,6,8,9	8	8	8	7	7	7		9	9				
Tabellaria flocculosa	8				7					9	9		8	8
Urosolenia eriense	8,9	8	8		7	7	7							
Dinophyta														
Glenodinium sp.	5,6,8				7									
Gymnodinium mirabile	6,7,8,9		8											
Gymnodinium sp.	8,9		8											
Gymnodinium uberrimuum	6,7,8,9,10	8	8		7	7	7	7						

	Site, month(s) recorded													
Taxon	**36**	**NDH**	**2**	**32**	**QL3**	**QL4**	**QL5**	**QL6**	**QL7**	**QL8**	**QL9**	**QL10**	**Peri**	**Moss**
Parvodinium inconspicuum/ pusillum			8											
Peridinium polonicum	7						7							
Peridinium sp.						7	7							
Peridinium willei			8											
Peridinium wisconsiense	8													
Euglenophyta														
Astasia sp..														8
Euglena acus	5,7,10		8											
Euglena sp.	5,6,7,8,10	8	8	8										
Trachelomonas volvocina		8												
Haptophyta														
Chrysochromulina parva	8,9			8										
Ochrophyta - Rhaphidiophceae														
Gonyostomum semens	7,8		8	8	7		7							
Mixotrophs														
Aulomonas perdyi	6,10													
Cryothecomonas scybalophora	5,7,8,9,10	8	8	8										
Gyromitus cordiformis	7,8,10	8	8	8										
Salpingoeca frequentissma	7													
Salpingoeca sp.				8										
Microzooplankton														
Arcella											9			
Askenasia	10													

	Site, month(s) recorded													
Taxon	**36**	**NDH**	**2**	**32**	**QL3**	**QL4**	**QL5**	**QL6**	**QL7**	**QL8**	**QL9**	**QL10**	**Peri**	**Moss**
Ciliate	8		8											
Difflugia globosa	9	8												8
Haltaria sp.	5,8		8	8	7									
Heliozoan	8													
Holophrya	5,6	8												
Mesodinium sp.	8,10	8	8											
Scuticociliates	5	8												
Strobilidium sp.	5,7,8	8		8										
Strombidium sp.	10					7								
Tintinnids	7,8,10		8											
Urotricha (Scuticociliate)						7			9	9	9	9		
Vorticella					7									
Polyarthra	7													
Trichocerca sp.							7							
Cyclopoid copepod					7		7							

* Charophyes indicated with an asterisk
**ID tentative; require SEM for positive identification

Plate S-1: Leonard Lake Periphyton/moss growth reported and sampled August 22, 2017, station 38.

Plate S-2: Leonard Lake images from inshore bloom material, September 2017

A: *Dolichospermum lemmermannii* shoreline bloom at QL6, Sept 14 2017;

B, C: Microscope photo images of *D. lemmermanni* colonies and fragments B: live, x400; C: preserved with Lugols, x200)

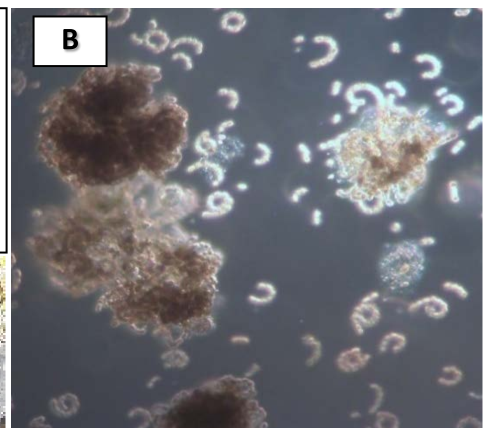
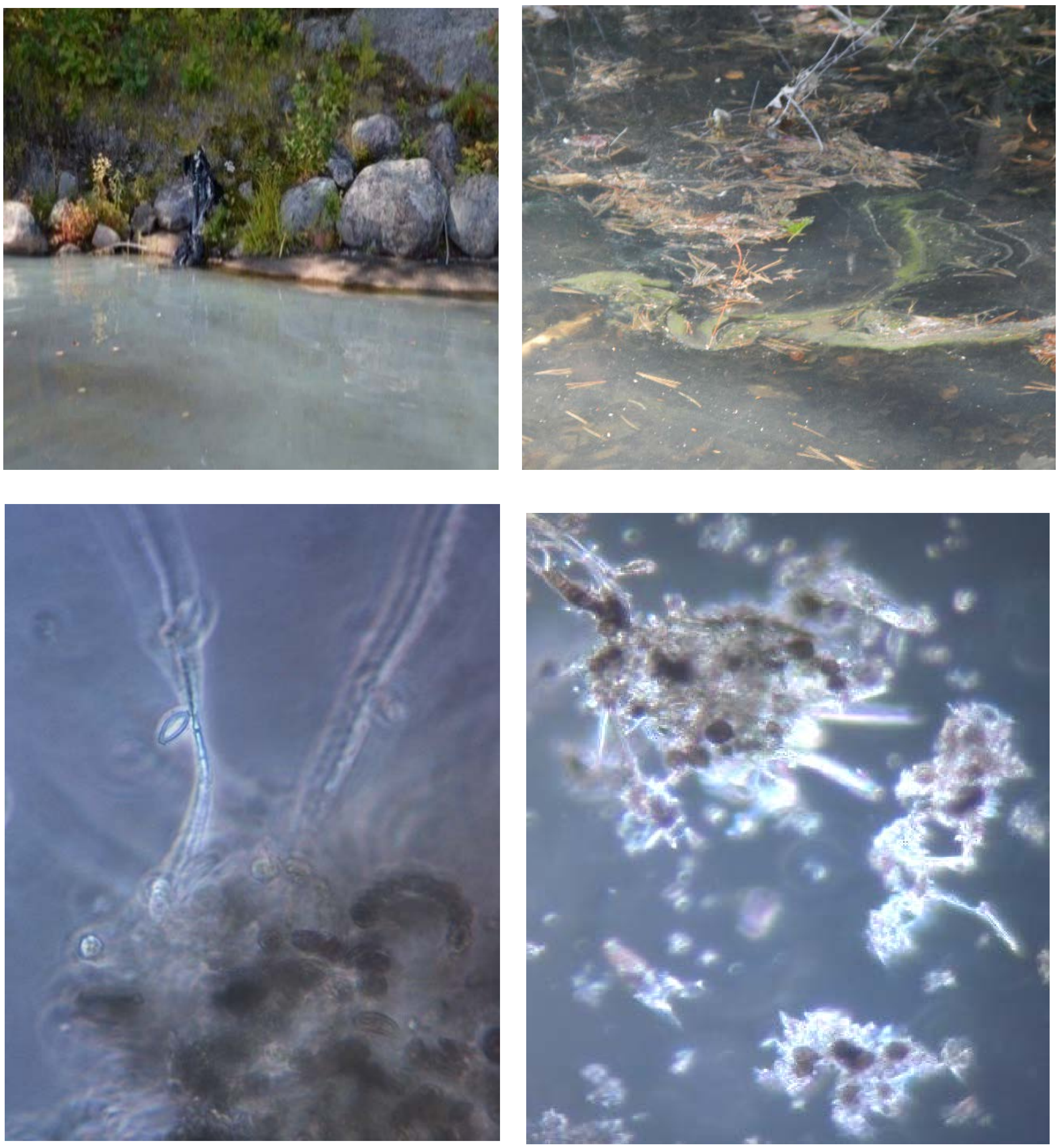


Plate S-3: Leonard Lake images from degrading inshore *Dolichospermum lemmermanii* bloom material, September 2017; top – showing milky, streaky scums; bottom images – microscope photo images of degrading filaments with attached fungal hyphae and debris.



Leonard Lake Water Quality and Phytoplankton: Status, Monitoring and Management
GLOSSARY OF TERMS

Algae mats	One of many types of microbial mat formed on the water surface or on the surface of rocks. One type is made out of blue-green cyanobacteria and sediments.
Algae mixotrophs, heterotrophs, autotrophs	Mixotrophic species of algae can use a mix of different sources of energy and carbon to support growth and maintenance. Heterotrophic species get their energy from organic carbon compounds in much the same way as yeast, bacteria and animals. Autotrophic species are photosynthetic, like plants and do not consume organic matter.
Bioturbation	The disturbance of sedimentary deposits by living organisms (e.g. worms, burrowing clams).
Bioavailability (TP - total phosphorus)	The degree to which phosphorus (P) will stimulate biological activity and increase the risk of noxious and/or toxic algal/cyanobacterial blooms.
Biomass	The combined mass of all of the living organisms (micro-organisms, bacteria, fungi, plants, animals, etc.) in an environment.
Buffering capacity	Water's ability to keep pH stable as acids or bases (alkaline) are added. Sufficient buffering capacity can absorb and neutralize without significantly changing the pH.
Calcium chloride	A white crystalline salt used to de-ice roads, and as a drying agent. Calcium chloride leaches into soil and water sources.
Catchment area	The area from which rainfall flows into a river, lake or reservoir.
Concomitant	A phenomenon that naturally accompanies or follows something (naturally accompanying or associated).
Chlorophyll a (chl a)	Chlorophyll is vital for photosynthesis (food creating process) which helps plants get energy from light. Monitoring chlorophyll-a in the lakes is important to understand algae levels and the resulting impact on lake health and food webs.
Cyanobacteria	Blue-green algae (cyanobacteria) are frequently found in freshwater systems. Cyanobacterial blooms can produce highly potent toxins. Both blue-green and green algae can produce dense mats, cause odor problems and oxygen depletion, green algae are not generally thought to produce toxins.
Deep Chlorophyll Maxima (DCM)	An increase in subsurface water chlorophyll and phytoplankton biomass.
Dissolved Organic Carbon (DOC)	Organic carbon occurs as a result of decomposition of plant or animal material present in soil or water bodies and may dissolve when contacted by water. The source can be allochthonous (from outside system, atmosphere or steam flow) or autochthonous (from within catchment, plant or microbial).
Dissolved Oxygen (DO)	The amount of gaseous oxygen (O2) dissolved in the water. Oxygen enters water by direct absorption from the atmosphere or photosynthesis by algae and plants.
Internal loading	A process when phosphorus and nitrogen are released from anoxic sediment surface. This release can stimulate surface blooms, DCMs or thick layers of benthic algae.

Interstitial	Living in the spaces between individual sand grains in the soil or aquatic sediments. “the interstitial fauna of marine sands”.
Morphometry	The process of measuring the external shape and dimensions of landforms, living organisms or other objects, e.g. lake surface, volume, depth contours, limnological mean depth, max depth, fetch, shoreline length, shoreline development, drainage basin sediment area, water strata, shoreline characteristics, nutrient supply and trophic status and lake productivity.
(N) Nitrogen	(N) is a naturally occurring element that is essential for growth and reproduction in both plants and animals, however, an excess of nitrogen in lake water causes algae to grow faster than ecosystems can handle. Nitrates from fertilizers, human and animal waste, etc. can be transported to water systems by rain, irrigation, surface and ground waters and atmosphere.
OXYGEN IN WATER (oxic, anoxic, hyperoxic, hypoxic)	**Oxic**: an environment in which oxygen is involved or present.
	Anoxic: depleted of dissolved oxygen and are a more severe condition of hypoxia. Anoxic sediment releases nutrients from soil (refer to internal loading).
	Hyperoxic: dissolved oxygen (DO) concentrations in excess of saturation.
	Hypoxic: low concentrations of dissolved oxygen (DO) in water less than 2mg/L range in the bottom layer (hypolimnion).
Redox (reduction) reactions	All chemical reactions in which atoms have their oxidation state changed – reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom or ion.
(P) Phosphorus	(P) is an essential element for plant life, but excess phosphorus in a body of water causes extensive algal growth called “blooms” which are a classic symptom of eutrophication and lead to decreased oxygen levels.
pH (potential of hydrogen)	A numeric scale used to specify the acidity or basicity (alkaline) of an aqueous solution. pH level 7 is neutral. Below 7 is acidic and above 7 indicates basic or alkaline. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients P and N and carbon and heavy metals (more toxic at lower pH because more soluble).
Plankon (phytoplankton and zooplankton)	Drifting organisms in aquatic environments, including marine and fresh water. They are the base of the food web in these environments. Zooplankton are small protists or metazoans that feed on the phytoplankton and ultimately provide an important food source for larger animals.

Leonard Lake Water Quality and Phytoplankton: Status, Monitoring and Management
GLOSSARY OF TERMS

Productivity (lake) Three possible classes of trophic state: oligotrophic, mesotrophic or eutrophic.	Productivity is defined as the rate of generation of biomass (growth) in a lake. The trophic state (i.e. the total weight of biomass in a given water body at the time of measurement) is usually expressed in units of mass per unit surface (or volume) per unit time, e.g. grams per square metre per day (g m -2 d -1).
	Oligotrophic: relatively low in plant nutrients which limits ability to support animal life and containing abundant oxygen in deeper parts due to low organic content.
	Mesotrophic: more nutrients and production than the oligotrophic lakes, but not nearly as much as eutrophic lakes.
	Eutrophic: rich in nutrients and minerals having an excessive growth of algae and thus a diminished oxygen content to the detriment of other organisms. For example, fish/aquatic life require a level of oxygen to live, reproduce and for eggs to hatch.
Secchi Disk Depths (SD)	A Secchi disk (8-inch or 20 cm with alternating black and white quadrants) is lowered into the water of a lake until it can no longer be seen by the observer. The Secchi depth (or depth of disappearance), is a measure of the transparency of the water.
Shoreline buffer zone 1 Riparian	The riparian zone sits between the upland area and the water's edge and is the last line of defense to buffer water bodies from the effects of activities on land. The most effective riparian zone consists of native trees, shrubs, and herbaceous plants.
Shoreline buffer zone 2 Littoral	The **littoral** zone is the near shore area beyond the riparian zone where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow.
Sulfate	Sulfate is sometimes called vitriol, SO4, or the salt of sulfuric acid. Most of the sulfate in water comes from dissolved minerals, i.e. sodium sulfate (salt cake), magnesium sulfate (Epsom salts) and calcium sulfate (gypsum). Sulfate can also come from fertilizer or sewage treatment.
Thermal Stratification	Refers to a change in the temperature at different depths in the lake, and is due to the change in water's density with temperature. Cold water is denser than warm water and the epilimnion layer generally consists of water that is not as dense as the water in the hypolimnion.
WATER LAYERS (Epilimnion, Metalimnion or Thermocline, hypolimnetic)	**Epilimnion**: the surface or top-most layer in a thermally stratified lake. It is warmer and typically has a higher pH and higher dissolved oxygen concentration than lower levels.
	Metalimnion (or Thermocline): the middle layer, which may change depth throughout the day.
	Hypolimnetic: the dense bottom layer of water (the under lake) in a thermally-stratified lake (below the thermocline). Typically, the hypolimnetic layer is the coldest layer of a lake in summer and warmest layer during winter.

Appendix H

Internal Phosphorus Load (2017), Gertrud Nurnberg, Ph.D., Freshwater Research

INTERNAL PHOSPHORUS LOAD

Prepared by **Gertrud Nürnberg, Ph.D.**

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Date May 17, 2017

Acknowledgement

Mark Greenham, Director of the Leonard Lake Stakeholders Association, and other association members provided much material including background information, maps, and reports. Bruce LaZerte, Ph.D., Freshwater Research, discussed this study and reviewed the report. All this friendly support is gratefully acknowledged.

The cover photo is taken from the *Brooklands Farm Wetlands and Leonard Lake Shoreline Inventory and Assessment* (2011). It shows turtle nesting sites and fish habitat at Leonard Lake shore

Executive Summary

The Leonard Lake Stakeholders Association retained Freshwater Research to investigate the carrying capacity of Leonard Lake, Township of Muskoka Lakes (formerly Monck), from previous modeling studies, lake characteristics, limnological (lake-related) information including monitoring data, and general professional knowledge. In particular it was to be investigated whether the addition of a proposed development of a mini-subdivision (6 large scale year-round cottage properties) located on one of the remaining stretches of untouched shoreline on the north-western shore of the lake (2,700 ft) would unfavorably influence Leonard Lake water quality.

Two previous District of Muskoka lake shore capacity models classified Leonard Lake as over development capacity, but the proposed changes (HES 2016) would take the Lake off this protective status. This 2016 report also erroneously classified Leonard Lake as an "oxic" lake while it was classified as "anoxic" in the previous models. MOECC oxygen profiles confirm severe anoxia in the bottom waters. Therefore Leonard Lake's possibly greatest vulnerability is its bottom water anoxia, when the stagnant bottom water layer becomes oxygen depleted in the summer and fall. Anoxia triggers the release of any legacy phosphate from the sediments as internal loading, which fertilizes the phytoplankton and can lead to potentially toxic cyanobacterial (bluegreen) blooms.

It is necessary to try to prevent any deterioration in the water quality that could promote the potential of toxic cyanobacteria blooms. Leonard Lake's water quality is vulnerable for several reasons:

- Headwater lake with a comparably small catchment basin
- Highly developed shoreline with cottage numbers indicating above capacity in two lake shore capacity models of the Muskoka District
- High impact development because 85% of cottages are within 30 m from the shore, 91% are located on thin soils, and 33% had moderate to steep slopes
- Bottom water anoxia during summer thermal stratification
- Phosphorus loading from the sediments (internal loading) likely
- Internal load and documented occurrence of cyanobacteria blooms in neighboring lakes indicate the high potential for such blooms in Leonard Lake
- Relatively low flushing rate and predicted climate changes may increase the potential of internal loading and cyanobacteria blooms
- A large shallow area is susceptible to sediment disturbance by boat traffic

Freshwater Research recommends preventing any further disturbance in this relatively small catchment basin. This would include not increasing cottage numbers, insuring that septic systems are in good working order, and encouraging shoreline naturalization and other best management practices.

At the very least, the importance of internal P loading and its effect on the phytoplankton in Leonard Lake should be determined, before any further development is approved. Monitoring with respect to TP concentration increases during the summer and fall in the bottom water and phytoplankton biomass and identification would provide such information.

In addition, setting a speed limit for areas less than 2-3 m deep is recommended to prevent sediment and fish habitat disturbance and increased turbidity in these areas.

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Acronyms and Glossary

Cyanobacteria: Often called *bluegreens* or *bluegreen algae*, although they belong to bacteria. They can produce toxins that can create health effects if ingested in quantity (life stock, pets).

DMM: District Municipality of Muskoka

External load: The sum of annual TP inputs from all external sources, i.e. stream, non-point and point sources, precipitation and groundwater. Much of its phosphorus is in a chemical form that is not available to algae.

HES: Hutchinson Environmental Services, Ltd.

Internal load: TP inputs from internal sources, i.e. the sediments. Most of this phosphorus is in a chemical form (phosphate) that is highly available to phytoplankton and bacteria.

MOECC: Ontario Ministry of the Environment and Climate Change, former *MOE*

MNRF: Ontario Ministry of Natural Resources and Forestry, former *MNR*

Thermal stratification: period when a deep lake basin is warm in the surface mixed layer (*epilimnion*), but remains cold in the bottom layer (*hypolimnion*). Temperature is intermediate between these layers at the *thermocline* in the *metalimnion*. *Dimictic:* spring and fall mixing occurs during spring and fall turnover with a stratified period in the summer and in the winter under ice. Leonard Lake is dimictic.

Total phosphorus, *TP*: All phosphorus (P) that can be analyzed in a water or sediment sample. It includes phosphate (highly available for algae), particulate forms (includes algae and non-living suspended particles), and forms not easily available for algae.

1 Introduction

The Leonard Lake Stakeholders Association retained Freshwater Research to investigate the carrying capacity of Leonard Lake, Township of Muskoka Lakes (formerly Monck), from previous modeling studies, lake characteristics, limnological (lake-related) information including monitoring data, and general professional knowledge. In particular it was to be investigated whether the addition of a proposed development of a mini-subdivision (6 large scale year-round cottage properties) located on one of the remaining stretches of untouched shoreline on the north-western shore of the lake (2,700 ft) would unfavorably influence Leonard Lake water quality.

In the limited amount of time available for this study, about 20 reports, submissions, and study analyses were reviewed, and specific entries and results from previous the District Municipality of Muskoka (DMM) models were inspected. Conclusions are based on information specific to Leonard Lake, to the region of Muskoka, and the chemical and limnological processes occurring in the Lake. Wherever possible, conclusions are substantiated by data and references.

2 Leonard Lake vulnerabilities

2.1 Highly developed in sensitive areas

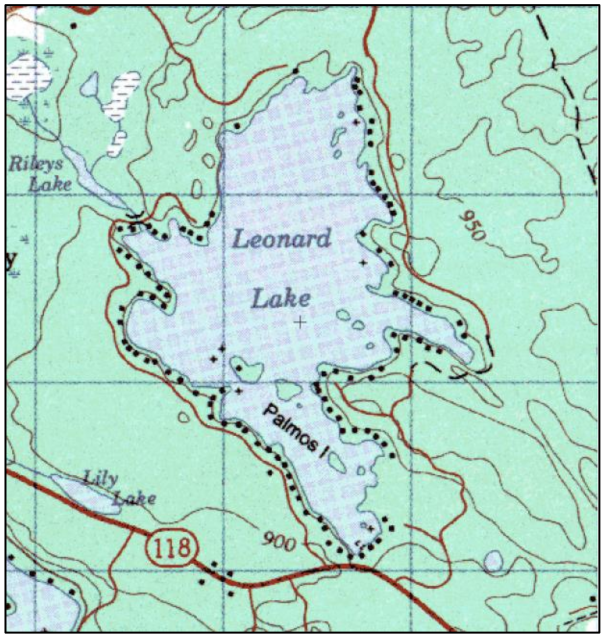
Leonard Lake has been developed since the early twenty century, when the southern section became accessible by road. Since then more and more cottages were built, many of which are now turned into permanent residences.

A *Love your Lake* (2013) study assessed 188 properties, totaling 15,053 metres (100%) of shoreline in the summer of 2013. Trained staff from DMM, in conjunction with the Muskoka Watershed Council, assessed each individual property using a detailed method involving a shoreline survey datasheet. Some results that directly influence lake water quality are summarized here.

Of the properties assessed, 159 properties (85%) were setback less than 30 metres from the shoreline with 44 properties located within 10 m. 29 (15%) were setback 30 metres or more from the shoreline. There were 2,297.52 metres (15.3%) of the total shoreline that was developed with structures and/or docks, and 532.55 metres (3.5%) with retaining walls. 171 properties, or 91% of properties assessed, had thin soils. Average slopes were recorded, and 1 property, or 0.5% of properties assessed, had a very steep slope, 16 properties, or 8.5% of properties assessed, had steep slopes, 63 properties, or 33.5% of properties assessed, had moderate to steep slopes, and 108 properties, or 57.4% of properties assessed, had gentle or flat slopes. Mowed lawns were observed on 32 properties, or 17% of properties assessed, and 3 properties, or 1.6% of properties assessed, had regenerative lawns.

The large proportion of cottages within 30 m from shore (85%), on thin soils (91%), and with steep to moderately steep slopes (43%) indicates a low phosphorus (P) retention capacity in the area between development (including septic systems, anthropogenic and pet disturbances) and the lake, so that the largest vulnerability with respect to P export has to be assumed. (For example, the 74% retention of septic input considered by Gartner Lee, 2005 p. 27, for thicker soils and larger setbacks does not apply to most of Leonard Lake’s cottages.)

Figure 1. Topographic Map (MOECC 2015, *year not specified*) **of Leonard Lake indicating cottages**



2.2 Lake characteristics, watershed and lake shore capacity: models and thresholds

Leonard Lake is a headwater lake with a comparably small catchment basin. The watershed is only 2.15 times of the lake area (DMM *Lake Data Sheet* 2015), which is extremely small. Because natural P input from a small catchment is low, any input from development has an ever larger effect.

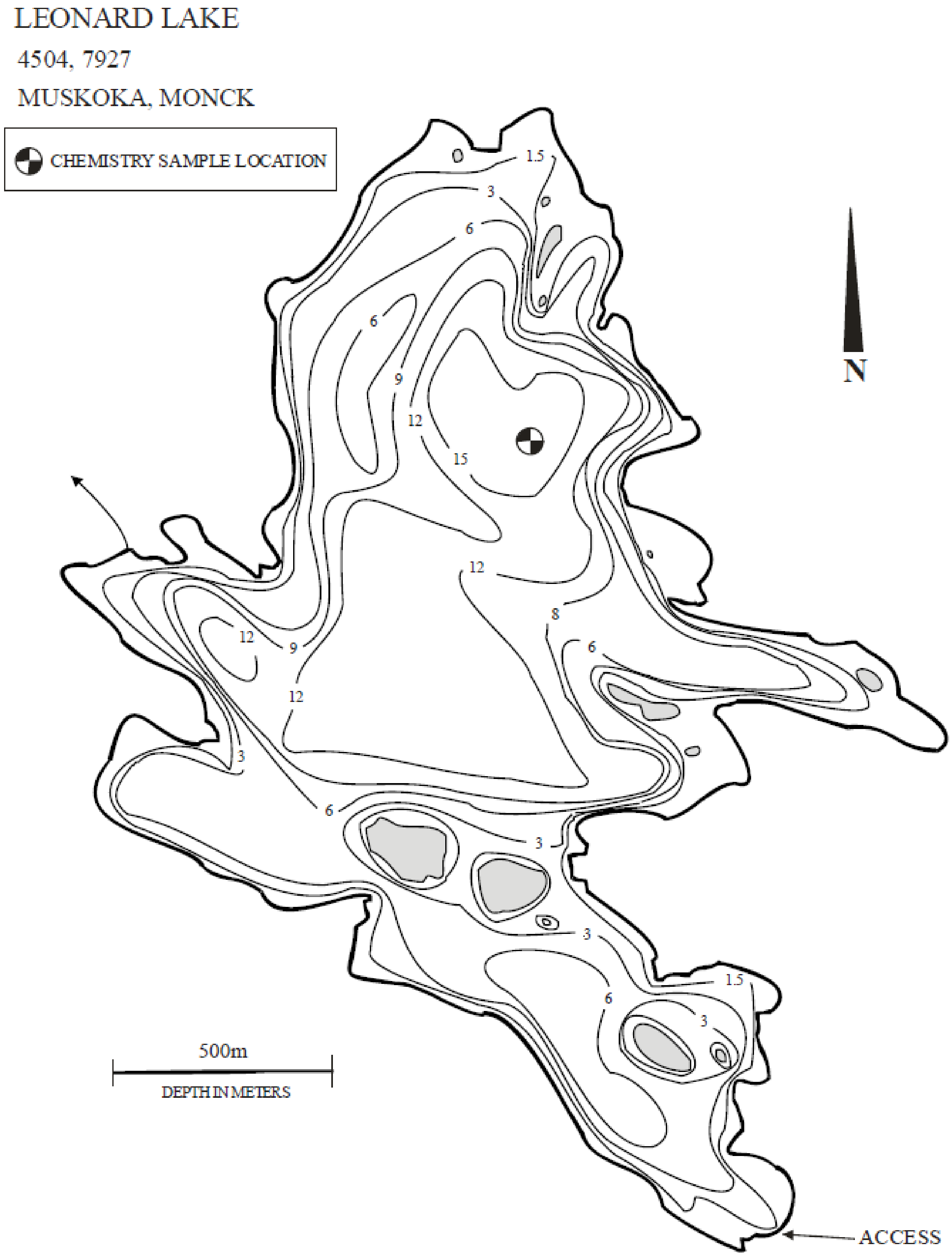
The increased vulnerability to development becomes obvious when using two separate models developed for the Muskoka District, the model of Freshwater Research (1998) and of Gartner Lee (2005). Both models predict that the development increased the P loading above the threshold of 1.5 of the natural background loading (2.1 in the 1998 model; 2.4 in the 2005 model, Appendix 3 of Gartner Lee 2005). The threshold of 1.5 times natural background was used previously by DMM and is suggested by MOECC (2010) as a trigger for stopping all additional development. Consequently, Leonard Lake was on the list for “Over Threshold” in the *Lake Classification Report* by the DMM (2005).

However, the most recent proposed DMM classification (HES 2016) does not consider such results as a trigger (any more). Instead, only three events are proposed, mostly based on monitoring data:

1. Total phosphorus (TP) concentration above 20 µg/L
2. Significantly increasing TP concentration
3. The occurrence of bluegreen algae (cyanobacteria)

TP concentrations are low (about 6 µg/L average, Section 2.4.2) and not increasing in Leonard Lake, and there are no known cyanobacterial (bluegreen “algae”) bloom presently. Accordingly, Leonard Lake would not have any development limits under this new classification system. However, besides the vulnerability with respect to shoreline soils and slope discussed in Section 2.1 above, there are further vulnerabilities that are not considered in the new classification (2016) and are discussed next.

Figure 2. Bathymetric map with contours in meters (MOECC 2015). The deep site in the northern end is the routine lake sample location.



2.3 Lake shape and depth

Leonard Lake is a two basin lake with a shallow southern part and a deeper northern part (Figure 2). Therefore, Leonard Lake is exposed to two types of shape related vulnerabilities.

Much of the southern lake section is 3-6 m deep. Fast driving boats can cause disturbance of fish and crayfish habitat including nurseries in such a shallow depths. The boat access at the most southern end and the location of the three islands encourages boat traffic along the western shore.

The wider basin to the north includes a deep site (16 -18 m). Such a depth compared to the relatively small area causes the thermal stratification that has been observed in Leonard Lake, when the surface layer of the lake is mixed and warm, while the bottom layer remains cool and isolated during the hot season. Thermal stratification is the reason for oxygen depletion and associated P release mechanisms as discussed next (Section 2.4.).

2.4 Internal P loading

Sediments that accumulate on the bottom of lakes document the past, but can also affect the current water quality when they release P as internal P load. As described in detail in Appendix A, it is especially important to consider this P source in relatively pristine lakes on the Canadian Shield, where recent anthropogenic nutrient enrichment of the sediments can fertilize the lake in the late summer and fall supporting cyanobacterial blooms.

Internal load is typically a result of oxygen-related (redox) changes at the sediment-water interface. Anoxia (lack of dissolved oxygen) at the sediment-water interface leads to the dissolution of iron hydroxides in the sediments and release of adsorbed P (i.e., P attached to the iron surfaces) into adjacent lake water. There are several indications, including monitoring data and historic information that make the occurrence of internal loading from the deep sediment likely in Leonard Lake.

2.4.1 Bottom water anoxia

In contrast to the HES report (2016, Table 8), that puts Leonard Lake into the oxic lake category, the 2005 DMM model classified Leonard Lake as anoxic (Gartner Lee 2005, Table 6.1).

In addition, low oxygen concentration has been observed for multiple years (Figure 3) as presented in the report on Leonard Lake by MOECC researchers (MOECC 2015). Anoxia has been occurring in the late summers and early falls in Leonard Lake for a long time as evident from early records by former departments for environment and natural resources. Less than 2 mg/L oxygen were found below 12 m down to lake bottom at about 15 m on September 6, 1969 and August 28, 1971 (Appendix B). At this low oxygen concentration it can be assumed that sediment/water interface is anoxic and can release P.

The persistent anoxia supports internal loading in Leonard Lake after sediment enrichment. P from anthropogenic development, including septic systems and fertilizer applications that may have supported phytoplankton and then settled to the bottom would be released in the water, after changes that formed a releasable P components in the anoxic sediments.

Figure 3. Figures copied from the MOECC (2015) report indicating that oxygen concentration drops below 2 mg/L 4 m above the bottom sediment at the deep station, the threshold at which sediment become anoxic (bottom), during the thermal stratification (top).

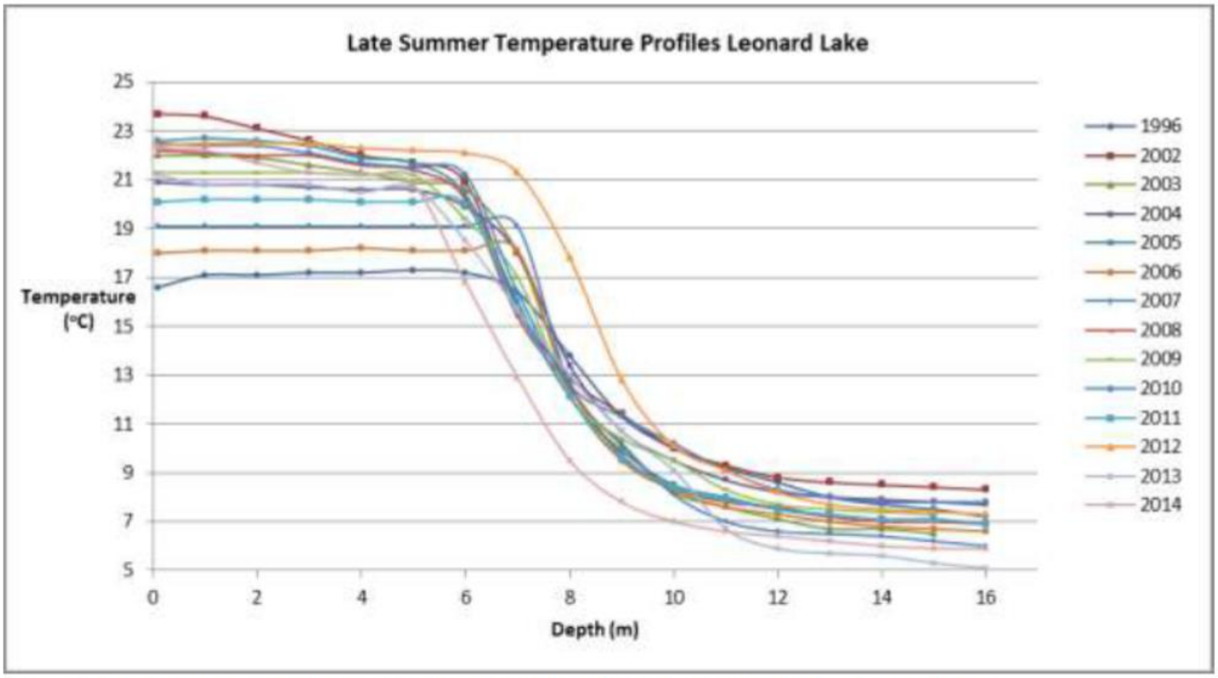


Figure 15: Late summer temperature profiles from Leonard Lake 1996-2014

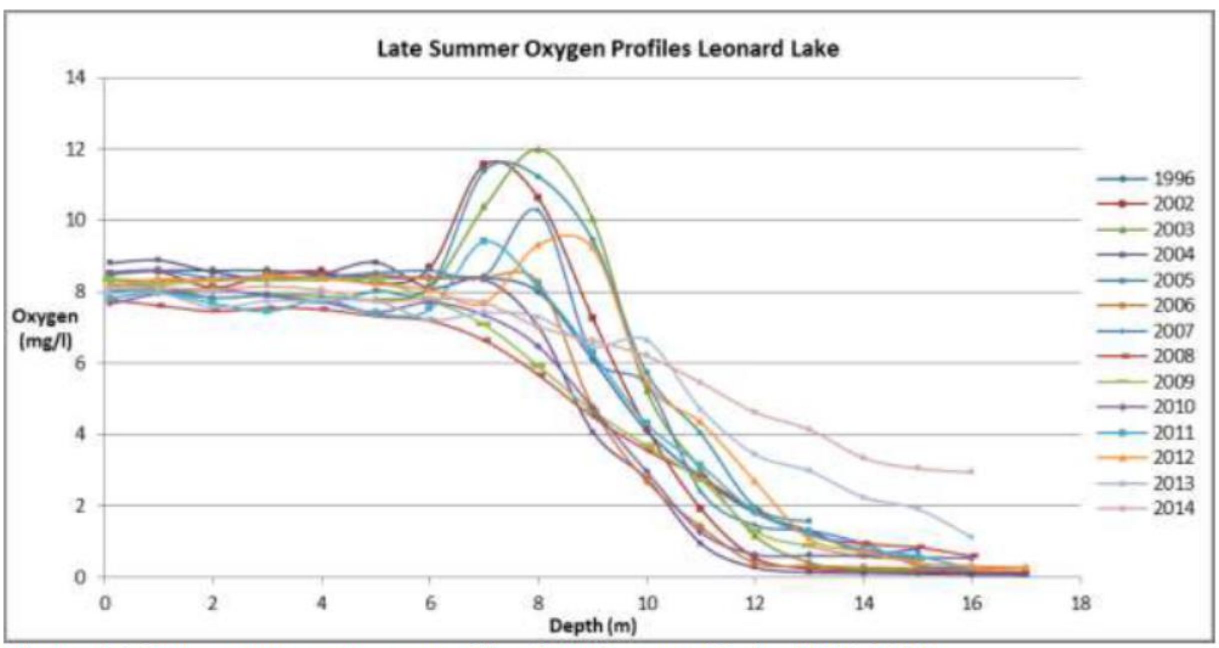


Figure 16: Late summer oxygen profiles from Leonard Lake 1996-2014

2.4.2 Phosphorus concentration indicating internal loading

Because Leonard Lake had been classified as an "oxic lake" in the latest DMM model (HES 2016, Table 8), it had not been considered for a special study to determine whether there was any elevated TP appearing as internal loading (HES 2016, Table 5, 7, 10). DMM attempted such a monitoring study in 2011 for other anoxic lakes.[1]

While DMM data are not available to determine the quantity of internal load in Leonard Lake, limited evidence from other data sources support the possibility.

The only direct bottom water sample analyzed in Leonard Lake available indicates severely elevated TP in 1971 (Table 1). But the DO profile measured 2 days before the TP sample of Aug 30, 1971, indicates relatively high, 50 % oxygen saturation which is about 5 mg/L. On Oct 12 October Leonard Lake was anoxic (0% oxygen) and bottom TP was slightly elevated. While there is evidence of internal loading the oxygen data are not consistent and more and newer monitoring is required.

The TP samples of 1971 are much higher than the long-term average spring TP of 5.8 µg/L (2002-2016, 13 years of MOECC Lake Partner Program, http://www.desc.ca/programs/lpp) or 6.3 µg/L (DMM *Lake Data Sheet* 2015). Higher concentration later in the summer and fall indicates internal loading in lakes where the higher P accumulated in the stratified bottom layer slowly move into the mixed layer when the stratification period comes to an end during fall mixing. But the Leonard Lake mixed layer TP concentrations in 1971 May to October are not consistent and further monitoring is required to determine whether TP concentration increases in the mixed layer in the fall.

Table 1. Water samples of 1971

Date	TP mixed layer (µg/L)	Depth Composite	TP bottom layer (µg/L)	Depth** Grab	DO at Grab*** Depth (mg/L)
1971-05-21	14	0-7_9 m			
1971-08-30	10	0-10 m	44	14 m	5
1971-10-21	8	0-10 m	14	15 m	0

*A composite sample takes water for the whole mixed layer

** A discrete grab sample collects water at the indicated depth

*** DO profiles of Appendix B

In a lake with internal P loading, the TP concentrations are not constant. In such lakes it is important to be consistent in using averages as "triggers" of management decisions (HES 2016). TP should be monitored throughout the growing season and at various depths to be incorporated in a meaningful spatial and temporal average value.

[1] *Freshwater Research* recommendations for the best timing and procedure include discrete bottom samples at 1 and 2 m above the bottom in late August, September and October, depending on lake depth and mixing status. The timing and spatial extent of such a monitoring effort is more likely to detect signs of internal loading than the DMM 2011 monitoring in July and August.

2.4.3 Low flushing

Several lake characteristics are favorable to internal P load having a greater effect in fertilizing a lake. Leonard Lake is a headwater lake, fed by water from precipitation, direct runoff and springs. In such lakes runoff is small and flushing rate is low. Based on a runoff coefficient applicable to that region (0.40 m/yr, Hydrological Atlas of Canada 1978) the water residence time is 5.4 years and only 19% of its volume (13.3 km^3) is flushed on average each year. There is often no running water in the outflow in the summer and early fall (Lake Resident, personal communication, Section 2.5). This means that a large portion of any incoming P load settles to the bottom where it accumulates as legacy load. A model predicts that 78% of the external P load is retained (for a mean depth of 6.8 m and the water detention time of 5.4 yrs (Nürnberg 1984)).

2.5 Historic events

Like many of the lakes in Central Ontario, the Leonard Lake catchment has been logged, and there was a sawmill on the lake at one time. There was also a fire in Sep 1925 that raged about three quarters around the lake (Appendix C).

According to a resident:

> When my grandparents built our cottage in 1955 the lake was quite barren and scrubby. The pines were pretty small. Not much taller than my dad who was 20 years old at the time.

Both, forest fires and logging enrich lakes in the vicinity through their added nutrient runoff and changes in the surficial soils of the catchment basin (Chanasyk et al. 2003). Increased P export from such soils in the Leonard Lake catchment basin would have added to the legacy sediment load.

There is a concrete dam at the Lake's outflow since the late seventies (Figure 4). The construction of this dam possibly increased the water residence time (Section 2.4.3) and the dam was adjusted to comply with MNR requirements.

According to a resident:

> The water stops flowing by late spring and typically remains completely dry until late fall - unless we have heavy rainfall activity. Historically, documented in 1955, the water flow was continual all year long before dam construction, when there were only approximately 20-25 cottages on the lake.

Figure 4. Manmade dam at the Leonard Lake outlet which flows to water falls immediately below (*credit, date*). The small adjustment that decreases dam height is seen on the right section.

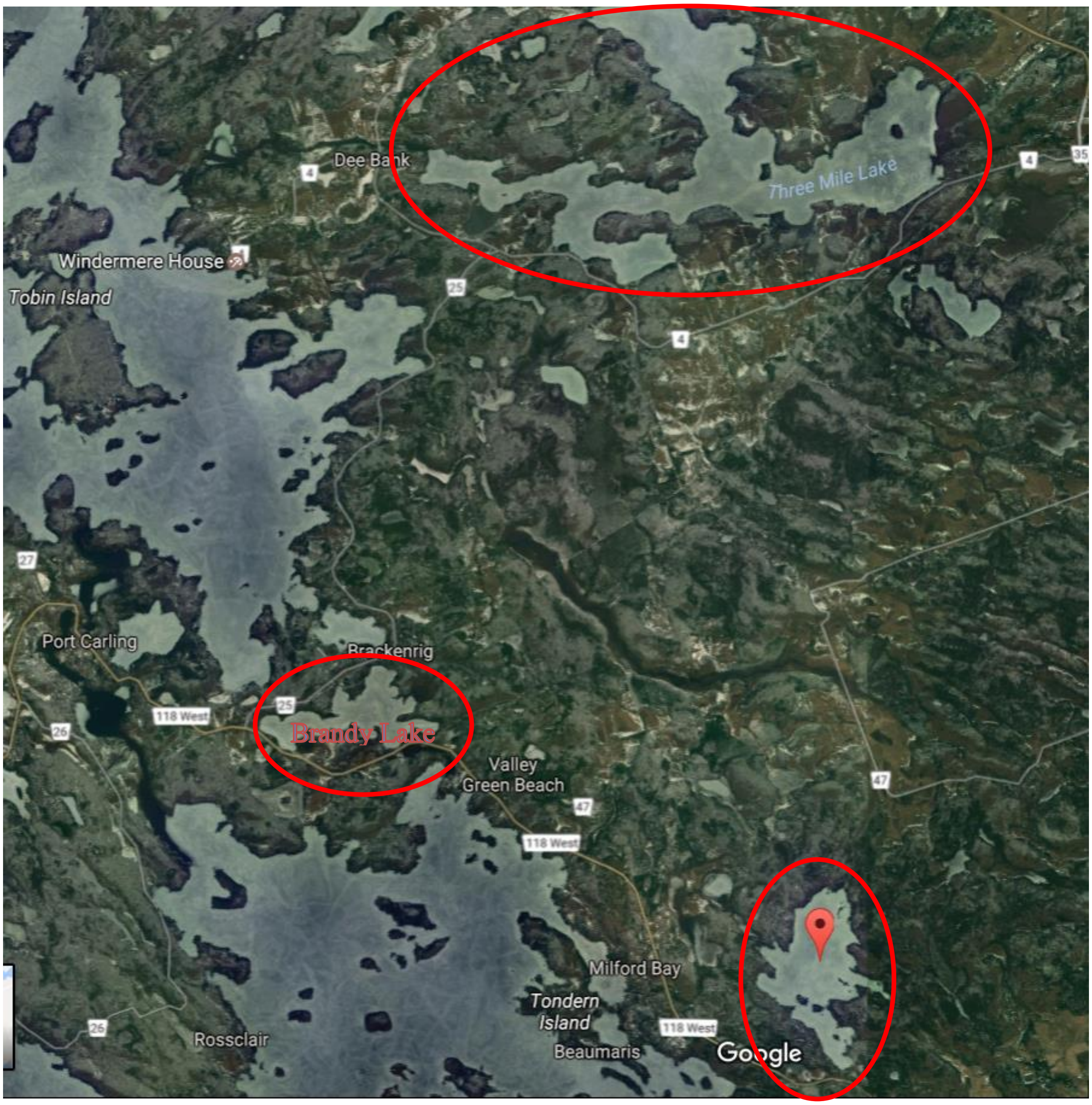
3 Future predictions with respect to climate change and bluegreen blooms

Predicted climate change for the region includes dryer and warmer summers with wetter winters, and more extreme weather patterns (Sale et al. 2016). The duration of ice cover is decreasing and the warm stratification period is lengthening, increasing the extent of thermal summer stratification. Such conditions are favorable to cyanobacteria directly, as they thrive in warm and stagnant water, and indirectly, because internal P loading is also affected positively. P release rates and oxygen depletion increase exponentially with temperature and the lengthening of the stratification period increases the duration of sediment release (Nürnberg 2009). Therefore, it can be expected that Muskoka lakes with bottom water anoxia may experience increases in internal P loading, increases in the overall water TP concentration, increases in cyanobacteria biomass, and increased probability of their blooms. Because cyanobacteria are sometimes toxic, such development can generate serious health concerns.

The connection between internal nutrient loading and increased phytoplankton productivity has become more and more evident and is being considered by many recent studies (Zamparas and Zacharias 2014). Geochemical processes convert the accumulated “legacy” P into a highly bioavailable nutrient (Nürnberg and Peters 1984) that can move out of the sediment into the overlying water; this is favoured by conditions of high productivity, a long summer stagnation period, and warm temperatures (Taranu et al. 2015). Studies from lakes in central Ontario suggest that late summer and fall internal loading may be important despite low trophic state of Precambrian Shield lakes (Nürnberg et al. 1986, Persaud et al. 2014). There are an increasing number of reports of fall cyanobacteria blooms in Ontario lakes in recent decades (Winter et al. 2011), which could be related to increased internal loading in the fall.

Toxic blooms have been detected in two neighboring Muskoka lakes within 12 km of Leonard Lake, Three Mile Lake and Brandy Lake (Figure 5). In both these lakes water column stability and bottom water TP concentration were determined to be important for controlling the blooms, in addition to wind and previous cyanobacteria biomass (Persaud et al. 2014, 2015).

Figure 5. Location of Leonard Lake (bottom) compared to Brandy and Three Mile Lake (Google Map)



4 Conclusions

It is necessary to try to prevent any deterioration in the water quality that could promote the potential of toxic cyanobacteria blooms. Leonard Lake's water quality is vulnerable for several reasons:

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- Highly developed shoreline with cottage numbers indicating above capacity in two lake shore capacity models of the Muskoka District
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- Phosphorus loading from the sediments (internal loading) likely
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- A large shallow area is susceptible to sediment disturbance by boat traffic

Freshwater Research recommends preventing any further disturbance in this relatively small catchment basin. This would include not increasing cottage numbers, insuring that septic systems are in good working order, and encouraging shoreline naturalization and other best management practices.

At the very least, the importance of internal P loading and its effect on the phytoplankton in Leonard Lake should be determined, before any further development is approved. Monitoring with respect to TP concentration increases during the summer and fall in the bottom water and phytoplankton biomass and identification would provide such information.

In addition, setting a speed limit for areas less than 2-3 m deep is recommended to prevent sediment and fish habitat disturbance and increased turbidity in these areas.

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Appendix A: Internal load in Cottage Country

NEWSLETTER Canadian Society of Environmental Biologists

Internal Phosphorus Loading in Ontario Cottage Country or The Devil is in the Sediments

Revised from an article published in the Federation of Ontario Cottages Association's (FOCA) Lake Stewardship Newsletter

Gertrud Nürnberg, Ph.D., Freshwater Research, 3421 Hwy 117, Baysville, Ontario P0B 1A0 gkn@fwr.on.ca ***www.fwr.on.ca***

By now, everyone in Cottage Country (starting about 150 km north of Toronto on the Canadian Shield) has heard about phosphorus (P), the nutrient that makes the water green because it makes algae grow. Eutrophication, or the overabundance of nutrients in waters, is the single most important cause for the deterioration of the water quality in our lakes and rivers, unless they are acid-stressed. "Acid" lakes, which are very clear and have a pH below 6 or so, are not in danger of turning green, because they have other problems, like toxicity caused by heavy metals and acidity.

To keep eutrophication at bay, shoreline residents have been striving to reduce phosphorus inputs into their lakes. They have been instructed to use phosphate-free soaps and detergents, to not wash hair in the shallows or cars at the beach, and to keep the shoreline as natural as possible minimizing the need for fertilization. (Shoreline buffer zones are better than grass at adsorbing phosphorus in the runoff water after rain or snow melt and don't need to be fertilized.) Thus, ideally, the external input of phosphorus to a lake is kept to a minimum.

Of course, it was not always so. The early settlers of the cottage country did not know about eutrophication. Their outhouses and sinks drained, "conveniently," right into the stream. The potato and tomato fields needed a lot of manure on this poor soil, livestock drank right from the creeks (defecating at the same time), and the towns discharged any collected wastes right into the bay of the next lake. Much of these early inputs into the waterways were flushed downstream, but a proportion was retained at slow flowing and shallow locations and remains there now, a time bomb ready to be released.

What is the trigger? The trigger is anoxia, which means complete oxygen depletion. As long as the water directly over the sediments still contains oxygen (at least 1 to 2 ppb), phosphorus stays bound in the sediments. However, when oxygen is used up completely, the chemistry of the sediments changes, phosphorus is no longer bound to the sediments, and large amounts of phosphorus may be released into the overlaying water. This water eventually mixes with surface water, so that algae up in the sunlit water can thrive. The water becomes green. Phosphorus released from the sediments is called "internal phosphorus loading."

Internal P loading is a complicated process. While fertilization of bottom sediments in lakes and rivers is the prerequisite, chemical changes within the sediments and oxygen-free conditions above them all work together to release P in a form that is highly biologically available as phosphate (just like in a fertilizer).

On the Canadian Shield, where most of Ontario's Cottage Country is located, fertilized bottom sediments are still few. In other regions, for example, where former seas were situated (e.g., in the Great Lake/St. Lawrence basin), the soils were naturally P enriched even before European settlement. But the trigger, bottom anoxia, occurs naturally in many lakes in Cottage Country. Many of these lakes do not encourage mixing because of their shape, deep and small, or because their tea-like color traps sunlight in the warm surface water so that the bottom water remains cold. In addition, this brown stain enhances bottom water oxygen depletion as it is produced by organic material. When the organic material decomposes, it consumes oxygen. For example, in half of the lakes in the District of Muskoka, anoxia is so frequent in the bottom water it is as if the whole lake surface area was completely anoxic for 10 days per year. In more eutrophic lakes, bottom anoxia occurs more because of algae and other plankton that settle to the bottom and are consumed by bacteria that use up the oxygen in the process.

> **Important phosphorus forms**
>
> Phosphorus (P): Usually means total phosphorus, which is all phosphorus that can be analysed in a water sample. It includes phosphate, particulate forms, and other forms not easily available to be used by algae. Much external loading is comprised of all these forms.
>
> Phosphate: A proportion of phosphorus that is directly available to plankton (algae, bacteria) in the water; it is usually below analytical detection limits in lakes on the Canadian Shield, except where internal loading occurs.

It is difficult to generalize the importance of internal load in lakes. The interplay between external and internal P loading is depicted as stages (Figure 1). Internal load was first described in highly eutrophic lakes in Europe and the USA (Stage 3), where, despite a major reduction of external load (usually by collecting and treating all waste water as point source reduction), in some lakes the P concentration did not decrease and water quality continued to deteriorate. More recently, it has been described in many other lakes even if it is not as obvious (Stage 2). Its quantification includes methods based on P budgets, P mass balance models, sediment incubation and analysis, and determination of anoxia. In general, it's been the consensus that internal loading may occur in more places than previously thought. Traditionally, it was only described in eutrophic lakes, as it usually takes a long time for sediments to become enriched and oxygen depleted enough to release P. But recent analyses has shown that oligotrophic systems on the Canadian Shield, like small deep lakes or those stained with organic acids, are vulnerable because of the natural occurrence

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La Société Canadienne des Biologistes de l'Environnement **BULLETIN**

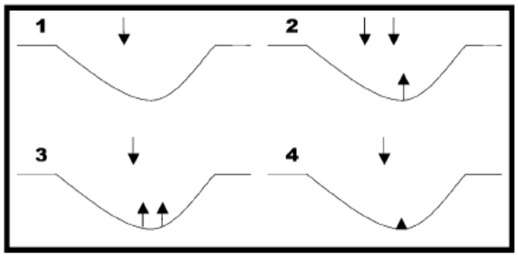

Figure 1. Presumed stages during the eutrophication process in lakes with respect to internal P load from the lake bottom (upwards arrow) in response to external load (downwards arrow). During Stage 1, external load happens, but no internal load. Even if the hypolimnia may be anoxic, there is not enough releasable P in the sediment surfaces to be released. In Stage 2 the external load increases, due to anthropogenic sources from development, and sediment P release will eventually commence, depending on the oxygen state of the sediment surfaces. Even when management efforts reduce the P load from the watershed as in Stage 3 internal load will still occur until the reductant-soluble sediment P has been flushed out (Stage 4).

of oxygen depletion; here, any P additions can potentially be released instantly and fertilize the water, perhaps creating cyanobacterial blooms.

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Base on:

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Appendix B: Historic dissolved oxygen profiles in Leonard Lake

Ontario Department of Lands and Forests Lake Survey (Code 1308) (1968):

G

Date Sept.6 ,19 68 | Air Temp. 68.0 °F | Therm. from 28 to

Depth	Temp	O_2	pH	Alk.	TDS	CO_2	Turb.	Total Hardnes
0	68.5	7.6	8.5	17.1		0.8		17.1
5	68.5	7.6	8.5	17.1		0.5		17.1
10	68.5	7.6	8.5	17.1		0.5		17.1
15	68.5	7.4	8.5	17.1		0.5		17.1
20	68.0	7.2	8.5	17.1		0.5		17.1
25	67.0	7.4	8.5	17.1		0.5		17.1
30	61.0	7.6	8.5	17.1		0.5		17.1
35	53.0	5.0	9.6	17.1		5.1		17.1
40	49.0	2.4	9.7	17.1		10.15		17.1
45	47.5	1.4	9.7	17.1		10.15		17.1
50								
55								

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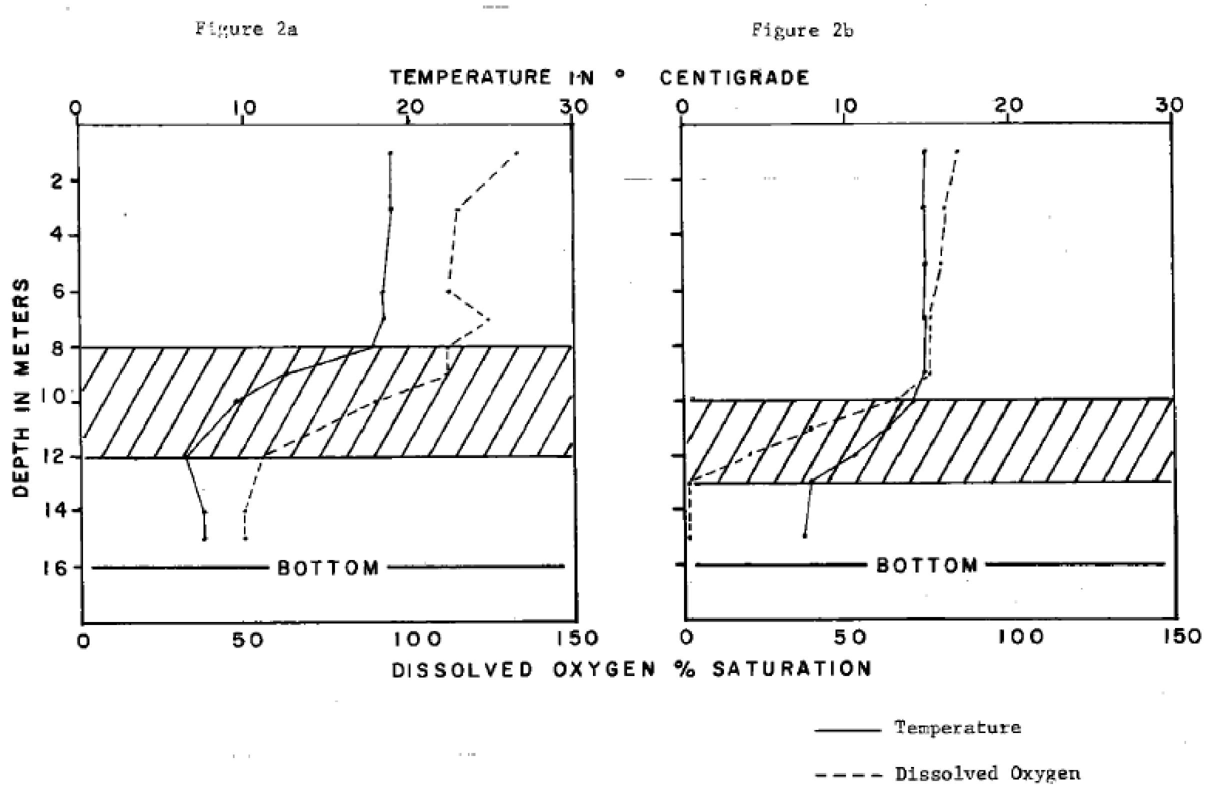

Figure 2: Temperature and dissolved oxygen profiles in Leonard Lake, Station 36 on (a) August 28, 1971 and (b) October 20, 1971. The shaded areas approximate the position of the thermocline.

Appendix C: 1925 forest fire in Leonard Lake, *Newspaper article Muskoka Herald - September 3, 1925*

SEPTEMBER 3, 1925

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Serious Forest Fires

Many Miles of Timber Swept near Torrance. Medora Station Burned: Fire at Leonard Lake Under Control

The air has been dense the last three or four days with smoke from forest fires. Near Bala, Torrance, Leonard Lake, Port Carling and on the road between Bala and Gravenhurst fires have raged while Strawberry Island in the Lake of Bays has been fire-swept.

The fire near Bala, which has covered an area of several square miles burned all last week. Kimberley Point on the Moon River, was threatened but escaped, but the C.N.R. station at Medora was destroyed. The blaze is said to have originated near Dudley, spread West, jumped the C.N.R. tracks and then the C. P. R., destroying all bush near Roderick. As the wind turned it burned back towards the C. N. R. line. On Monday the flames were fanned up again by the freshened breeze and crept up closer to the town limits of Bala. Nearly 500 men are busy fighting the flames in an effort to save the bridge at Bala and outlying property. Seven of the poles of the Bala-Port Carling telephone line were burned on Sunday and the service put out of commission. Repairs were made the following day, the fire having passed the line.

Fire started on Sunday in the Gibson Indian reserve and in a few hours had travelled many miles. The homes in the reserve have been protected with trenches and it is hoped they will be saved. Fire is also burning on Sahanatien Island in the Moon river.

The fire at Leonard Lake is pretty well under control, with no property damage other than the timber through which it has passed. It is being watched night and day to prevent a second outbreak.

A fire also broke out a few days ago near Mr. Schomberg Mahon's residence, on the Port Carling road and threatened the properties in the neighborhood, help having to be secured from Port Carling to keep it from spreading.

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Appendix I

Leonard Lake Water Quality in 2017 and 2018 (2018), Gertrud Nurnberg, Ph.D., Freshwater Research

Memo

To: Leonard Lake Stakeholders Association (LLSA)

From: Gertrud Nürnberg, Ph.D., Freshwater Research

Date: 2018-09-06

Re: Leonard Lake water quality in 2017 and 2018 and cautionary comments on the development plans for 1080 Glen Gordon Road, Township of Muskoka Lakes

Context

The Leonard Lake Stakeholders Association had retained Freshwater Research in spring 2017 to investigate the carrying capacity of Leonard Lake, Township of Muskoka Lakes (formerly Monck), from previous modeling studies, lake characteristics, limnological (lake-related) information including monitoring data, and general professional knowledge. In particular it was to be investigated whether the addition of a proposed development of a mini-subdivision (6 large scale year-round cottage properties) located on one of the remaining stretches of untouched shoreline on the north-western shore of the lake (2,700 ft) would unfavorably influence Leonard Lake water quality.

In that report, Freshwater Research recommended the prevention of any further disturbance in this relatively small catchment basin. This would include not increasing cottage numbers, insuring that septic systems are in good working order, and encouraging shoreline naturalization and other best management practices.

Freshwater Research also recommended that the importance of internal phosphorus (P) loading and its effect on the phytoplankton in Leonard Lake be determined, before the approval of any further development. To provide such information, monitoring was proposed with respect to P

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concentration increases during the summer and fall in the bottom water and phytoplankton biomass and identification.

The Leonard Lake Stakeholders Association (LLSA) retained Dr. Sue Watson, a cyanobacterial specialist, to supervise the suggested monitoring and interpret the findings, which were presented in a comprehensive report (Watson and Kling, 2018).

Leonard water quality, contentious points

Background

There is some controversy about the state of Leonard Lake's water quality with respect to cyanobacteria ("blue-green algae"). While the *Palmer Environmental Consulting Group Inc* (here called "Palmer 2017") report does not acknowledge the possibility of any cyanobacteria proliferation and downplays any conditions that may support such blooms (i.e., bottom water anoxia and sediment P release as internal loading), evidence was found to the contrary in the 2017 monitoring study by Watson and Kling (2018). Before describing such evidence in more detail, I here outline the scientific relationships that are involved.

When the bottom water (hypolimnion) becomes oxygen depleted, fish habitat is diminished and sediment may release P as internal P loading. Many lakes in Muskoka have low dissolved oxygen concentration (DO) in the late summer and fall until fall turnover (when the lake layers mix down to the bottom after thermal stratification throughout the summer). Lakes with a history of P enrichment e.g., from naturally enriched catchment area soils (rare on the Precambrian shield), by natural P sources (e.g., beaver ponds and breaches of their dams), or by anthropogenic development can release P as legacy sediment P. Because such sediment released P is in the form of phosphate it acts as an immediate fertilizer of lake phytoplankton. Such fertilization typically occurs at a time when the lake is stratified and the lake water is warm, and then can preferentially support the development of cyanobacteria (see references in Nürnberg 2007).

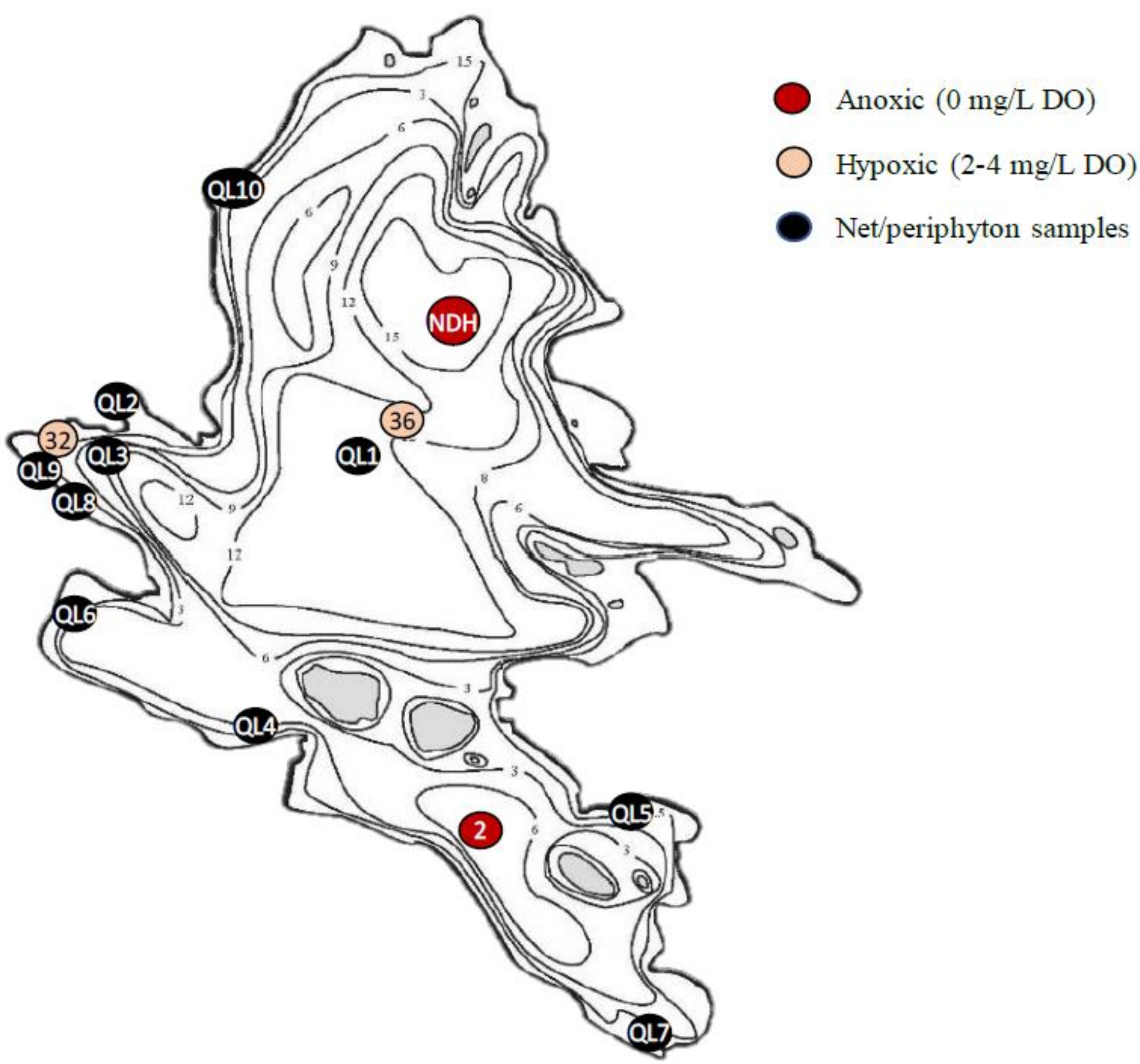
In a lake that exhibits both, summer bottom anoxia and cyanobacteria proliferation, added development and disturbance will increase the danger of extended, potentially toxic, cyanobacteria blooms and should be avoided.

This conclusion is scientifically defensible, despite the contention stated in Palmer's 2018 addendum: "The link between shoreline development and cyanobacteria blooms has not been clearly demonstrated." The Palmer argumentation is based on total P (TP) and does not consider the almost 100% availability of sediment P that is released as phosphate. Also, there is no way of confirming the absence of a link, only the occurrence of a connection. (I.e., the lack of a correlation does not mean that there is none.)

The following sections investigate and summarize the current knowledge about Leonard Lake's characteristics respective anoxia, internal P loading, and cyanobacteria. Sites are indicated in the map provided by Watson and Kling (2017) (Figure 1)

Figure 1. Leonard Lake map with depth contours and 2017 monitoring sites (referred to as appendix Figure S-4, Watson and Kling 2017)

Fig. S-4. Leonard Lake sampling sites, LLSA 2017



Bottom water anoxia (dissolved oxygen profiles)

Nürnberg (2017) reported numerous DO profiles that showed bottom water anoxia and hypoxia (DO< 2.0 mg/L). This is indirectly acknowledged by Palmer (2017): "DESC data show that Leonard Lake does not always have an anoxic hypolimnion in lake summer (Appendix F-2, Figure H)." (Figure 2). Lake characteristics are subject to climatic influences and the important conclusion is that Leonard Lake's hypolimnion can and does become anoxic in some years.

Figure 2. Referred to as Figure 3 of Nürnberg 2017, and as Figure H by Palmer (2017), copied from the MOECC (2015) report indicating that oxygen concentration drops below 2 mg/L 4 m above the bottom sediment at the deep station, the threshold at which sediment become anoxic.

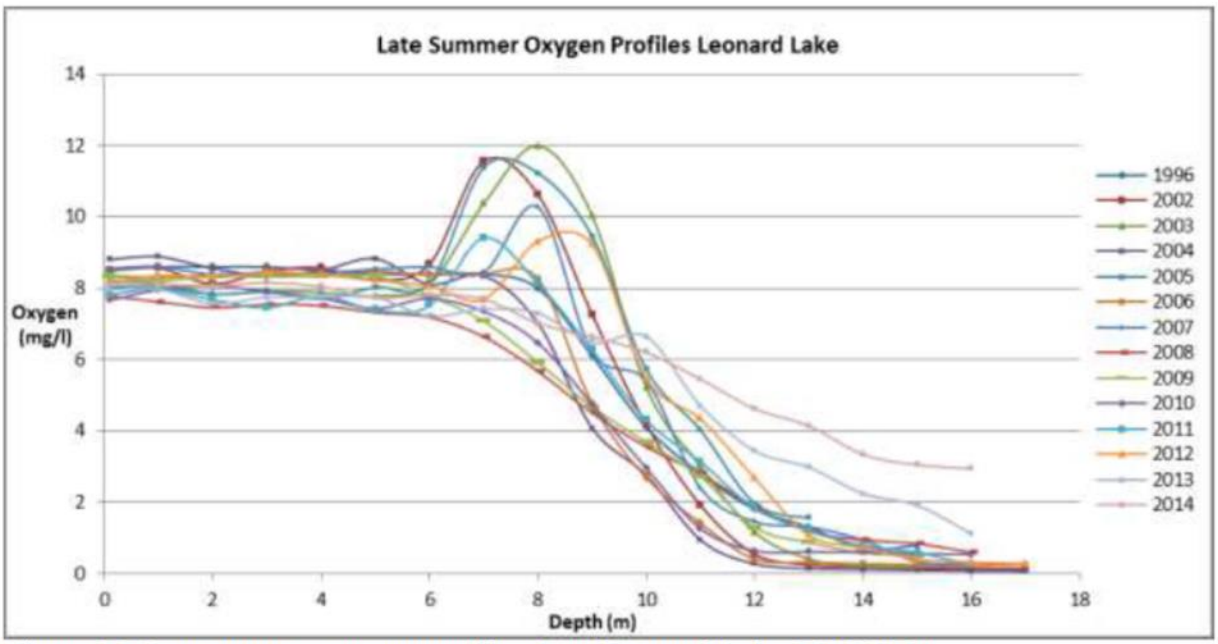


Figure 16: Late summer oxygen profiles from Leonard Lake 1996-2014

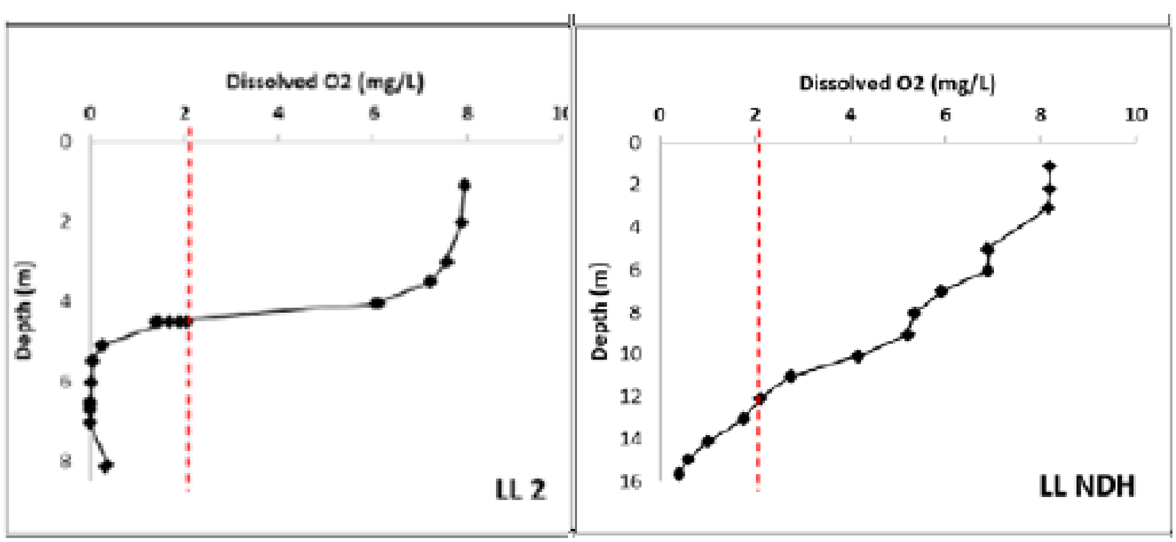
There are new DO profiles taken in August 2017 independently by Clark Environmental, the consultant for Palmer (Table 1) and by Mark Verschoor for LLSA (Figure 3).

Table 1. Referred to as Table 7 in Palmer (2017). The deep station has DO> 3.4 mg/L on Aug 29, 2017.

Table 7 – Temperature and Dissolved Oxygen at the Deepest Location in Leonard Lake on August 29, 2017 (Depth at the sample location was 17m)

Depth (m)	Temp °C	Dissolved Oxygen (mg/L)
0	20.2	9.8
1	20.3	9.7
2	20.3	9.6
3	20.3	9.6
4	20.3	9.6
5	20.3	9.5
6	20.3	9.5
7	18.7	8.6
8	16.6	8.1
9	13.0	7.3
10	11.4	6.7
11	10.3	6.3
12	9.1	5.7
13	8.8	5.3
14	8.4	4.7
15	8.2	4.2
16	8.0	3.4

Figure 3. Partial figure referred to as Figure S-5 in Watson and Kling (2018). The south basin shows severe anoxia and the deep station shows DO< 2 mg/L on Aug 21-23, 2017. LL2 is a 9 m site at the south side of Leonard Lake (left). LLNDH is the deep station at the location of data presented in Table 1 (right).



These profiles were both taken by experienced limnologists. The slight difference at the bottom 4 m shows that the deep station is not yet fully anoxic at the end of August. However, when DO is decreased to 4 mg/L in late August, it can be expected to further decrease until fall turnover, which is not expected to occur until the end of October, based on the relatively cold (7 C) bottom water. (The date of fall turnover is correlated with the bottom summer temperature and can be predicted from *Julian Date (number) = 352 - 6.8 x July-August average bottom water temperature*, in eastern NA lakes (Nürnberg 1988). (It is important to know DO for the whole stratification season and not just for "September 01 +/- 14d [which] is the standardized date used to assess hypolimnetic dissolved oxygen to examine the quality of lake trout habitat by MNRF," as stated in the Palmer 2017 report. Because at this time, lake water is still warm and sun irradiation high enough to support cyanobacteria blooms, which could be fertilized by nutrients from the sediments, see below.

Further, the profile at the South station (Figure 3) indicates severe anoxia already in August 23, 2018. Shallower basins of lakes are often more productive and experience earlier anoxia and sediment P release (e.g., Long Lake, Sudbury; Hammel's Bay of Three Mile Lake, Nürnberg et al. 2018). It means that the shallower south basin is more enriched than the open water at the deep station.

To summarize the knowledge on potential anoxia of Leonard Lake:

1. Leonard Lake has been found to exhibit anoxia and DO < 2 mg/L throughout the years since monitoring in the seventies.
2. Relatively low DO concentration in August 2017 profiles indicate potential anoxia at the deep station later in the stratification season (expected fall turnover not before the end of October).
3. Anoxia was recorded on Aug 22, 2017 at the shallower (9m) site in the south basin.
4. In conclusion, Leonard Lake is to be categorized as a seasonally anoxic lake (i.e., experiences bottom water anoxia).

Lake chemistry and internal phosphorus loading

Occasional anoxia was established in Leonard Lake (previous section) and elevated TP and total dissolved P (TDP) concentration were found at least at the south sampling site that also exhibited a clearly anoxic hypolimnion on August 21/22, 2017 (Watson and Kling, 2018), (Table 2). The redox-dependant metals iron (Fe) and manganese (Mn) were elevated at the deepest depths, as well as ammonia (NH_3), also indicating hypoxia in August and possibly (for NH_3) in October.

Table 2. Summer 2017 monitoring results (all units in µg/L), Watson and Kling, 2018.

	NDH, Deep (main) site			South, Site #2		
Depth	1 m	3.5 m	15 m	1 m	3.5 m	7 or 8 m
21/22 Aug 2017						
TP	17*	7*	6*	8	8	16
TDP	5	4	3	5	8	11
Fe	21	17	318	22	28	1291
Mn	11	2	446	2	4	910
NH_3	53	20	595	39	51	62
17-Oct-17						
TP	6		12	6		8
TDP	2		3	2		3
NH_3	<MDL		189	<MDL		178

* Watson and Kling (2018) indicated a potential mix-up of bottom with surface sample at the deep site.

These monitoring results support the occurrence of internal P loading in Leonard Lake, in addition to the known importance of internal P loading in lakes with small watersheds compared to their surface areas (ratio of 2.1). Also, there is a morphometric inclination to hypolimnetic influences on the surface water (morphometric index, mean depth divided by the square root of the lake surface area, $z/A^{0.5}$ = 4.9 m/km), indicating that the Lake is stratified during the summer with increased bottom water mixing into the surface mixed layer in the fall (Nürnberg 1995).

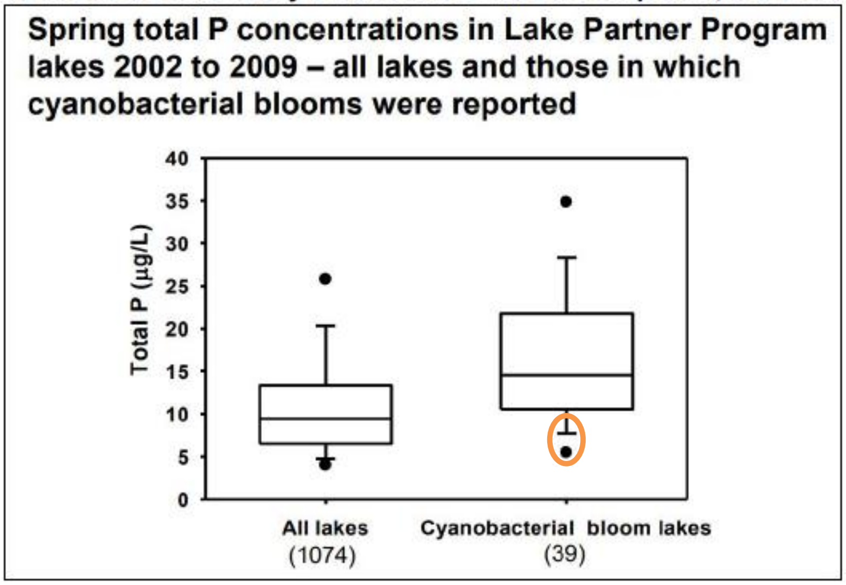
Cyanobacteria

The conclusion by Nürnberg (2017) that potential internal loading may lead to cyanobacteria blooms in the future in Leonard Lake was not accepted by Palmer (2017, p. 37), highlighted by GN:

> **"7.5.4 Impact Assessment Findings**
> Long-term water chemistry data and current conditions in Leonard Lake do not indicate the potential for harmful algal blooms. Leonard Lake does not express the full loads that can occur from shoreline development but is presently measuring background plus 50% concentrations which therefore requires the completion of a WQIA. Any further development on the lake that can effectively eliminate P loads to the lake will maintain the current trophic status of the lake."

This reluctance was exhibited despite the presentation of such occurrences in similar circumstances in the scientific literature, including the Winter et al. (2011) figure of Precambrian shield lakes that have blooms despite spring TP concentration below 10 µg/L (Figure also presented in Palmer as Figure K, oval marking added for emphasis by GN).

Figure K. Spring total P concentrations in Lake Partner Program lakes 2002 to 2009 in all lakes and in those where cyanobacteria blooms were reported, from Winter.



The speculation whether cyanobacteria are or will be present in Leonard Lake and whether blooms may occur is moot, because monitoring revealed such proliferation in the summer and fall of 2017 as described by Watson and Kling (2018, p. 3, 4):

- Low levels of noxious bloom-forming cyanobacteria such as *Dolichospermum* were present across much of the lake for most of the sampling period. While the background presence of these cyanobacteria is typical of low nutrient lakes, they are opportunistic and can develop localised blooms in response to nutrient influx e.g. from shoreline septic systems. Furthermore, some strains of these species can produce potent toxins that can have serious effects if ingested by pets, other animals and birds, or humans.
- In the summer of 2017, an LLSA "Eyes on the Lake" campaign resulted in 10 reports of possible near-shore bloom sightings. These were quickly sampled by LLSA volunteers and dispatched for species analysis. Four of the samples collected in mid-September from surface scums were composed largely of *Dolichospermum*, which has been reported as a toxin producer in other lakes.[4] Public awareness and reporting of algal blooms has escalated and can exceed laboratory and field capacity for timely sampling and analysis of these events, which can form and disperse rapidly. During September 2017, LLSA contacted the Spills Action Centre three times to report a scum. MOECC sampled a single site, but could not do so until after the bloom had disappeared.

In addition, a most recent sample of Aug 22, 2018 from the boat launch dock at the south-west side of Leonard Lake (site QL4 in Figure 1, Code name *LEO 2018/8/22 Leo algae 5*) detected microcystin, albeit at a low level of 0.1 µg/L (e-mail by Tom Teske, Senior Environmental Officer, Barrie District Office, Ministry of the Environment, Conservation and Parks, Sep 5, 2018), which is below the Ontario and Canadian drinking water and recreational guidelines. Other samples of Aug 13, 14 (Figure 4, 40 m^2 area bloom at 1098 Leonard Lake Rd 2) were identified by Hedi Kling, the phytoplankton identification specialist, as Anabaena (now *Dolichospermum*), a potentially toxic cyanobacteria also identified in 2017. 2018 samples were collected by staff of the Ministry of the Environment, Conservation and Parks (MECP).

Figure 4. 40 m^2 area Anabaena (*Dolichospermum*) bloom at 1098 Leonard Lake Rd 2 in the south-western region of Leonard Lake, August 13, 2018. *Photo by Bill Tryon.*

Health Canada (HC) recreational guidelines and provincial drinking water standards exist for cyanotoxins. The maximum concentration for microcystin-LR under the Ontario Drinking Water Quality Standard is 1.5 µg/L (O. Reg. 169/03, Schedule 2) and the provisional HC guideline for recreational activities is 20 µg/L (Health Canada, 2009).

MOECC regards any cyanobacterial bloom as potentially toxic, whether or not toxins are detected in the water upon testing (Winter et al., 2011). This is because toxicity changes with the state of the bloom and is not necessarily correlated to cell number. While the potential risk to human and animal health depends on the extent the water is used recreationally (e.g., public beaches, parks, and swimming areas), in a developed lake like Leonard Lake with a year-round population any detection of cyanotoxins is worrisome.

The confirmed sightings of *Dolichospermum* in 2017 and 2018 support the conclusions and recommendations by Nürnberg (2017) to prevent any further disturbances in the watershed including new development.

Potential development impact (including septic system and road usage)

The lake capacity model (Tables 6a and 6b by Clark Environmental) that are presented in the Palmer Addendum (2018) indicate that Leonard Lake is at capacity in all presented scenarios. This result contradicts the overall conclusion that additional development is permissible.

The Palmer Report (2017, p. 37, highlighted by GN) claims that the proposed development would eliminate P loads.

> **"7.5.4 Impact Assessment Findings**
> Long-term water chemistry data and current conditions in Leonard Lake do not indicate the potential for harmful algal blooms. Leonard Lake does not express the full loads that can occur from shoreline development but is presently measuring background plus 50% concentrations which therefore requires the completion of a WQIA. Any further development on the lake that can effectively eliminate P loads to the lake will maintain the current trophic status of the lake."

Perhaps this statement is based on the proposed application of special P-adsorbing material as septic system amendment. However, considering that the proposed development is situated on a granite outcrop with little soil (at various sites along the septic effluent path soil depth is only 0.15 m) and a relatively steep slope (more than 9% at 4 lots), any connotation of P load elimination upon development appears erroneous (Palmer 2018, referred to as Table 1).

Table 1: Soil Depths and Percent Slope

Lot #	Soil Depth at 20 points along 30 m flow path (m)	% Slope
Lot 1	0.35, 0.45, 0.30, 0.27, 0.35, 0.15, 0.15, 0.15, 0.2, 0.4, 0.5, 0.65, 0.7, 0.9, 0.9, 1.1, 1.2, >1.2, >1.2, >1.2	9%
Lot 2	0.2, 0.65, 0.4, 0.15, 0.2, 0.3, 0.4, 0.5, 0.5, 0.3, 0.7, 0.45, 0.45, 0.55, 0.1, 0.45, 0.3, 0.35, 0.65, 0.6	9%
Lot 3	0.5, 0.35, 0.4, 0.15, 0.6, 0.5, 0.3, 0.2, 0.2, 0.35, 0.4, 0.5, 0.2, 0.25, 0.4, 0.3, 0.15, 0.2, 0.25, 0.2	24%
Retained Lot	0.15, 0.2, 0.3, 0.55, 0.4, 0.6, 0.8, 0.9, 0.7, 0.6, 0.8, 0.8, 0.7, 0.6, 0.65, 0.8, 0.9, 0.85, 1.0, 1.1	18%
Lot 5	0.6, 0.65, 0.5, 0.25, 0.3, 0.6, 0.75, 0.70, 0.4, 0.65, 0.70, 0.65, 0.85, 0.95, 0.85, 1.0, 1.05, 0.9, 1.0, 0.85	6-7%

Summary and Conclusion

The vulnerability of Leonard Lake to increased disturbances was determined again, with results similar to Nürnberg's (2017) and Watson and Kling's (2018) reports. This assessment is based on the long-term and recent anoxic and hypoxic bottom water at a south and the deep lake sites in late summer and fall (based on observations of oxygen concentration below 2 mg/L, increased reduced metals, and increased ammonium close to the bottom), on signs of internal P loading from bottom sediments (based on elevated P concentrations with depth at the south site in August 2017), and on the occurrence of potentially toxic cyanobacteria in 2017 and 2018.

Increased anthropogenic usage and development around Leonard Lake should be avoided and best management practices employed in the catchment basin so that the cyanobacterial blooms do not continue and become more frequent. Especially development at such steep sites and low soil cover as that proposed can be expected to increase the Lake's vulnerability, despite any amendments with P adsorbing material.

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Further pertaining references to the scientific literature are available in Nürnberg 2017 and Watson and Kling (2018).

Endnotes

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[i] (See 3.3.10 Water Quality and the Relationship to Development Capacity)

What can be done to improve on this "fact of life" regarding phosphorus loading?

There are new technologies in wastewater treatment systems. Tertiary Wastewater Treatment Systems add a level of treatment that can improve efficiency in phosphorus retention or reduction. What are these systems and what do they do?

- Tertiary systems provide a higher level of waste treatment in the tank prior to the tile bed
- The liquid effluent that enters the tile bed is 1/10th the strength of a conventional system. Note that "strength" is measured by Biological Oxygen Demand (BOD) in mg/l. A liquid which has a high BOD will strip available oxygen out of a lake and lead to more anoxia
- Phosphorus and Nitrogen levels in the effluent entering the tile bed is significantly reduced up to 90% depending on the system. Significantly reduces the quantum of P and N that will enter the watershed and lake from the tile bed
- These systems will require regular maintenance and pump outs
- Some systems have a small blower to introduce air into the tank for enhanced treatment – "Aerobic" treatment systems. Some systems have additional "filters" that provide the tertiary component – an example is Waterloo Biofilter.
- Tertiary systems are typically more expensive than a conventional system but can be implemented in places that conventional systems cannot. i.e., less topsoil, rocky lots, tight spaces etc.

[ii] (See 3.3.10 Water Quality and the Relationship to Development Capacity)

The best estimate for development-generated Phosphorus entering a lake in the Muskoka area comes from a calculation based on the Lakeshore Capacity Model (LCM, Ministry of the Environment 2010), and the Muskoka Revised Water Quality Model (MWQM) (Gartner Lee, 2005).

While the LCM calculation focusses on phosphorus from septic systems as the major human contributor, cleared areas, gardens and grass areas are recognized as additional contributors of phosphorus as a result of increased overland runoff. As the phosphorus enters the lake, much will quickly settle into the lake sediments, and become fixed - so it is undetected in surface-measured water samples. However, bioavailable phosphorus can be subsequently released from the fixed phosphorus in these sediments when conditions are right (low oxygen in water at the bottom of the lake or turbulence), leading to water quality deterioration and possible algae blooms.

The MWQM included an "attenuation factor" based on soil retention from septic systems, which made the LCM model more accurate. The retention factor for Leonard Lake (as indicated in the Hutchinson 2005 report, as well as used by the consultants carrying out the Leonard Lake Water Quality Impact Assessment in 2018) was approximately 50%. Improved septic systems can ameliorate, but not eliminate phosphorus from entering the lake.

The LCM Handbook estimates that .66kg of phosphorus per person per year enters the lake for seasonal residences, and almost double that for full year residences. Therefore, one assumed five-person lakefront seasonal residence would result in an average of 1.65kg of phosphorus entering the lake each year, and one year-round five-person lakefront residence would result in approximately 3.0kg of phosphorus entering the lake each year.

Consequently, in addition to existing residences on Leonard Lake, new dwellings - seasonal, extended seasonal or permanent - would increase the amount of phosphorus entering the lake annually as per the LCM model, commensurate to the number of additional dwellings and the average number of residents per dwelling.