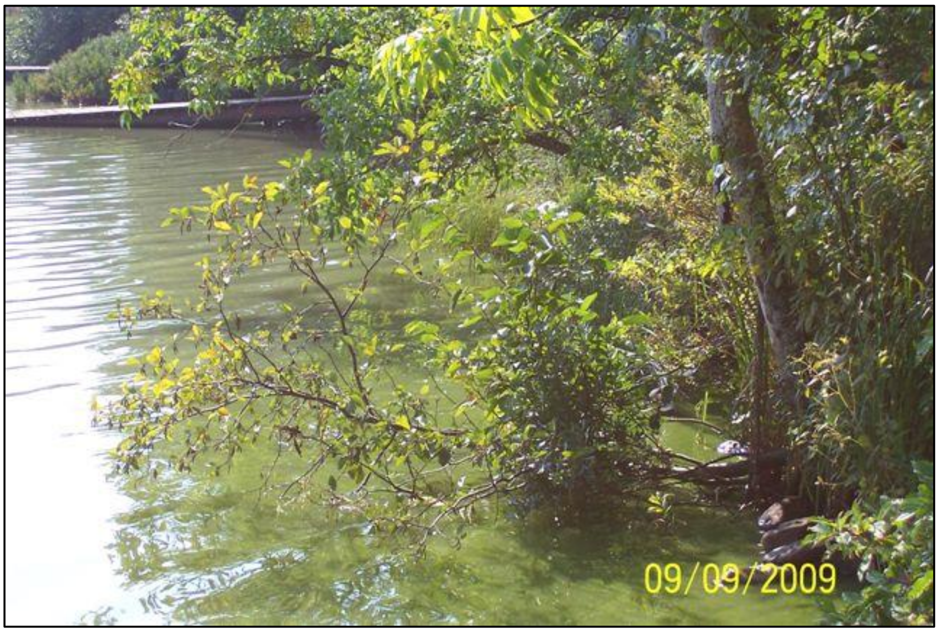
Water Quality and Remediation Options for Desbarats Lake, Johnson Township



Prepared by

Gertrud Nürnberg, Ph.D.
Bruce LaZerte, Ph.D.
Freshwater Research

gkn@fwr.ca
3421 Hwy 117
Baysville, Ontario, P0B 1A0

Prepared for the

Central Algoma Freshwater Coalition

Bruce Mines, Ontario

24 May 2013

Acknowledgement

The staff, Lindsey Palumbo, Chris Graham, and the members of the Central Algoma Freshwater Coalition (CAFC) were immediately involved in all aspects of this study.

Tracey Cooke, Stewardship Coordinator of the East Algoma Stewardship Council, Ministry of Natural Resources provided extensive support including the provision of maps and digital information on lake bathymetry and watershed land use information. Walter Shields of the MOE in Sault Ste. provided information, copies of old reports and phytoplankton/cyanobacteria analysis.

Many sampling trips involved volunteers and all are gratefully acknowledged. Peter Pollard was responsible for the MOE Lake Partner sampling 2010-2012 and physically and financially supported the upstream sampling program in 2011 and 2012 that was added to the workplan at a later time. Other volunteers that provided much needed support were Karl Wicke, who often accompanied Peter Pollard, and Professor Ryan Namespetra and students of Sault College, who conducted the sampling through the ice in spring 2012 with Lindsey Palumbo.

Sediment sampling equipment was provided by Lisa O'Connor, Department of Fisheries and Oceans, Sault Ste. Marie).

Bright Lake Association and John Milito, its vice president, provided steady support including the provision of equipment and knowledge which is gratefully acknowledged.

Hugh Coverley and Edith Orr, both CAFC Board members and year round residents, and other Board members added valuable comments to an earlier version of this report.

Johnson Township and an Ontario Trillium Foundation grant to the Central Algoma Freshwater Coalition provided funds for part of this study including support for equipment and lab analyses in 2011 & 2012 as well as the preparation of this report.

All this friendly support is gratefully acknowledged and made this study possible.

Cover Photos Sep 2009 and Aug 2011 showing cyanobacterial bloom ("bluegreens") in Desbarats Lake. Samples of 17 Aug 2011 tested positive for microcystin so that Desbarats Lake was posted to be closed for recreational activity and any contact with its water was to be avoided. (*Photos by Peter Pollard*)

Executive Summary

Central Algoma Freshwater Coalition (CAFC) was formed, a not-for-profit organization, and commenced collaboration with scientific partners to identify the major causes for blooms in Desbarats and other Central Algoma lakes and develop a community-based remedial action plan. CAFC applied successfully to the Ontario Trillium Foundation for a grant to support a thorough limnological evaluation of Desbarats Lake. In particular, the study was to pinpoint the causes of the blue-green algae blooms and determine any knowledge gaps. Where possible, remedial options were to be indicated that would improve Desbarats Lake's water quality.

Desbarats Lake is a eutrophic, oligomictic lake on the Canadian Shield in Northern Ontario (3.6 km^2, 10 m max. depth) with a history of summer and fall phytoplankton blooms and turbid water. Desbarats Lake is severely eutrophied with trophic state variables indicating meso- to hyper-eutrophic conditions, implying low water quality. Extensive blooms of cyanobacteria (specifically of *Aphanizomenon flos aquae*) started in the early nineties (and perhaps existed in the sixties) and have since varied annually. Extremely low Secchi transparency during periods of high total phosphorus concentration (TP) apparent in 2010 despite low algal biomass (based on chlorophyll concentration) indicates that Desbarats Lake has occasionally been light-limited.

Trophic state variables (nutrients and Secchi transparency) have improved since 2010 (summer averages improved from 2010 to 2012: TP from 36 to 24 µg/L, total nitrogen: from 464 to 301 µg/L and Secchi depth transparency from 0.65 to 1.22 m) they were still worse than the monitoring results of 1995, and cyanobacterial blooms are still frequent.

Desbarats Lake is categorized as supporting a warm water fishery so that the provincial water quality objective (PWQO) of 5 mg/L dissolved oxygen (DO) applies. In the deep water, DO concentration was below 5 mg/L most of the summer 2010 and at several occasions in 2011 and 2012. Such low DO was more wide-spread in 1995 and 1996. Winter profiles from 2011 and 2012 suggest that hypoxia happens under ice and may be the reason for fish kills observed in the lake in several springs.

The watershed includes upstream lakes and wetlands with beavers, but little agricultural land, primarily cattle pasture. Lake shore development likely contributes some nutrients as only 19 of 65 lake shore residents have a sewage disposal permit. Further, occasional incidences of hypoxia and elevated TP in the bottom water indicate the potential of internal phosphorus loading from anoxic lake bottom sediments, but sediment fractionation results reveal that releasable P is low.

Management options to address TP sources are available and made in this report. Because the most apparent water quality issue conflicting with lake use and health is an overabundance of algae, the control of algal growth and especially cyanobacterial blooms should be attempted. The most common method is to reduce the nutrient inputs (in particular of P), as most excessive algal growth is the result of fertilization from external sources like agriculture, field and lawn runoff, septic and sewage outflows. Specifically in the Desbarats Lake watershed, septic system inspection and renovation, and shoreline best management practices and the prevention of cattle access to inlet creeks are recommended. Beavers and development, as well as human-inflicted disturbance of beaver dams appear to increase TP concentration and may contribute to the high TP in Desbarats Lake. The low Secchi transparency and associated high TP concentration in 2010 and the increased blooms in the nineteen-nineties may have been caused by upstream beaver dam ruptures. Therefore, a survey and inventory of these wetlands including the number, extent and status of the dams is recommended.

In general it is recommended to

- Apply best management practices in the watershed wherever possible. For example, livestock access to inflow streams and the lake should be minimized, buffer zones around water ways respected.
- Ensure septic system compliance (inspection, maintenance, renovation, installation)
- Continue education to insure environmentally friendly lifestyles (selection of cleaners and detergents; low impact ice fishing, boating and bathing; etc.)
- Continue future monitoring to verify improvement in trophic state variables and to corroborate the observed patterns of cyanobacteria blooms.
- Review morphometric and hydrological characteristics of the lake and land use patterns of the watershed.
- Examine the potential impact from upstream beaver activity in more detail.
- Prepare a lake shore capacity assessment including a phosphorus budget.

Remediation of the Desbarats Lake appears to be particularly important since it drains via the Desbarats (Walker) River through a Provincially Significant Wetland (PSW) into the North Channel of Lake Huron. Average TP outflow concentration varied from a high 46 µg/L in fall 2010 to 15 µg/L in fall 2012, despite fall blooms in 2012. Further monitoring should verify whether this promising trend is sustained.

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Glossary

Annual areal water load, q_s (m/yr): The annual outflow volume (Q, cubic m) per surface area (A_o, square m), where $q_s = Q/A_o$.

Annual water detention time or *annual water residence time,* tau (yr): lake volume (V) divided by annual outflow volume (Q), where tau= V/Q.

Aphanizomenon flos-aquae: Cyanobacteria ("bluegreen algae") that most occurs in Desbarats Lakes

Chlorophyll a: A measure of algae biomass, the pigment that is analyzed in water is chlorophyll *a*. Because of natural patchiness and a high probability of analytical errors this measure of algal biomass in lake water is not very precise.

Eukaryotic algae: Phytoplankton and "real" algae, but not cyanobacteria, which are prokaryotic.

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.

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.

Limnological seasons used in this study: Spring: Apr, May; Summer, *period used for trophic state evaluations*: June, Jul, Aug, Sept; Fall: Oct, Nov; Winter: Dec, Jan, Feb, Mar

Oligomixis: The mixing state in lakes where thermal stratification is short-lived, i.e., it lasts only a couple of days to a week.

Soluble reactive P, SRP: soluble fraction of TP that consists mostly of the biologically available phosphate

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

Desbarats Lake, Johnson Township, Ontario (46°23, 83°56', 193.5 m above surface level) is a eutrophic, oligomictic lake on the Canadian Shield in Northern Ontario with a history of summer and fall phytoplankton blooms. Its water has been exceptionally turbid during the open water season.

Local concerns about the implications for human and ecosystem health were reinforced when a surface bloom sample from fall 2009 contained a high abundance of the potentially toxic cyanobacterium *Aphanizomenon flos-aquae*.

The Central Algoma Freshwater Coalition (CAFC) was formed in March 2009 and incorporated in May 2011, in response to seasonal and permanent residents concern for deteriorating water quality in Lakes in the Central Algoma area. Re-occurring blue-green algae blooms and the spread of Eurasian watermilfoil in the North Channel were the most prevalent concerns. An application to the Ontario Trillum Foundation by a three party agreement involving the East Algoma Stewardship Council, the Kensington Conservancy and the CAFC was successful. The grant provided a two year full time co-ordinator staff position for CAFC and included two additional years of research in phytoplankton blooms and their causes for Desbarats Lake. Added funding from the Township of Johnson over the two years paid in large part for the analysis of the water samples.

In particular, this study was to pinpoint the causes of the blue-green algae blooms and determine any knowledge gaps. Where possible, remedial options were to be indicated that would improve Desbarats Lake's water quality. Remediation of the lake appears to be particularly important since it drains via the Desbarats (Walker) River through a Provincially Significant Wetland (PSW) into the North Channel of Lake Huron. A public boat launch at the mouth of the Walker River is a major access point for the many cottager located on the islands within the channel and for local recreational fishermen.

For this project, any available reports, surveys, documented communication, photos and local wisdom were inspected and summarized by CAFC staff in a preliminary report (Verdone 2010). The main part of the current report presents the analysis of water quality data obtained during the three years of monitoring (2010-12) and an evaluation based on these results as well as the historic water quality data (1995-1996) of the Ontario Ministry of the Environment (MOE 1995).

This study does not include a lake shore capacity assessment (e.g., Nürnberg and LaZerte 2011a). Such a study would be based on detailed land use information, resident number and hydrological information which is not yet complete. Accordingly, no attempt is made to assemble a phosphorus (P) budget and predict nutrient concentration and water quality variables in Desbarats Lake.

Preliminary investigation of available data identified that excessive nutrient input, in particular of phosphorus, may facilitate these blooms. Sources could be external and stem from streams and direct runoff around the lake from anthropological development and natural causes such as wetlands and beaver activity. Another source could be internal, as internal P load released from anoxic bottom sediment surfaces (Nürnberg 2007a) and was to be investigated.

2 General characteristics of Desbarats Lake

Desbarats Lake is located in and belongs to Johnson Township, about 60 km south east of Sault Ste. Marie in the District of Algoma. It drains into the Desbarats (or Walker) River and from there into the North Channel of Lake Huron (Figure 1).

Figure 1. Satellite view of Desbarats Lake, from Google Map

The lake sampling stations are indicated as white squares and the monitored out- and inflows are indicated as yellow tacks. Inflow 4 (yellow arrow) was only monitored upstream.

2.1 Morphometry

Desbarats Lake is a relatively shallow lake (Table 1). Its morphometric index (mean depth/square root of surface area) of 3.55 m/km indicates that Desbarats Lake is an oligomictic lake that thermally stratifies only occasionally during the warm season, because of its shallowness, which is also evident by its temperature and dissolved oxygen profiles (Section 4.1). If the bottom sediment in such oligomictic lakes is enriched enough, it may release P during intermittent periods of stagnant and low oxygen (hypoxic) conditions and elevated bottom temperature. A pattern of lake TP increases throughout the summer and fall with little external inputs, indicates internal P loading in oligomictic lakes. Such enrichment may trigger algal and cyanobacterial blooms.

Desbarats Lake flushes 2.45 times per year (survey from 1968, this value should be reviewed), by 4 distinct inflows and one outflow (Figure 1).

Table 1. Morphometry and hydrology

Characteristics	Value
Surface area, Ao (km²):	3.57
Maximum depth, z_{max} (m):	10.5
Mean depth, z (m):	6.71
Morphometric Index ($z/A^{0.5}$, m/km):	3.55
Volume (10^6 m³):	23.93
Annual flushing rate (per yr):	2.45*
Annual water load (m/yr):	16.41*
Watershed area, A_d (km²):	23.2**
Area Ratio, A_d/Ao	6.5**

* Hydrological characteristics are from a lake survey of 1968 and should be reviewed
**The watershed area should be reviewed

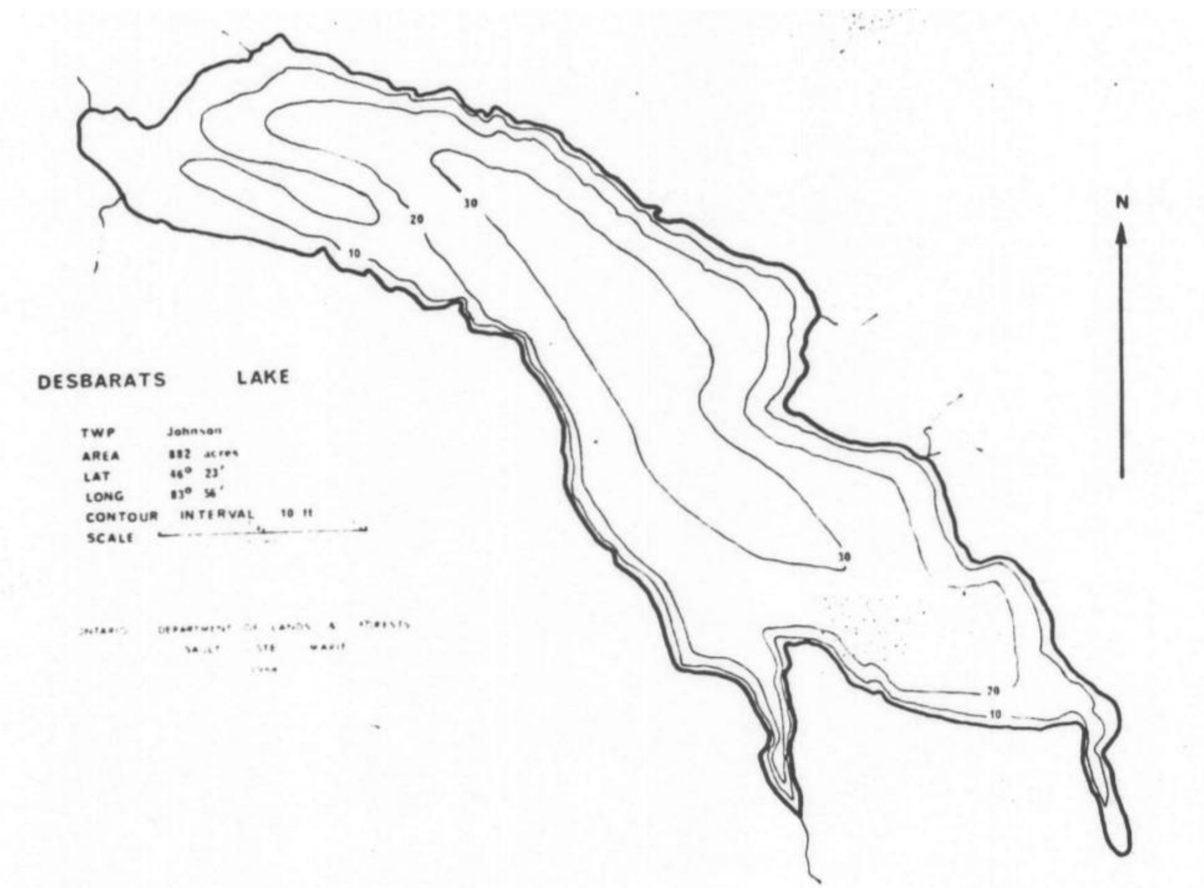

Figure 2. Bathymetric map of Desbarats Lake (1968)

2.2 Watershed

The watershed or catchment basin can have a large influence on a lake's water quality, because most of the pollutants are flushed with runoff via the inlets to end up eventually in the lake. Because there are inconsistencies with respect to the watershed area, the value should be reviewed. The area ratio between watershed and lake is 6.5 (Table 1), which is relatively low and indicates that both external and internal nutrient sources can influence the water quality in Desbarats Lake.

Almost 10% of the Desbarats Lake watershed consists of several upstream lakes and wetlands with their catchment basins (Figure 3).

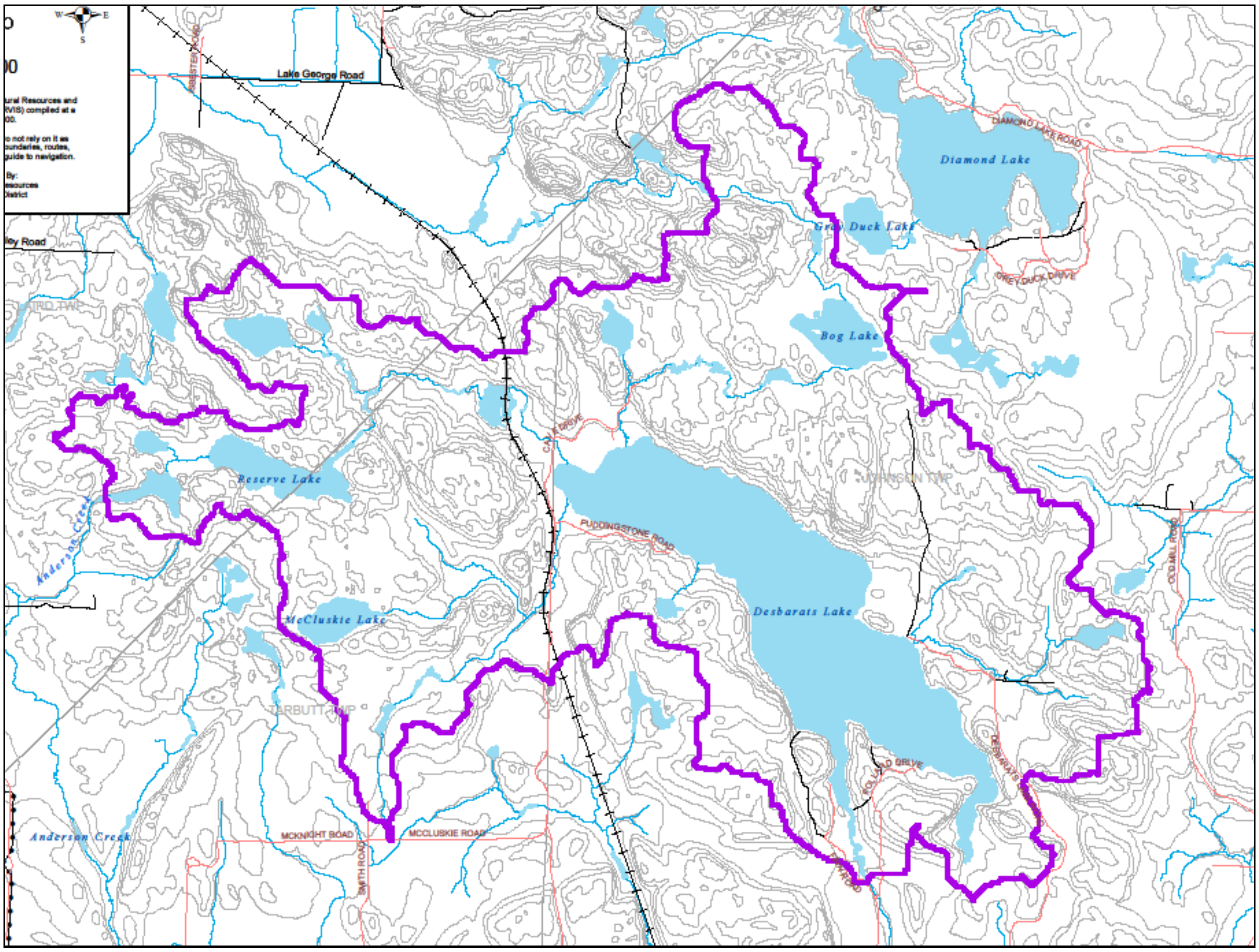

Figure 3. Desbarats Lake watershed *(Source: MNR 2011, Sault Ste. Marie District)*

Note that local knowledge (Edith Orr, pers. comm.) disagrees with this watershed boundary. Even if it does not affect the water quality evaluation of this report, this discrepancy should be resolved.

2.3 Trophic state classification

Based on several water quality variables a lake can be classified with respect to its trophic state (Table 2). Clean pristine and clear lakes are called oligotrophic and have high Secchi disk transparency, and low nutrient concentrations and algae biomass (expressed as the green pigment, chlorophyll a concentration). Lakes with more nutrients and algae are intermediate and called mesotrophic or eutrophic. Only lakes that have a high nutrient load from the watershed and from the sediments are hyper-eutrophic, showing extremely high nutrient and algae concentrations, high turbidity and exhibit an oxygen deficit (below saturation) in their bottom waters during periods of thermal stratification. In oligomictic lakes such as Desbarats Lake, stagnant conditions occur intermittently (days or weeks) during the growing season, prohibiting extended oxygen deficits even though other indicators indicate a high trophic state.

Algal growth in lakes is usually limited by the supply of phosphorus. Even if other nutrients such as nitrogen, or light become limiting, algae biomass and blooms usually increase with increasing phosphorus concentrations in the water. Increasing the mass of phosphorus entering a lake or pond (loading) will increase the average concentration of phosphorus and consequently of algae, increasing eutrophication as well.

Nitrogen is the second most important nutrient in lakes and reservoirs, after phosphorus. In fact, it often co-limits algal growth, so that any addition of available nitrogen compounds enhances algal growth and eutrophication. Total nitrogen (TN) and total phosphorus (TP) concentrations are often closely correlated, but generally algae biomass is better correlated with TP rather than TN. For this reason and because phosphorus can be more easily controlled than nitrogen, management and restoration efforts typically concentrate on the reduction of phosphorus.

As shown in the following section, Desbarats Lake's trophic state changed throughout the monitoring period and differed for the different trophic state indicators between mesotrophic to hyper-eutrophic conditions (Table 2). The enriched conditions are usually only encountered in lakes in an urban or agricultural setting with a long history of pollution. They represent an extreme state that is rare for a lake on the Canadian Shield. High P concentration and low Secchi in Desbarats Lake at the beginning of this study in April 2010 indicated light limitation, rather than nutrient limitation and one goal of this study was to determine the cause of this unusual state. (For explanation and details see Section 4.11.)

Table 2. Trophic state categories based on summer water quality (Nürnberg 1996)

	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
Secchi Disk Transparency (m)	> 4	2 – 4	1 – 2	< 1
Total phosphorus (µg/L)	10	10 – 30	31 – 100	> 100
Total nitrogen (µg/L)	< 350	350 – 650	650 – 1 200	> 1 200
Chlorophyll *a* (µg/L)	< 3.5	3.5 – 9	9.1 – 25	> 25
Anoxia in oligomictic lakes	none	some	some	some

3 Water quality evaluation - Methods

3.1 Sampling locations and times

Six sampling sites were established within the lake and were routinely sampled for water quality during the course of the study. Two stations are located at the central locations in the northern (Station 1) and southern section (Station 3), which is the main and overall deepest point. Three stations are located close to the inflows of creeks (In1, In2, and In3) and one is located close to the outflow (Table 3). In 2012, monitoring results of Station 1 were found to be redundant and sampling was discontinued. In addition, several creeks were sampled upstream of Desbarats Lake (summer 2011, spring and fall 2012). Sampling for water was either done as grab samples from the surface or by Van Dorn for discrete depths.

Table 3. Routine sampling locations and typical sampling depths for this study (Figure 1)

Location	Site	Water Depth (m)	Sampling depth (m)	Year of sampling
Within the lake				
Shallow Station	1	5	1,3,5	2010-12
Main, deep Station	3	10.5	1,3,5,7,9	2010-12
Inflows (location in the lake)				
From McCluskie Lake	In 1		Surface	2010-12
From Reserve Lake	In 2		Surface	2010-12
From Bog Lake	In 3		Surface	2010-12
	Out		Surface	2010-12

*Surface samples are actually withdrawn just below the surface at about 20 cm

This study describes the monitoring effort that started on 14 Apr 2010 on a schedule of biweekly to monthly sampling until 21 Nov 2012. All sampling was done by CAFC staff (Lindsey Palumbo nee Verdone and Chris Graham) with help of volunteers and students of Sault College, including three sampling occasions in the winter through the ice (Figure 4). In addition, Secchi transparencies and replicate TP concentrations (grab samples at about 30 cm) at Station 3 were determined independently in the MOE Lake Partner Program.

To determine the contribution of the bottom sediments to water quality issues, one sediment core was collected by CAFC staff and helpers at each of the two lake stations (1 and 3) on 14 Jul 2010. Two depth samples (0-5 and 5-10 cm) of each core were analyzed by *Spectrum Analytical* (http://www.spectrum-analytical.com) for sediment TP, reductant soluble P (Fe-P), total iron, total calcium and general chemical composition.

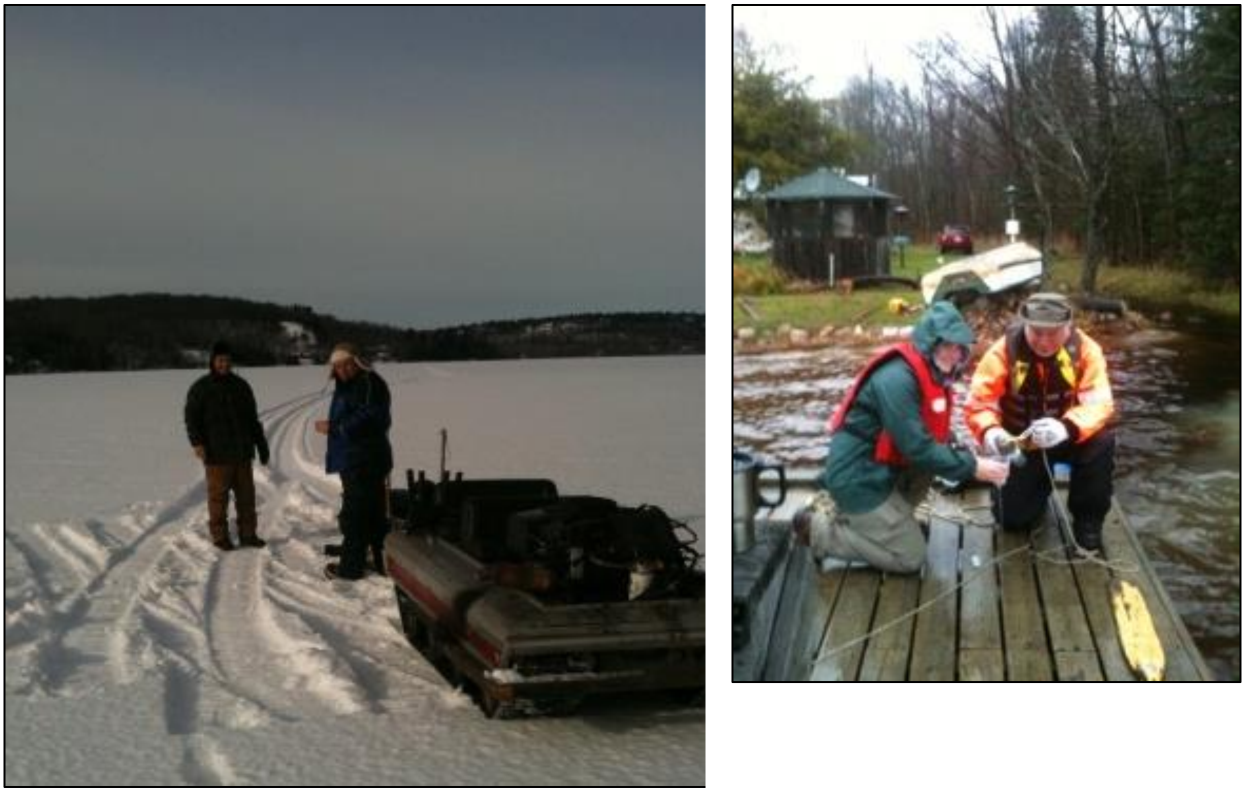

Figure 4. Winter and fall sampling by volunteers *(Photos by Lindsey Palumbo, 15 Feb 2011 and 3 Nov 2010)*

3.2 Field and analytical methods

Temperature and dissolved oxygen (DO) profiles at 1 m depth intervals were initially taken with Hanna Instruments, HI 9146, Portable Waterproof Microprocessor DO Meter borrowed from the Blind River MNR and since 20 May 2010 with a YSI 550A DO meter.

Water samples were collected with a discrete depth sampler (Van Dorn) at 1 m depth for the regular surface sample and in depth profiles (Table 3) to determine the nutrient concentration of phosphorus (P) and nitrogen (N). All stream samples were taken as grab samples at about 20 cm below the surface.

All water samples were kept in a cooler and shipped for analysis by the Trent University Laboratory at the Dorset Environmental Science Centre with Ministry of the Environment (MOE) certified methods (including: MOE Methods 3036_2007, E3374_2007, and E3424_2008). Typically, total phosphorus (TP) was analyzed in duplicates because of the high possibility of contamination.

A Secchi disk reading was taken as a measure of transparency during all routine monitoring. Chlorophyll *a* was analyzed by Testmark Laboratories Ltd. (www.testmark.ca). It is the green pigment of phytoplankton and serves as an estimate of algal biomass. Often chlorophyll concentrations are quite patchy and variable in space and time and frequent Secchi transparency readings may be superior in determining algal blooms. Therefore and because it is an expensive analysis, it was discontinued in 2012. Because of the relatively low Secchi transparency measured in the lake water, total suspended solids were analyzed in 2012 (by Testmark Laboratories) to identify whether turbidity was due to sediment particles rather than algal pigments. In this way it was to be distinguished whether physical processes including lake shore erosion caused the turbidity or nutrient related processes such as eutrophication.

General chemical composition of the water was determined twice in 2010, on 14 April sampled by CAFC and analyzed in the Trent lab, and, unknown at the time, by MOE on 27 April. Detection limits for the different labs are compiled in Appendix A.

For the lake stations Sites 1 and 3 field and analytical data are available for 1995 and 1996 sampled by MOE (MOE 1995). These data represent composite samples from the surface down to a depth between 2.5 and 10 m and were analyzed in the MOE labs with MOE methods.

4 Limnology and water quality of Desbarats Lake

Sampling events between 1. June and 30. September were averaged to constitute the summer period average; ice-out to 31 May constitutes the spring average, 1 Oct to ice-in the fall and under ice, winter averages.

4.1 Temperature and dissolved oxygen concentration

Summer temperature profiles from previous sampling efforts (1995-96) and this study (2010-12) indicate that Desbarats Lake was usually mixed to about 5-6 m at deep Station 3 (Figure 1, Figure 5, Figure 6) and mixed to the bottom at 6 m of the shallow Station 1. Close inspection of the temperature profiles reveals that periods of stratification and mixing vary between years. On most dates temperature differences between surface and bottom layers were apparent at Station 3, albeit small (typically less than 4 C between surface and bottom) and therefore stratification periods were probably short. Occasional stratification is typical for oligomictic shallow lakes such as Desbarats and supported by its morphometric index (Table 1).

Despite only intermittent stratification incidences of hypoxia occurred throughout the monitored summers (Figure 7, Figure 8). DO profiles from 1 June – 7 Sep 2010, on 8 Aug 2011 and on 26 July 2012 indicate sub-saturation concentrations throughout the water column and concentration below 6 mg/L below 4 m. Such a pattern is usually created by a severe sediment oxygen demand that is likely augmented because of relatively high bottom temperatures (16-21°C during hypoxia in 2010, 15-21°C in 2011, and 19°C on 26 Jul 2012). Monitoring by MOE personnel in 1995 indicate more severe hypoxia (DO concentration below 5 mg/L) at 7 m starting on 27 June 1995 (Figure 8; MOE 1995). There were extreme hypoxic conditions (DO below 2 mg/L) throughout the water column in July 1996.

In oligomictic lakes like Desbarats Lake, occasional hypoxia indicates mesotrophic to eutrophic conditions (Table 2).

Desbarats Lake is categorized as supporting a warm water fishery so that the provincial water quality objective (PWQO) of 5 mg/L DO applies. In the hypolimnion below 8 m, DO concentration was below 5 mg/L most of the summer 2010 and at several occasions in 2011 and 2012. Such low DO was even more wide-spread in 1995 and 1996.

Winter profiles from 2011 and 2012 suggest that hypoxia happens under ice (Figure 7) and may be the reason for fish kills observed in the lake in several springs (Peter Pollard, pers. comm.).

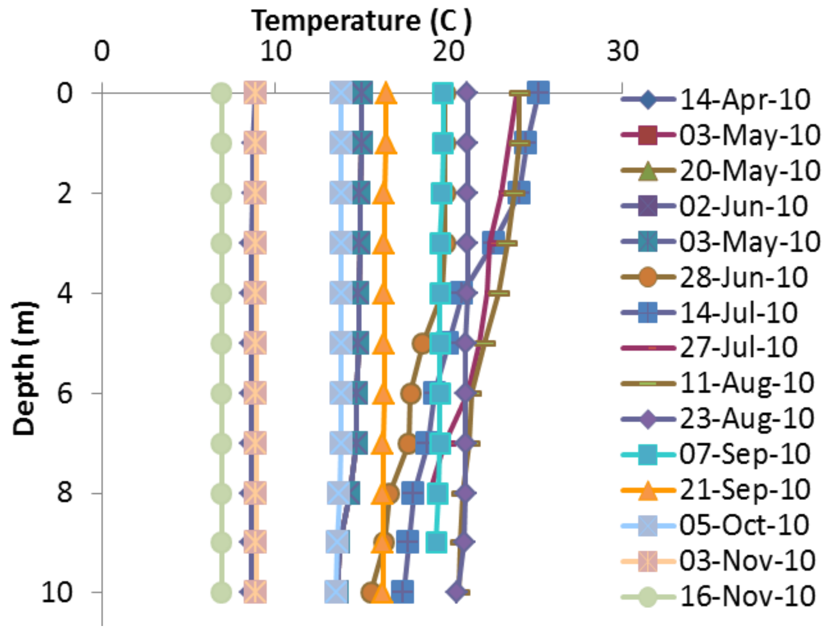

Figure 5. Temperature profiles for 2010

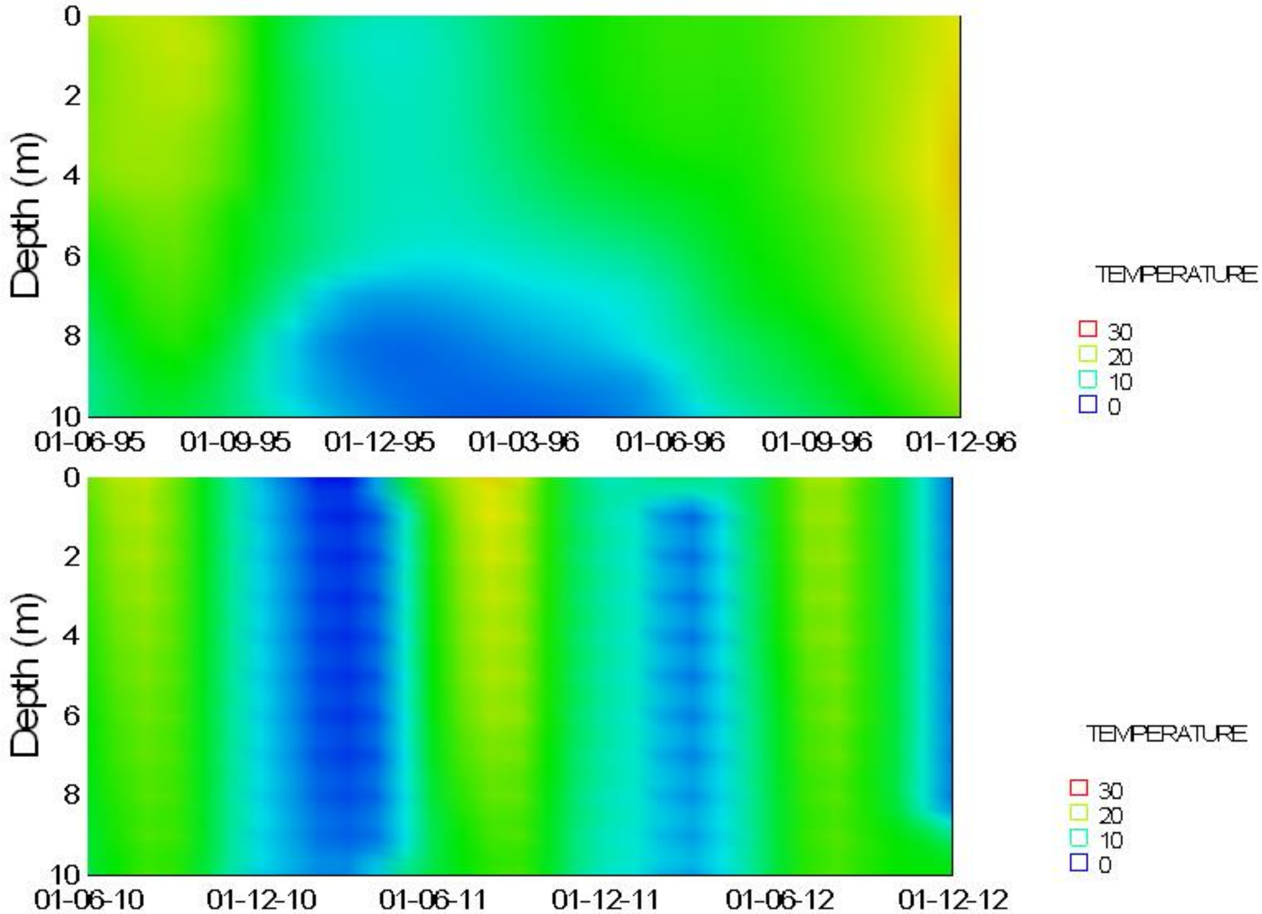

Figure 6. Temperature contours for 1995-1996 (top, summers) and 2010-2012 (bottom).

There were no profiles taken between 26-Jul-2012 and 25-Sep-2012.

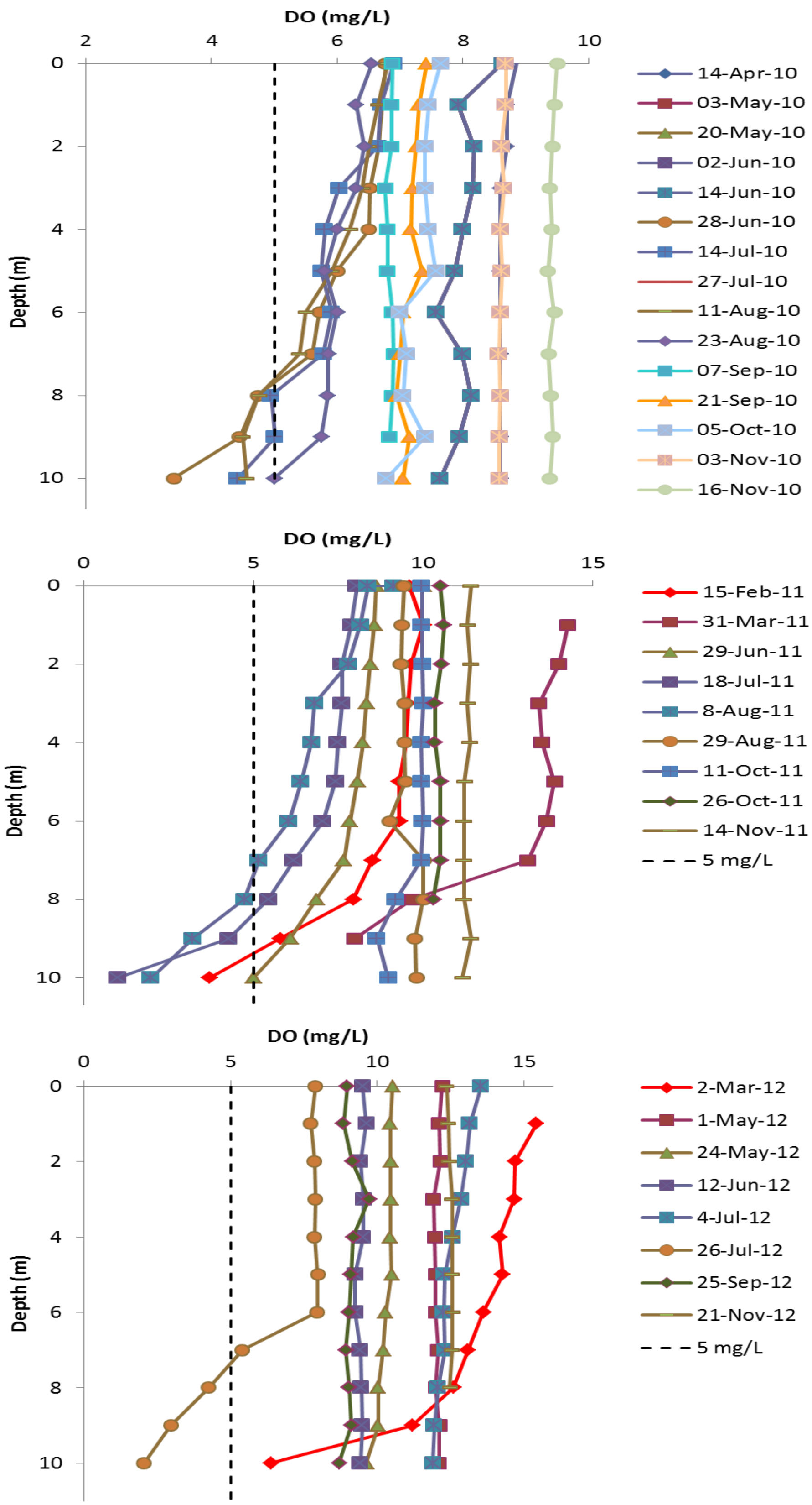

Figure 7. Dissolved oxygen profiles for 2010, 2011, and 2012 *(dashed line represents PWQO)*

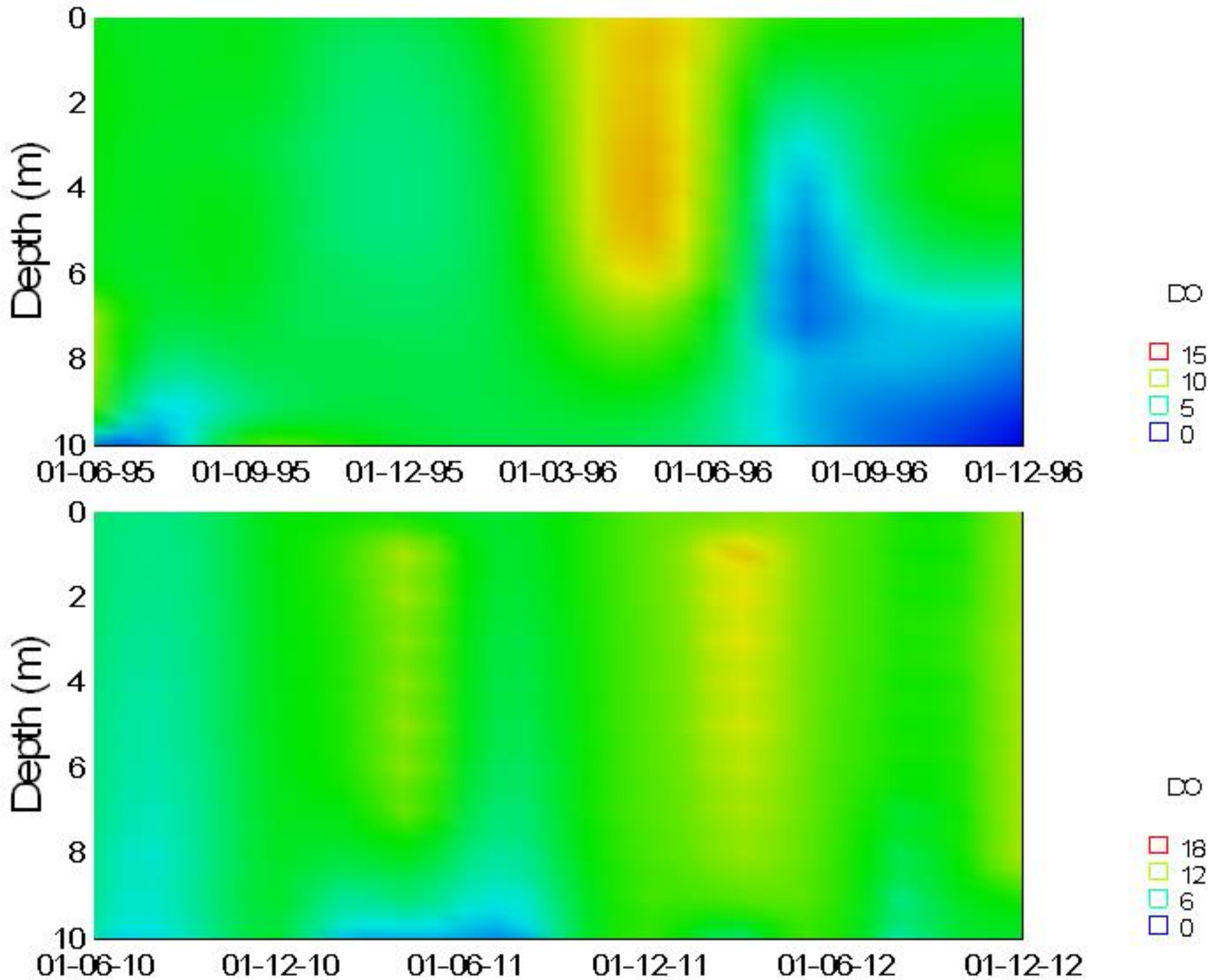

Figure 8. Dissolved oxygen contours for 1995 and 1996 (top) and 2010-2012 (bottom).

There were no profiles taken between 26-Jul-12 and 25-Sep-12

4.2 Water clarity measured as Secchi disk transparency

Secchi transparency was surprisingly low for a northern lake (Figure 9). Summer average Secchi transparency at the main station was 0.65 m in 2010 and 0.84 m in 2011, indicating hyper-eutrophic conditions. It was 1.23 m in 2012 which is representative of eutrophic conditions. In most years it was lowest in the spring (Figure 10). All readings in 2010 and 2011 were below 1.2 m, therefore exceeding the Health Canada guideline for recreational activities (Health Canada 2009). However, readings improved in July 2012 to above 1.20 m and the Jun-Sep (summer) of 1.23 m.

Secchi readings at the shallow Station 1 were similar to that of deep Station 3 throughout the monitoring period. Desbarats Lake's trophic state with respect to Secchi transparency has to be classified as hyper-eutrophic (at 1 m and below) in 2010 and 2011 and eutrophic in all other monitored years (Table 2).

Figure 9. Secchi Disk depth of 0.60 cm, at Station 3 on 14 April 2010 *(Photo by Gertrud Nürnberg)***.**

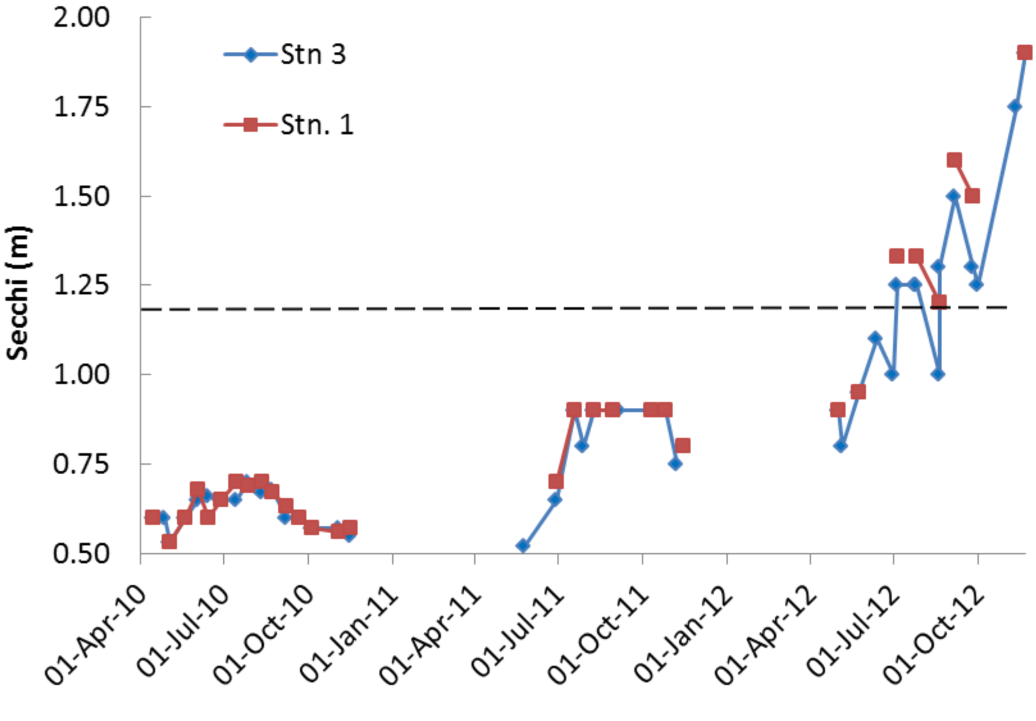

Figure 10. Secchi disk transparency in 2010, 2011 and 2012 at Stations 1 and 3. (The barred line indicates the federal guideline of 1.20 m)

In comparison, Secchi readings taken during the MOE studies in 1995 and 1996 were all higher (Figure 11), indicating a far better transparency and water quality. The summer averages of 3.1 m (1995, n= 12) and 1.8 m (1996, n= 8) indicate mesotrophic and eutrophic conditions (Table 2).

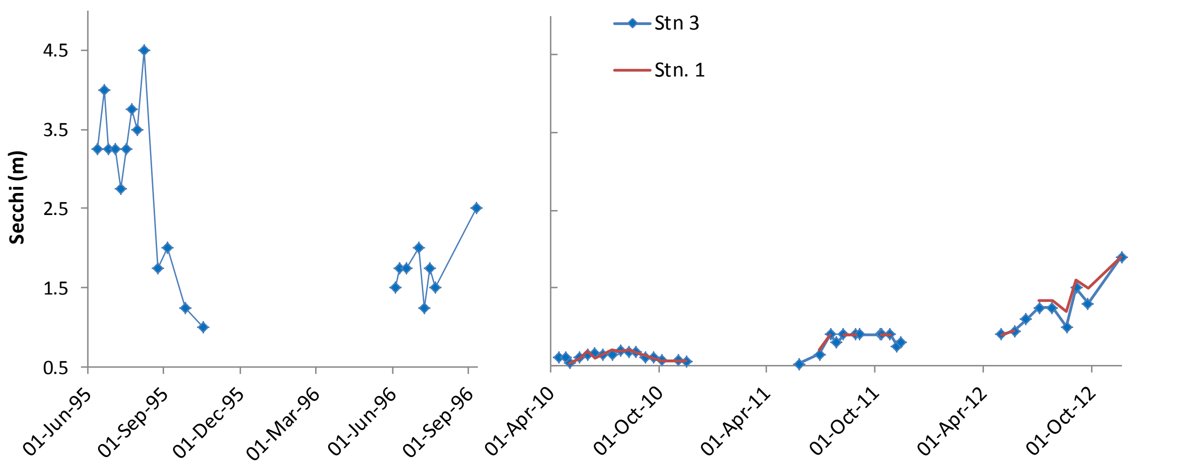

Figure 11. Comparison of Secchi disk transparencies in 1995-96 with 2010-2012

4.3 Water turbidity measured as total suspended solids (TSS)

As an additional measure of turbidity besides Secchi transparency, total suspended solids (TSS) concentration was determined in 2012. TSS includes all particles suspended in water that will not pass through a filter (pore size 0.47 µm).

In Desbarats Lake TSS fluctuated between 1 and 5 mg/L at the main open water Station 3 in 2012 (Figure 12). It was highest in the spring at 5 mg/L, which is similar to a high spring measurement in 2010 (27 Apr 2010, 6 mg/L, measured by MOE, Appendix B). High turbidity in the spring can be attributed to snow melt when high volumes of runoff water flushes sediment particles and other debris into the inlet creeks and the lake itself. During the remaining open water season in 2012, TSS ranged from 1.5 – 3.5 mg/L without any apparent trend, indicating relatively clear water.

For comparison, in the open water of several Algoma lakes TSS ranged from 0.9 to 1.8 mg/L (27 Apr 2010 in Caribou Lake and 22 Aug 2012 in four Day Lakes). It is often higher in creeks and rivers and was 4.4 and 7.1 mg/L in Pickerel Creek and Bolton River of Bright Lake (2 May 2010), but far higher in Desbarats Lake's inflow stations and upstream creeks (Section 0).

TSS and Secchi did not always follow the same trend in Desbarats Lake (Figure 12). Discrepancies are likely due to algal turbidity that is incorporated in the Secchi measurements and different effects of inorganic particles on these measurements. Spring turbidity should be largely affected by inorganic particles, while fall turbidity may be affected by the *Aphanizomenon* bloom, which occurs at high water clarity despite high particle concentration (Section 4.5).

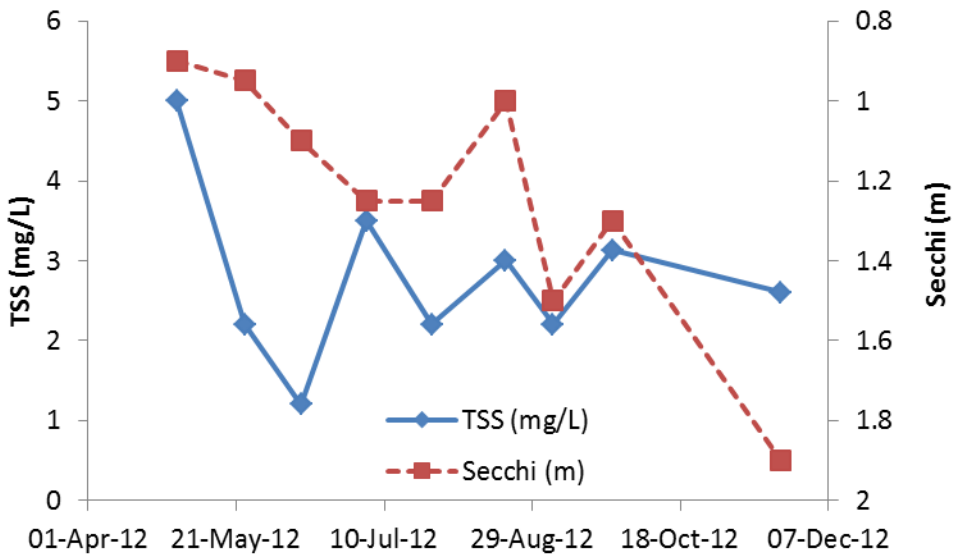

Figure 12. Comparison of total suspended solids (TSS) with Secchi disk transparencies

Secchi is plotted on a reversed axis (right) so that potential trends are more comparable with TSS.

4.4 Phytoplankton pigment: Chlorophyll *a*

The green algal pigment chlorophyll *a* is often used to indicate phytoplankton biomass. Chlorophyll concentration was quite variable as often found in oligomictic lakes, but levels were always low and certainly below bloom concentrations (below 20 µg/L) in 2010 and 2011. The average was 4.8 (Stn. 3) and 6.4 (Stn. 1) µg/L at the deep and the shallow station in 2010 indicating mesotrophy, and a low 1.3 and 3.1 µg/L in 2011, indicating oligotrophy.

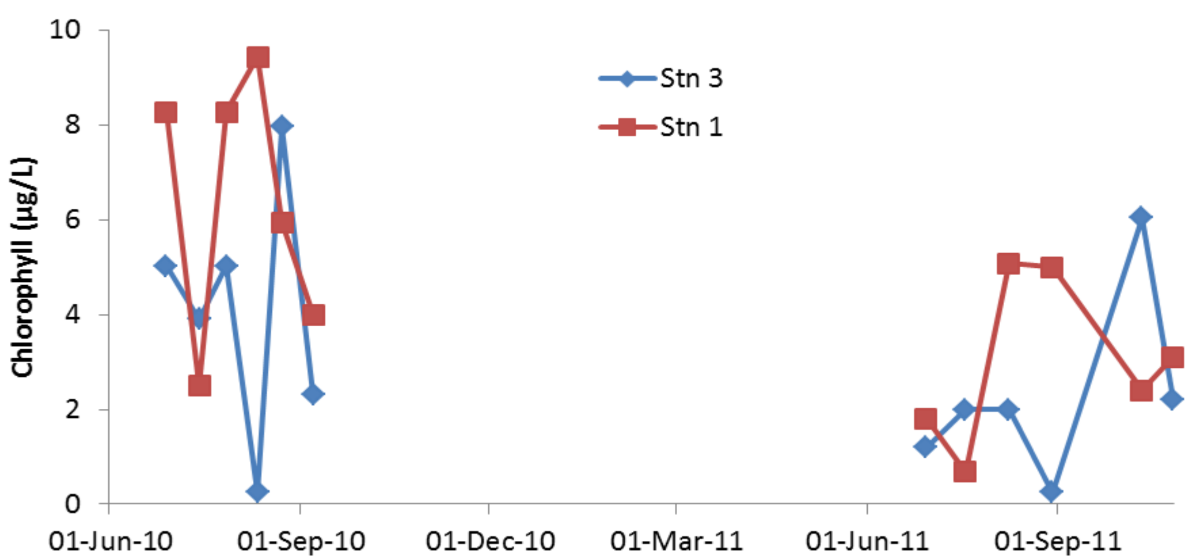

Figure 13. Chlorophyll concentration in summer 2010 and 2011

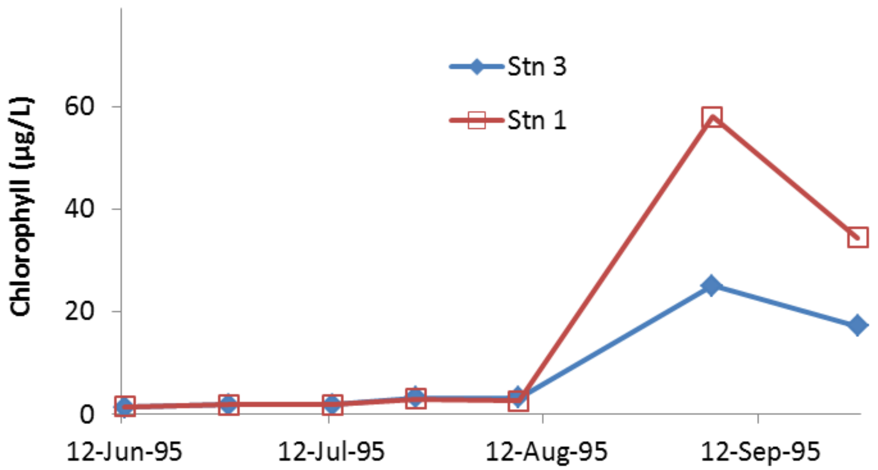

Figure 14. Chlorophyll concentration in summer 1995 *(note the large scale)*

In 1995 chlorophyll that was analyzed by MOE labs, averaged to 2.1 µg/L in 12 Jun - 8 Aug (n=5, Figure 14). It drastically increased to 58 µg/L at Stn 1 and 25 µg/L at Stn 3 on 5 Sep and dropped to 34.4 and 17.2 µg/L on 26 Sep indicating a fall bloom that was probably cyanobacteria. Further sampling in the spring 1996 showed again very low chlorophyll (1.2 µg/L, 27 May-19 Jun, both stations).

Chlorophyll concentration was usually higher at Station 1 compared to Station 3. This could indicate that blooms are fuelled from the inflow that occurs mostly at the north-western end close to Station 1. But it also could just indicate dilution where the larger depth of Stn. 3 distributes cyanobacteria and algae throughout the whole water column.

Low chlorophyll concentration in recent years (2010 and 2011) and visual inspection of the lake water (Figure 9) indicates that the low Secchi transparency is not necessarily due to algae in Desbarats Lake. Its water almost appeared to be a thick organic, possibly bacteria-rich, liquid. Chlorophyll concentrations are probably accurate, even though they can be underestimated, because the pigment is easily destroyed during handling and sampling. Because of these low chlorophyll results and the potential problems and appreciable costs associated with its analysis, chlorophyll was discontinued in 2012.

4.5 Cyanobacteria

The main reason for this study and this report is the occasional occurrence of cyanobacterial blooms since 1994 (Table 4). In all blooms with identified phytoplankton (since 2007) the key documented species was the filamentous cyanobacterium *Aphanizomenon flos-aquae*.

Aphanizomenon consists of bright green filamentous (hair-like) cells that can form dense accumulations. In many lakes (such as Desbarats) these cells form colonies that look like grass clippings. The colonial form of *Aphanizomenon* may be a result of an association with a large zooplankton, such as cladocera (e.g., Daphnia), which assists *Aphanizomenon* by eating competing algae and clearing the water (Lynch and Shapiro 1981). In turn, Aphanizomenon supports Daphnia by providing visual shields, which allows Daphnia to avoid predators. This interaction may explain the observed clearing up at the beginning of a bloom in Desbarats Lake with increased transparency (Peter Pollard).

In lakes with colony-forming *Aphanizomenon* there was less chlorophyll compared to other lakes with similar phosphorus content (Ganf 1983; Osgood 1988). When the colony-forming *Aphanizomenon* was replaced by other algae, the overall amount of algae (and chlorophyll concentration) sometimes increased, even when the amount of phosphorus decreased (Osgood 1988). This phenomenon may explain the low chlorophyll concentration in Desbarats Lake compared to the high TP concentration even during blooms.

Aphanizomenon blooms and internal P loading were sometimes observed simultaneously and it has been argued that resting cells rise from the lake bottom into the water and bring phosphorus from the lake sediments (Osgood 1988). It is not clear, whether redox-dependent internal load or rising *Aphanizomenon* are most important in specific lakes (Barbiero and Kann 1994).

Table 4. Cyanobacteria blooms and toxicity

Year	Date	Bloom	*Aphanizomenon (A. flos-aquae).*	Microcystin LR or LA (µg/L)	Anatoxin-A
1994	Fall to end of Nov	x			
1995	05 Sep	x			
2007	19-Aug	x	x	0.25	0.10
2008	20-Aug			<nd	
	25-Sep	x	x	0.25	
2009	09-Sep	x	x	0.50	0.20
	25-Sep		x		
2010	14-Jul	none	x	<nd	
2011	14-Aug	x	x		
	17-Aug	x	x	1.67	
2012	15-Aug – 15 Sep	x			
	09-Nov	x	------ Sent to MOE, but not determined -----------		

Before 2010, observations were compiled from previous reports (Verdome 2010) and MOE Memos (Appendix C); fall blooms lasted until ice cover (based on observations by lake shore residents)
nd, measured, but not detectable

In Desbarats Lake, cyanobacterial blooms were documented since 1994 (Table 4). Starting 2007, MOE algal identification and toxicity testing were conducted occasionally (Appendix C). On Sep 9 2009 was a large abundance and on 14 July 2010 was a small abundance of the filamentous cyanobacterium *Aphanizomenon flos-aquae* identified. Toxicity was only tested with the Elisa test and not detected, but the specific neurotoxins of *A. flos-aquae* would not be identified with this test. The spring sample of Apr 27 2010, did not reveal any cyanobacteria or other harmful organisms, as is usual in the spring. However, samples collected on 17 Aug 2011 that included *A. flos-aquae* cells tested positive for microcystin so that Desbarats Lake was posted to be closed for recreational activity and any contact with its water was to be avoided. There were two bloom periods in 2012, one in late summer and one in the fall (Table 4). Although collected samples were not identified by any lab, past documentation, photos, and the increased clarity just before and during the bloom indicate that this blooms also consisted of *Aphanizomenon* (Figure 15).

Many blooms were photographically documented (Title photos, Figure 15, and Verdone 2010).

Figure 15. Bloom on the east end of Desbarats Lake (23 Aug 2007, top and 9 Nov 2012, bottom, *Photo by Peter Pollard*)

4.6 Nutrient concentration

The nutrients that increase algal growth and biomass are typically phosphorus and nitrogen. Most temperate lakes are P limited, but previous nutrient data revealed that Desbarats Lake water has uncharacteristically high phosphorus concentration so that sampling effort was placed on both nutrients and their fractions.

The different compounds of nutrients were analysed to determine (a) their possible sources and (b) their impact on nuisance algal blooms. The most important trends are discussed and presented in this section.

The soluble reactive fraction (SRP) that indicates inorganic and readily available phosphate was determined once by MOE on 27 Apr 2011 and was high (15 µg/L) which indicates that Desbarats water was not P limited in the spring 2011 and could sustain a large amount of phytoplankton.

4.6.1 Total Phosphorus

With respect to phosphorus, Desbarats Lake can be classified as eutrophic in 2010 and 2011, because the average TP summer concentrations (1 and 3 m depth samples) of both stations were above 30 µg/L (Table 2, Table 5).

Table 5. TP concentration averages at stations 1 and 3 for different depths

Season	Year	Stn 1	Stn 3			Outflow**
		0-3 m	0-3 m	7 m	9 m	1 m
Spring	1996	24*	24*			
	2009		39			
	2010	43	39			39
	2011		38			
	2012		29			28
Summer	1995	22*	19*			
	2010	35	36	38	43	35
	2011	34	32	34	43	28
	2012	na	24	25	29	24
Fall	1995	31*	26*			
	2010	44	45	44	47	46
	2011	29	30	28	30	28
	2012	na	17	16	18	15
Winter	2011		41	38	67	
	2012		20	24	28	

*1995 and 1996 samples by MOE are composites from the surface to up to 10 m depth.
**TP averages close to the outflow are presented for comparison and discussed in Section 0

TP was lower in the summer of 2012, 24 µg/L on average, indicating mesotrophic conditions. In 2012 all individual values were below 30 µg/L except for one sampling date, 05-Sep-12, when a high 38 µg/L was measured throughout the water column (Figure 16). This elevated concentration coincided with the partial destruction of a beaver dam 500 m above the lake (Section 0). As there was a rain storm on 03-Sep after a prolonged dry period it is unknown whether the dam destruction was produced by natural causes or by human activity. Trend analysis reveals that there is a decreasing trend of TP concentration since the sampling began in the spring 2010.

In all years 2010-2012 the provincial water quality objective for lake water of 20 µg/L summer average mixed surface layer TP (Ministry of Environment 1994) was exceeded.

Different from the recent years, mixed layer TP was below 20 µg/L in 1995 between 12-Jun to 8-Aug (composite depth 6-11 m). But starting 28 Aug through the remainder of the summer and fall, TP were drastically elevated (Figure 17, composite depth 2.5-5 m) and were still above 20 µg/L in the following spring. These high nutrient concentrations may have led to the *Aphanizomenon* bloom, low Secchi transparency and high chlorophyll concentrations in September 1995 (Table 4, Figure 11, and Figure 14). (It is not clear whether the different depth of the composite samples influenced the TP concentration before and after mid-Aug 1995, so that higher TP concentrations were caused by higher depth samples. However, this is unlikely and high surficial TP concentrations were not found in the 2010-2012 monitoring effort as discussed in Section 4.6.1.)

Higher fall compared to summer TP concentrations can indicate internal loading from bottom sediments that increases during warmer periods in the late summer. In 1995 and 2010 average fall concentration were elevated compared to summer concentration, but in 2011 and 2012 they were not (Figure 16, Figure 17, and Table 5). We conclude that seasonal TP changes are consistent with sediment P release in previous years, but not in the recent years 2011 and 2012.

TP profiles including deep water samples were taken throughout 2010-2012 at the main deep Station 3, to look for any indication of P release from the bottom sediments. In an oligomictic lake like Desbarats Lake, the possibility of sampling during a stratified period that would show these conditions is slim, but in general, summer TP averages were higher at 7 and 9 m compared to 1 and 3 m samples (Table 5). Occasionally, DO profiles indicated bottom hypoxia (Figure 7, Figure 8) but stratification was probably transient. For example, in the summer of 2010, higher TP concentrations coincided with only marginally smaller DO concentrations in the lower samples at Station 3 (Figure 18). We conclude that summer TP depth profiles provide (only) a weak indication of sediment P release in Desbarats Lake.

Winter profiles under ice revealed that TP increased with depth in both years when profiles were taken but were only half in 2012 compared to 2011 and reflected the trend in summer and fall TP (Table 5). DO concentrations were relatively high (Figure 7), so that we conclude that winter profiles do not provide any strong evidence of sediment P release.

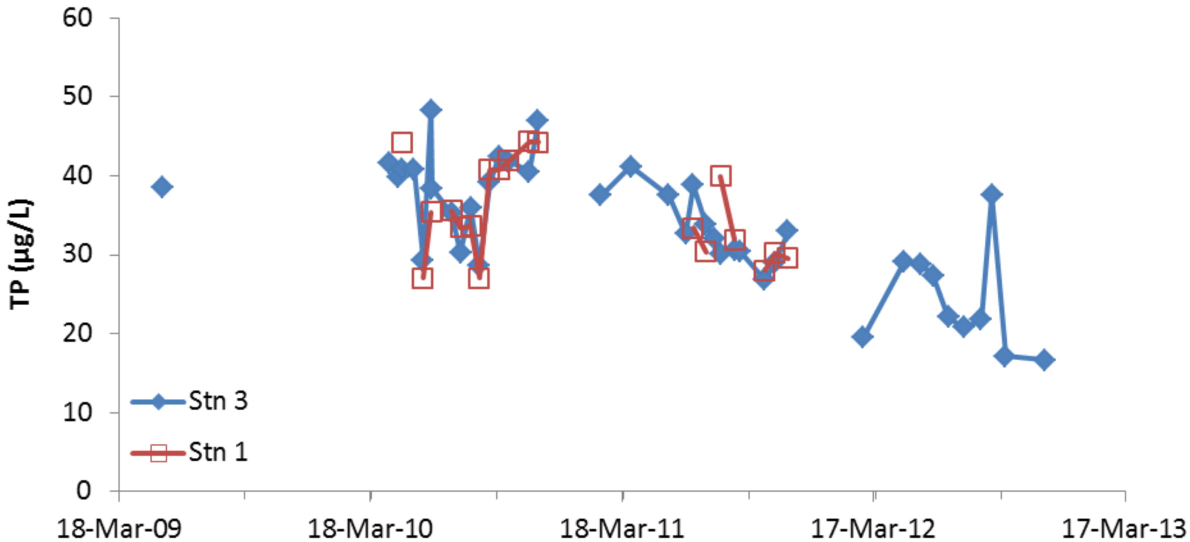

Figure 16. Lake TP concentration in the mixed surface layer (average of 1 and 3 m samples) at Stn 1 and Stn 3, 2009-2012.

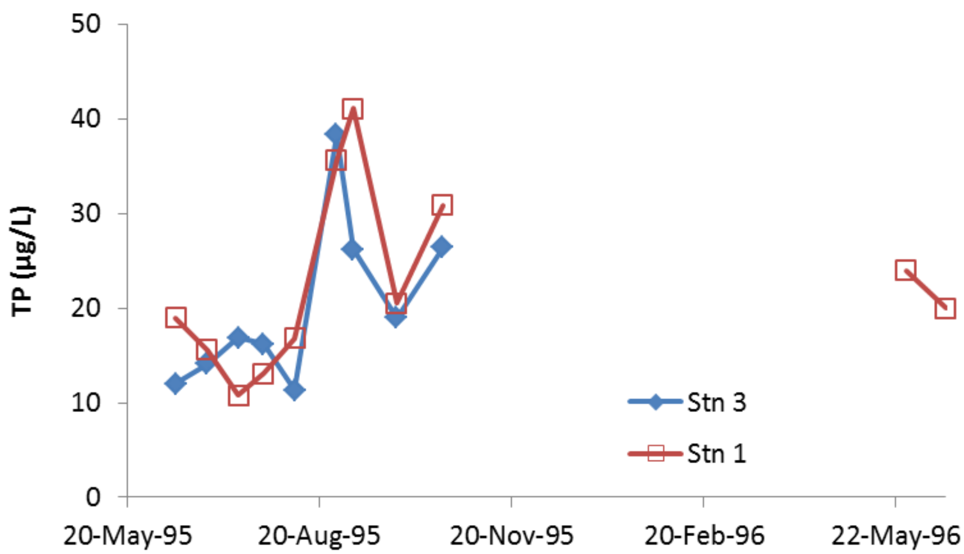

Figure 17. Lake TP concentration in the mixed surface layer (composite down to 2.5 to 10 m, Stn 1 and Stn 3), 1995 - 1996

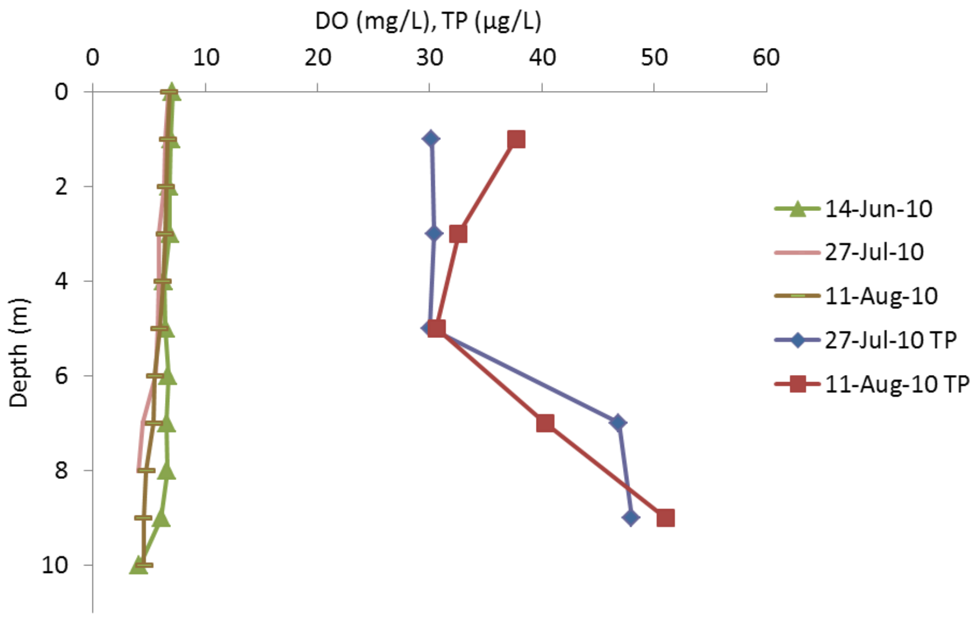

Figure 18. Selected DO and TP profiles for station 3 in 2010.

4.6.2 Nitrogen compounds: nitrate and nitrite, total N

Besides total P (TP), N-fractions of nitrate-nitrite, ammonia, and total Kjeldahl were determined so that total N (TN) could be computed (sum of TK-N and nitrate-nitrite). Inorganic N compounds (nitrate-nitrite and ammonia concentrations) are especially important, because of their inverse relationship with the occurrence of cyanobacterial blooms (Nürnberg 2007b). These compounds can be depleted to below 50 µg/L levels when bluegreens proliferate. Because several cyanobacteria species, including *Aphanizomenon flos-aquae*, have the ability of fixing nitrogen that they need for their growth, they can outcompete other phytoplankton under these conditions.

Total nitrogen (sum of total Kjeldahl and nitrate/nitrite fractions), was representative of mesotrophic conditions in 2010 and 2011, and of oligotrophic conditions in 2012 (Table 2, Table 6, and Figure 19). No inorganic N compounds were determined in the MOE sampling effort in 1995 and 1996 and TN could not be computed. However, its largest component, TKN, was highest in 1995 (Figure 20) and gradually declined in 2010-2012 (Figure 19).

The readily biologically available inorganic fractions, nitrate and nitrite (abbreviated as NO_3) was relatively high throughout 2010 and early summer 2011 and 2012, but drastically declined in August 2011 to below 30 µg/L (Figure 19, Table 6). Summer and fall concentration were also low in 2012. These low concentrations coincided with *Aphanizomenon* blooms (Table 4) as observed before in south Ontario reservoirs (Nürnberg 2007b). The inverse relationship can be explained by the ability of *Aphanizomenon flos-aquae* of fixing nitrogen that it needs for its growth and therefore it can out-compete other phytoplankton at low nitrate concentrations.

Ammonia (abbreviated as NH_4) is the reduced (in an oxygen-free atmosphere) form of inorganic nitrogen and is also highly available to phytoplankton. It can indicate hypoxic conditions, besides contamination from external sources, especially fertilizers and sewage, and often occurs at the same time when the sediment surfaces become anoxic. Ammonia concentration varied between 7 and 81 µg/L and was a low 30 µg/L on average.

Table 6. Nitrogen compounds (µg/L)

	Station 1				Station 3			
Period	NO_3	NH_4	TKN	TN	NO_3	NH_4	TKN	TN
Summer 2010	116	29	357	473	115	27	349	464
Summer 2011	67	41	346	413	64	35	331	395
Summer 2012	na	na	na	na	15	36	285	301
Fall 2010	142	20	427	569	135	18	406	541
Fall 2011	30	31	267	297	27	29	277	304
Fall 2012	na	na	na	na	2	41	253	255

na, not available

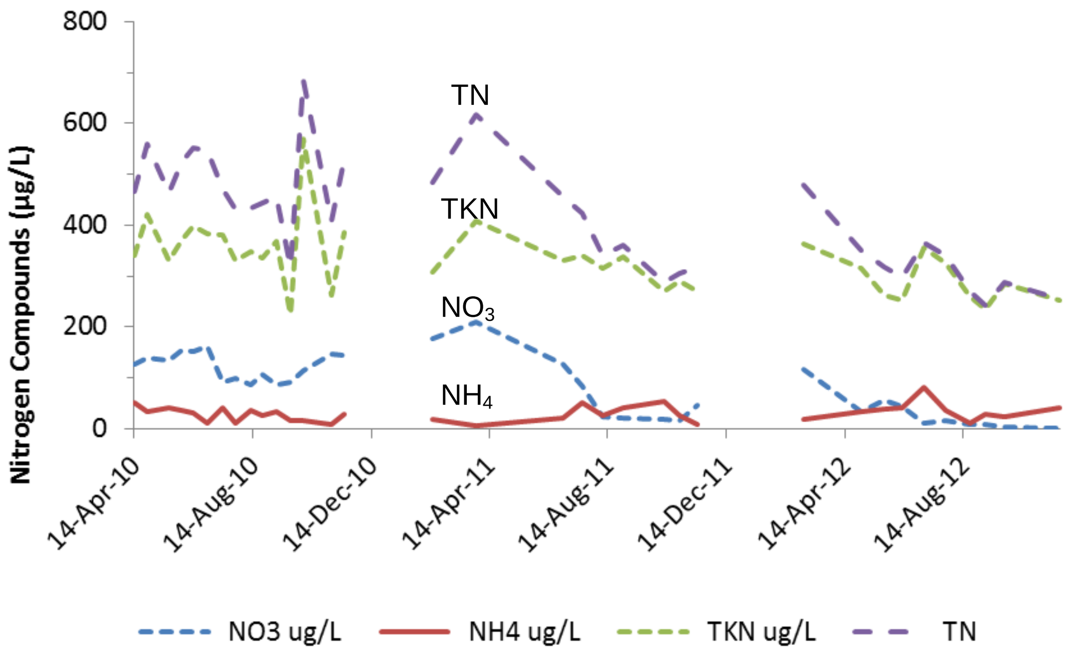

Figure 19. Nitrogen compounds at Station 3, 2010-2012 (mostly in the 1 m water layer)

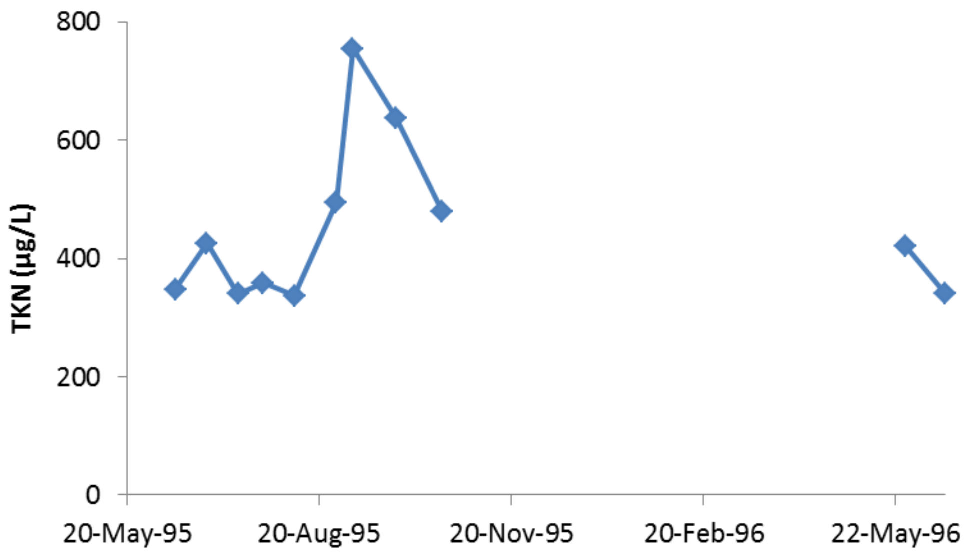

Figure 20. Total Kjeldahl nitrogen at four stations (composite down to 2.5 to 10 m), 1995 - 1996

4.7 General background chemistry

Most of the chemical characteristics (Table 7) are typical for tea-stained brown water lakes, rich in organic (humic and fulvic) acids. Such lakes have comparably higher colour values and DOC concentration, because naturally occurring organic acids from wetlands and swamps stain the water of such lakes. They usually have higher TP concentration, but lower phytoplankton biomass because of light limitation (Nürnberg and Shaw 1998).

Individual colour and DOC measurements are close to the median for a data set of more than 100 coloured lakes from North America and Europe (Nürnberg and Shaw 1998). High colour (58 true colour units, 27 Apr 2010, MOE) and dissolved organic carbon (DOC for eight 1 m Station 3 samples in 2012, range: 4.7 – 5.3 mg/L, average: 5 mg/L) support that Desbarats Lake is a tea-stained lake. However, the water's appearance was murky instead of clear brown as is typical for a brown-water lake, despite its many wetland inflows. TSS is high compared to other regional lakes, especially in the spring (Section 4.3). Also, its sediment characteristics are not consistent with humic acid rich water (Section 4.8).

Dissolved and total organic carbon concentrations were not distinguishable and did not fluctuate much (6 samples in 2012 ranged from 4.6 to 5.3 mg/L and averaged 4.9 mg/L for both) so most of organic carbon was dissolved and not bacterial or algal plankton. Relatively high alkalinity and circum-neutral pH indicate that the organic acids do not render Desbarats Lake acidic. Calcium concentration is relatively high as well (Table 7) so that there is no sign for a recent calcium decline to below 2.5 mg/L at which the zooplankton community was affected in Muskoka Lakes (declining *Daphnia* population, Jeziorski et al. 2008). In fact, Desbarats Lake has been supporting a thriving mussel population around its perimeter indicating sufficient calcium (personnel communication from lake shore resident).

Chloride, which indicates anthropogenic sources such as road de-icing material, was low at 1.1 mg/L (Table 7) as is typical for a little developed watershed.

Table 7. General chemistry Stations 1 and 3, 2010

	Calcium	Chloride	Sulfate	K	Mg	Na	Alkalinity*	Conductivity	Turbidity	pH	Colour
	(mg/L)							(µS)	(NTU)		(TCU)
14-Apr-10											
Stn 1	4.4	1.1	4.6	1.3	1.5	1.6	na	na	14.3	na	na
Stn 3	4.6	1.1	4.6	1.4	1.5	1.6	12.5	44	20.2	6.9	na
27-Apr-10											
Stn 3	4.8	na	4.7	na	na	na	14.8	46	na	7.4	58.0

*Alkalinity as $CaCO_3$ (pH 4.5)
na, not available

4.8 Bottom sediments and internal P load

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 Nürnberg 2007a, it is especially important to consider this P source in relatively pristine lakes on the Canadian Shield, because 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 redox changes at the sediment-water interface. Anoxia leads to the dissolution of iron hydroxides in the sediments and release of adsorbed P (i.e., P attached to the iron surfaces) to adjacent lake water. Because of Desbarats Lake's enriched trophic state and tea-stained water, P may also be released from organic compounds and poly-phosphates. Whatever the mechanism, P gets released in the highly biologically available form of phosphate (approximately measured as SRP) which becomes quickly incorporated into phytoplankton and bacteria. Because of its timing that coincides with elevated water temperature during summer the effect on the growing season water quality of a lake can be severe.

However, it is not always easy to determine the quantity of the internal load especially in oligomictic lakes and there are many potential problems associated with separating the contribution of internal from external P sources to a lake (Nürnberg 2009).

Evidence from lake TP concentrations is not consistent: While increases in the fall of 1995 and 2010 could be due to internal loading, TP profiles of 2010, 2011 and 2012 only occasionally display increased TP concentration with depth. However, occasional mixing may prevent a strong gradient to establish.

A more direct measure of the potential of internal load is the determination of the releasable P form in the sediments. Therefore, bottom sediment was collected with a device that keeps the layers intact so that distinct sediment depths can be analyzed. The results of two cores from the main Station 3 and Station 1 for two depth intervals are presented in Table 8.

The sediment was dark, almost black and muddy without smell. The sediment was very loose requiring the corer to be lowered gently so as not to disturb it. No woodchips were observed. Chemical characteristics at both collection sites were similar. Organic content (loss on ignition, LOI), which is an indicator for eutrophic conditions and nutrient pollution in unstained waters, was between 8 and 12 %. This low value is not representative of tea-stained lakes, which often have close to 50% LOI (Nürnberg 1988). Sediment TP was less than 0.7 mg/g dry weight. Reductant-soluble P (Fe-P, which is involved in the redox-dependent P release from sedimentary iron hydroxides) was below 0.1 mg/g dry weight in the 0-5 cm sample, and even lower in the deeper sample. Most values are slightly higher at the deep station as expected because of increased accumulation of sediments at the deepest location of lakes (Sediment focussing).

Such low concentration of organic and nutrients were observed in fast flushed reservoirs (Nürnberg unpublished data) and could be a consequence of bottom scouring in this relatively fast flushed lake. The low sediment P concentrations in Desbarats Lake do not indicate a large potential of internal loading. In particular, the size of the reductant-soluble P pool is barely large enough to sustain any sediment P release as internal load. However, these results should be verified with the collection and analysis of more sediment cores.

For comparison, a stratified hardwater lake in southern Ontario (Lake St. George, Oakridges Moraine) with high internal loading had more than 30% organic content, a higher TP content (more than 1.2 mg/g dry weight, TP) and releasable Fe-P (0.19 mg/g dry weight, Nürnberg 1988). The Algoma lake, Bright Lake, which shows sign of internal P load also had higher sediment concentrations of 0.9 mg/g dry weight for TP, and 0.19 mg/g dry weight for releasable Fe-P (Nürnberg and LaZerte 2011b).

Table 8. Sediment characteristics of cores

Station	Moisture	LOI	TP	Fe-P	Calcium	Iron
Depth	(%)		(mg/g dry weight)			
Station 1, 5 m						
0-5 cm	62.3	8.44	0.618	0.049	4.74	23.0
5-10 cm	66.9	8.21	0.592	0.027	6.64	39.5
Station 3, 10 m						
0-5 cm	74.1	13.6	0.677	0.090	5.04	29.3
5-10 cm	73.9	13.4	0.682	0.033	5.25	32.1

4.9 Fisheries

There is no detailed report available by MNR of the Desbarats fisheries. Nonetheless, the MNR website lists at least six fish species in Desbarats Lake and a lake resident describes additional species (Table 9).

At least one fish kill has been observed. On 31 Aug 2011 a number of dead fish were seen along the shores of Desbarats Lake, mostly sucker, minnows, walleye, and yellow perch (Peter Pollard, pers. comm.). It is not clear what caused this fish kill, since DO profiles of 29 Aug 2011 indicate well-oxygenated waters (Figure 7).

Table 9. Fish species in Desbarats Lake

Species	Source
Bluegill	MNR website*
Northern Pike	MNR website*
Rock Bass	MNR website*
Smallmouth Bass	MNR website*
Walleye	MNR website*
Yellow Perch	MNR website*
Sucker	Peter Pollard, pers. comm.

*http://www.web2.mnr.gov.on.ca/fish_online/fishing/fishingExplorer_en.html (accessed 3-Oct 2012)

4.10 Climate, hydrology and water level

Patterns of precipitation and flows affect the water quality of lakes in various ways. As is typical for temperate wetlands, flows and levels are highest in the spring at spring melt and lowest during the summer at a gauge station near Desbarats Lake (Figure 21). This means that most of external pollutant input occurs in the spring and fall and least in the summer, when any direct runoff into the lake is minimized. This is the time period when potential internal nutrient sources are most important, because they would be used by phytoplankton immediately. Variations of patterns between years may contribute to annual variability in water quality. We recommend monitoring flows and water levels specific to Desbarats Lake in the future.

However, there is evidence that beaver activity upstream of Desbarats Lake affects flows and nutrient loads and contributes to the annual and seasonal variability of flows and water quality to Desbarats Lake.

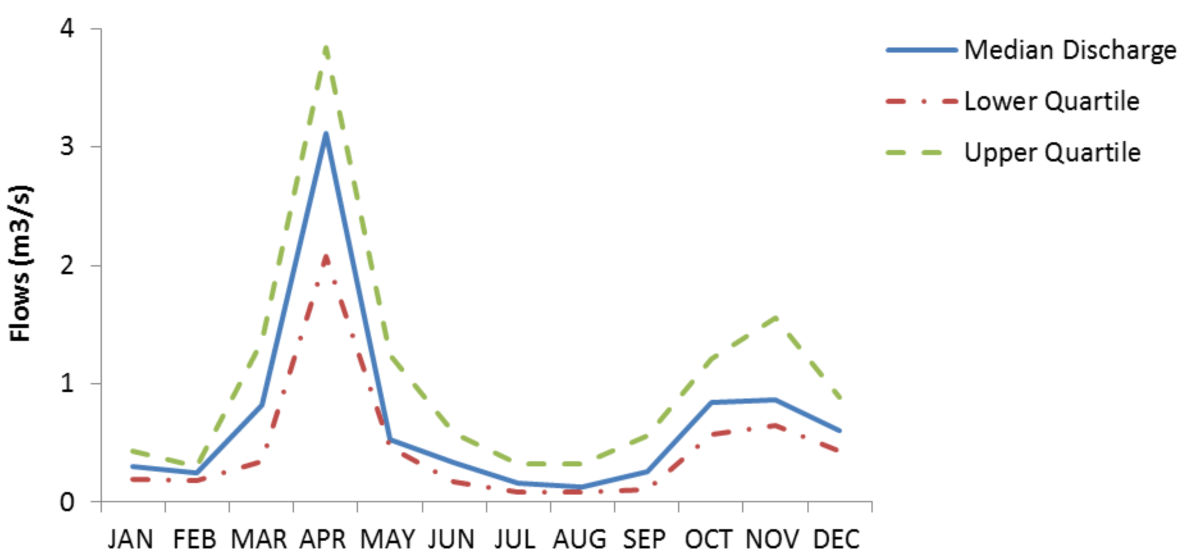

Figure 21. Flow pattern at a gauge station near Desbarats Lake (Big Carp River near Sault Ste. Marie, Station No. 02BF004). Monthly discharge for the period January 1979 - December 2008.

Another climate effect is air temperature that influences lake warming and mixing status. Ice-out was unusually early in Central Ontario in 2010 and 2012, when it happened on 25 March 2010 and 26 March 2012 in Desbarats Lake. It was more typical in 2011, when ice-out happened on 23 April 2011. Early ice-out increases the growing period and thus changes the mixing regime of a lake.

4.11 Water quality of Desbarats Lake – Summary

As noted above and summarized in Table 10, the Desbarats Lake's trophic state varied between indicator variables and between years. Desbarats Lake limnology is not typical for a small Algoma lake, and its uniqueness is investigated here.

Table 10. Trophic states for individual years based on Secchi transparency and chlorophyll concentration (top) and nutrients (bottom)

Year	Secchi (m)		Trophic	Chlorophyll (µg/L)		Trophic
	Stn 1	Stn 3	State	Stn 1	Stn 3	State
1995	3.00	3.04	meso	14.7	7.6	meso
1996	1.84	1.75	eu	n.a.	n.a.	
2010	0.66	0.65	hypereu	6.4	4.8	meso
2011	0.85	0.84	hypereu	3.1	1.3	oligo
2012	1.39	1.22	eu	n.a.	n.a.	
Average	1.55	1.50		8.1	4.6	
2010-12	0.97	0.90	hypereu-eu	4.8	3.1	meso-oligo
1995-96	2.42	2.40	meso-eu	14.7	7.6	meso

	TP (µg/L)		Trophic	TN (µg/L)	Trophic
	Stn 1	Stn 3	State	Stn 3	State
1995	21.6	19.3	meso	n.a.	
1996	n.a.	n.a.		n.a.	
2010	34.2	36.4	eu	464	meso
2011	33.9	32.6	eu	395	meso
2012	n.a.	24.5	meso	301	oligo
Average	29.9	28.2		387	
2010-12	34.1	31.2	eu-meso	387	meso-oligo
1995-96	21.6	19.3	meso	n.a.	

Transparency measured as Secchi disk depth indicated hyper-eutrophic conditions in two of the study years. The nutrient phosphorus indicated eutrophic, the nutrient nitrogen, mesotrophic and chlorophyll oligo-mesotrophic conditions. Secchi transparency was quite low while chlorophyll concentration was also low, which means that transparency was not controlled by algal biomass as confirmed by visual inspection (e.g., Figure 9), TSS concentration (Section 4.3) and chlorophyll concentration (Section 4.4). Further, TP and even SRP concentrations were high when measured in April 2011 (Section 4.6), which means that Desbarats Lake was not P limited.

Most likely algal growth was limited by light, at least in 2010 and early 2011. Interestingly, only when transparency increased, blooms of the cyanobacterium *Aphanizomenon flos-aquae* started, which is consistent with experience from other lakes with *Aphanizomenon* (Section 4.5).

Of all measured physical and chemical variables, the most obvious coincidence with blooms (Table 4) was the lack of nitrite-nitrate (Section 4.6.2). In the 2010 growing season, when there was no bloom, nitrate did not decrease below 86 µg/L, while it declined to below 24 µg/L in late summer and fall 2011 (8 Aug - 26 Oct 2011). The nitrate-poor period lasted even longer in 2012, when it decreased to below 11 µg/L already on 4-Jul and remained that low until the end of the monitoring period on 21-Nov. During both years, *Aphanizomenon* blooms were prolific and in 2012 they extended until ice cover (Figure 15). Such an inverse relationship between nitrate and cyanobacteria blooms can be explained by *Aphanizomenon's* ability of fixing nitrogen from atmospheric nitrogen gas that is unavailable to eukaryotic algae. Therefore, it can proliferate even though concentrations of inorganic N compounds, like nitrate and ammonia, are very low (such as 11 µg/L nitrate in 2011), when eukaryotic algae cannot thrive. This relationship has been noted before in a Southern Ontario reservoir of the Upper Thames River and was used to determine the periods of cyanobacteria blooms in that river (Nürnberg 2007b).

Despite more cyanobacteria blooms in 2011 and 2012, all other water quality indicators (TP, TN and Secchi transparency) have improved since 2010, even though they were still worse than the monitoring results of 1995. There were no severe cyanobacterial blooms in 2010 in Desbarats and other Ontario lakes that often exhibit them, including Bright Lake (Nürnberg and LaZerte 2011b) and ponds in Southern Ontario (Gertrud Nürnberg, unpublished data).

Including the early measurements of 1995, which exhibited blooms, Secchi transparency changed with time from mesotrophic conditions in 1995 via hyper-eutrophic conditions to eutrophic conditions (Table 10). Nutrients and chlorophyll followed the same trend, although the TP concentrations represent mesotrophy in 1995, eutrophy in 2010 and 2011 and mesotrophy again in 2012, while TN and chlorophyll are another classification step lower.

With respect to a time trend there appears to be a drastic Secchi transparency decrease in 1996 and further in 2010. Since then, transparency seems to slowly increase and recuperate to 1996 values (Figure 11). As farming was mostly discontinued in the nineteen eighties (except that cattle have access to some inflow streams) and lake shore development happened only slowly, the occurrences of blooms in the early nineties were unexpected. It appears that the main explanation is the impact of broken beaver dams as described by Peter Pollard (slightly edited):

> "The rupture of beaver dam in 1994 of McCluskie Lake was major. McCluskie lake water levels dropped 10 to 12 feet in a twelve hour period, with this happening in the dry season, with all silt etc. washed into Desbarats Lake. There was also a beaver dam break on a creek coming from Bocage Lake, in spring 1999 or 2000. This beaver dam break was very close to Desbarats Lake. This break washed out a section of road about 16+ feet wide more than 3+ feet deep, for approximately 200 feet long (still obvious now). Some of this soil may have settled in the creek before going into Desbarats Lake, but most would have gone into the Lake." - "There were also a beaver dam ruptures on McCluskie Lake in the spring of 1991, and on Reserve Lake in spring of 1994."

Beaver dams can retain nutrients from upstream sources and the beavers in the pond. When a major break occurs, the accumulated nutrient and organic material becomes released and moves downstream. Such occurrences have been observed before. For example, abandoned beaver ponds in remote lakes in New England had a stronger influence on downstream water quality than actively maintained ponds (Błędzki et al. 2011). Abandoned ponds led to higher downstream turbidity during a dam failure, with increased sediments, nutrients and water temperature.

Further, a meta-analysis of about 1800 East American lakes proved that in regions with low amount of agriculture, local wetlands were associated with increased lake TP (Fergus et al. 2011). Beavers increased P loading, especially the biologically available form of SRP, downstream of wetlands on the Canadian Shield (Devito and Dillon 1993; Paterson et al. 2006) and New York State wetlands (Klotz 1998).

To investigate whether beaver dams (Figure 22) could in fact contribute to Lake Desbarats' high phosphorus content upstream sites in the four main inflow streams were monitored in the last two study years, as much as funds allowed.

Figure 22. Beaver dam on one of the upstream inlets *(Photo by Hugh Coverley)*

5 Upstream and outflow water quality

To determine the origin of the water quality problems, locations in Desbarats Lake close to three inlets (IN1, IN2, and IN3, Figure 1) were monitored routinely. In addition, sites farther upstream of the three inlets and a fourth inlet (IN4, Figure 1) were sampled on several occasions in 2012 to further determine the sources of nutrients and turbidity. There was no easy access to the headwater lakes McCluskie for IN1, Reserve Lake, Tarbutt Township, for IN2 and Bog Lake (2.7 m maximum depth, 0.26 km^2) for IN3, therefore no samples were taken at these lakes. However, a MNR map of Bog Lake is available (Appendix D).

The relative contribution of flow by the individual streams is not exactly known. However, crude estimates by P. Pollard based on area (Appendix E) and his one-time inspection suggests that the four inlets probably contribute a similar proportion to the total water load (Table 11). On the other hand, it has been observed by year-round resident Hugh Coverley, that Inlets 1, 2 & 3 have upstream lakes that provide flow year-round (with greatly reduced flow during the summer months) while water flow from Inlet 4 nearly dries up during prolonged dry periods (Table 11). At any rate, the importance of Inflow 4 respective Desbarats Lake's water budget does not affect the conclusions in this report.

The collected water quality results provide spot checks and indicate where to put future monitoring efforts. They cannot serve to determine annual external TP loading (from the creeks) or export (from the outflow) because: (1) the TP concentration data are not frequent enough and (2) there is no hydrologic information available. For example, it would be necessary to know the flow rates for the individual sampling occasions to be able to calculate a load for that occasion.

The measurement of outflow TP concentrations serves two aims: (1) They are supposed to be similar to those in the lake, especially at Station 3, based on the limnological assumption that outflow and lake concentrations are comparable. In this way, these samples offer a check of the lake concentration. (2) The water quality of a lake outflow affects the downstream water quality. As Desbarats River (Walker River) flows through a Provincially Significant Wetland into the North Channel of Lake Huron its water quality is important.

Table 11. Proportioning of flows from the different inflows (from site visits on 23 Nov 2012, by P. Pollard, pers. comm. and Appendix E; and by H. Coverley, pers. comm in parentheses)

Stream	Flow estimate (%)
1	20 (17)
2	28 (26)
3	22 (22)
4-1	5 (7)
4-2	20 (9)
Others	5 (15)
Total	100

5.1 Water quality close to the inflows and the outlet in Desbarats Lake

TP concentrations at the various inflow stations are much more variable than in the deeper lake stations (Figure 23), reflecting any disturbances in the upstream creeks. IN1 has the highest concentration on most sampling occasions; values for IN2 are lower and for IN3 are often lower still (Table 12).

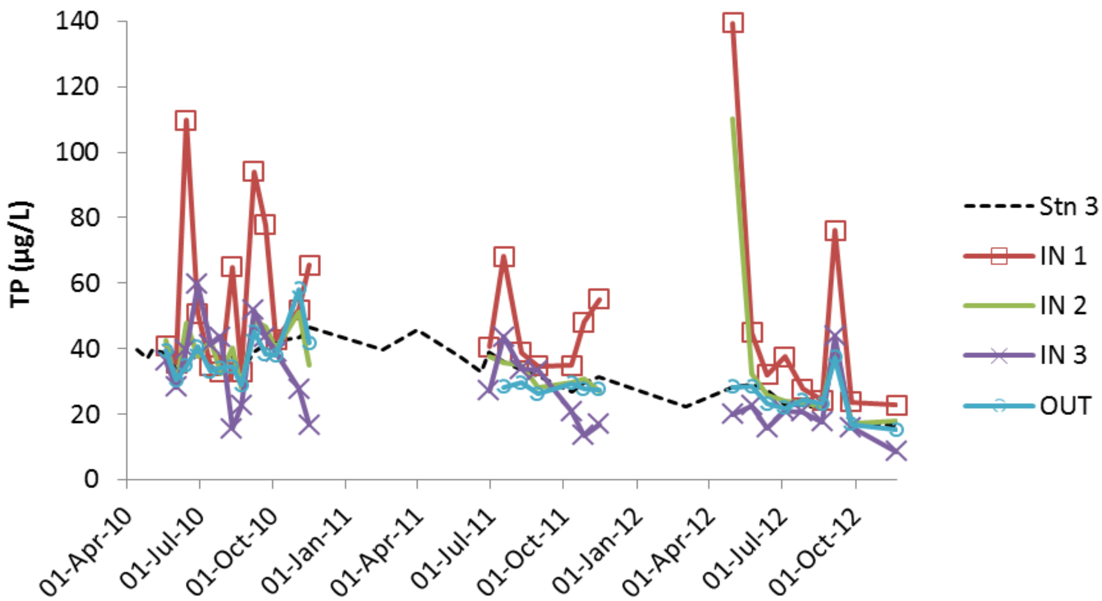

Figure 23. Lake TP concentration at the inflow and outflow stations. Station 3 mixed surface layer values are indicated for comparison (broken line)

Table 12. Annual TP concentration averages (µg/L) at the inflow and outflow stations in Desbarats Lake.

Season	Year	IN1	IN2	IN3	Out
Spring	2010	41	42	36	39
	2012	92	71	21	28
Summer	2010	59	39	38	35
	2011	46	34	34	28
	2012	37	26	22	24
Fall	2010	53	42	28	46
	2011	46	29	17	28
	2012	23	18	9	15
Average		**50**	**38**	**26**	**31**

Some of the extreme values can be explained by natural processes, like snowmelts and spring runoff, but others are explained by human interference with the creek bed or upstream beaver dams. Some examples are listed below:

- In1 14-Jun-10: Extreme N and P values probably due to sediment particles or other contamination. “Sample collected was very 'murky', filtered 2X to get rid of large particulates”, *Lindsey Palumbo*.
- In3 14-Jul-10: “Someone pulls the beaver dam north of the inlet … and as a result, lots of silt and sediment is forced into the lake”, *lake side resident*.
- In1 and In2, 30-Apr-12: High TP and TSS concentrations, possibly due to snow melt disturbance.
- In1 05-Sep-12: High IN1 TP and TSS concentrations: This elevated concentration coincided with the collapse of a beaver dam 0.5 km above the lake, *lake side resident*.
- In 1: Cattle have access to the stream for 6 months each year, at least since 2010, *lake side resident.*

Despite the variability, there is a strong and monotonic decreasing trend in all inflow’s average summer and fall TP concentration (Table 12).

Total suspended solids can explain some of the elevated TP concentrations. TTS was determined in 2012 at the lake stations and usually ranged from 1 – 6 mg/L. Higher values occurred mostly at the inflow basin of IN1 and happened during the spring melt on 30 April, and during the beaver dam destruction on 5 Sep and some other times. At high TSS, TP concentrations were also elevated reflecting the P-rich particles. It can be concluded that these TP concentration are affected by mud particles and are not typical for the open water.

Table 13. Total suspended solid (TSS) concentration elevated above 5 mg/L

Station	Date	TSS (mg/L)	TP (µg/L)
IN 1	30-Apr-12	178.0	140
IN 2	30-Apr-12	54.0	110
IN 1	24-May-12	35.8	45
IN 1	26-Jul-12	7.3	28
IN 1	05-Sep-12	71.0	76
IN 3	05-Sep-12	6.0	44
IN 1	25-Sep-12	5.7	24

Outflow TP concentrations are similar to those at Station 3 (Figure 23, Table 12) and corroborate the limnological assumption that outflow and lake concentrations are comparable. They also exhibit a decreasing trend indicating that the negative effects on downstream wetlands are lessening.

5.2 Water quality of the creeks upstream of Desbarats Lake

To more exactly determine the potential sources of water quality problems in Desbarats Lake, five field excursions were conducted to determine temperature and DO concentration and sample water for nutrients and dissolved organic carbon in various sections of the four inflow streams. While these spot checks cannot yield long-term conditions, the following questions were addressed.

1. Are there any obvious nutrient sources (“hotspots”) upstream of Desbarats Lake?
2. If such hotspots exist, in which of the four inflow creeks are they located?
3. Is it possible to determine whether the source is natural or anthropogenic?
4. How are beaver ponds and wetlands influencing nutrients and water quality problems in Desbarats Lake.

At all investigated locations, temperature and DO values were as can be expected for the season and time of day. Only at location STR10 hypoxia was found once (Section 5.2.1). The nutrient and dissolved organic carbon results are presented in Table 14 and discussed separately for each stream.

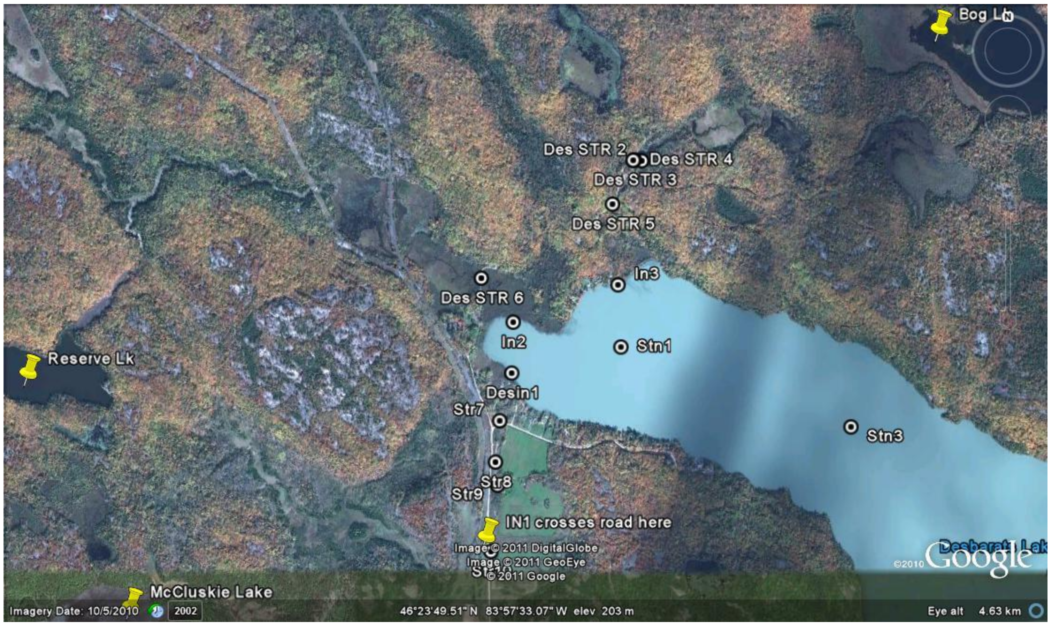

Figure 24. Upstream sites at inlet IN1: STR7 to STR10; IN2: STR6, and IN3:STR2-STR5

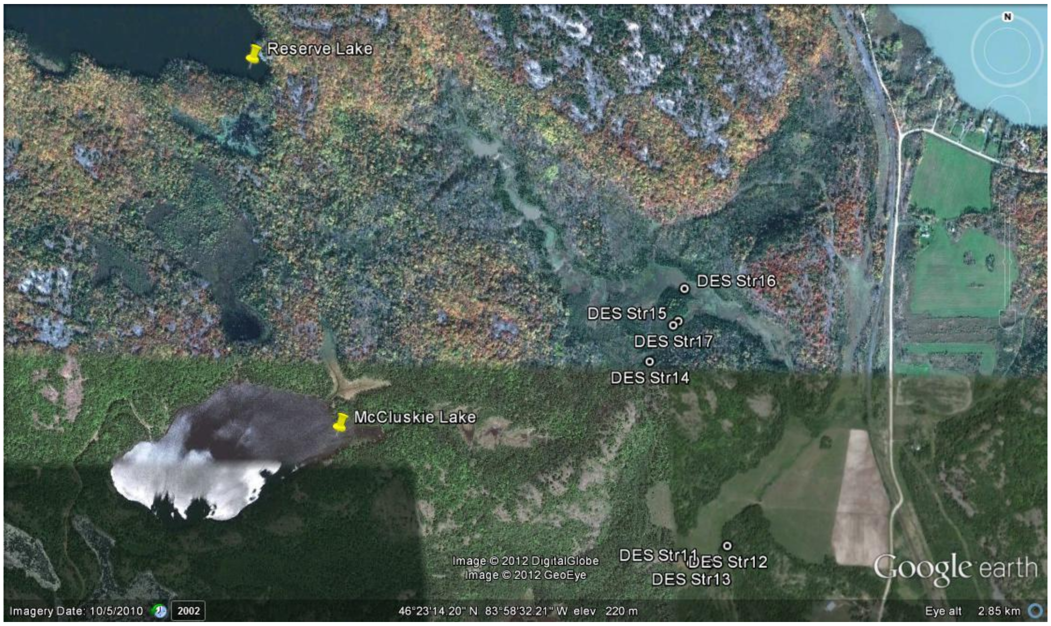

Figure 25. Upstream sites at inlet IN1: STR11 to STR15; IN2: STR16 to STR17

Table 14. Upstream creek TP concentration

Station	Date	DOC (mg/L)	TP (µg/)	NH_4 (µg/)	NO_3 (µg/)	TKN (µg/)	TN (µg/)	Notes
IN1								
STR7	31-Aug-11		66	54	13	564	577	Most downstream, close to inflow 1
STR8	31-Aug-11		31	36	11	388	399	Beaver ponds/dams upstream from Puddingstone Road
STR9	31-Aug-11		47	56	8	507	515	Culvert at residence on Puddingstone Road
STR10	31-Aug-11		31					Just Upstream of STR9 (Hypoxic DO 3 mg/L)
STR13	16-Apr-12	8.6	45					Upstream of DAM 1
	23-Oct-12	13.1	24					
STR12	16-Apr-12	8.1	75					Downstream of DAM 1
STR14	16-Apr-12	5.9	26					STR 14 was taken upstream of DAM 2 from McCluskie Lake
	23-Oct-12	8.4	21					
STR15	16-Apr-12	5.7	33					SRT 15 was taken downstream of DAM 2
IN2								
STR6-2	23-Oct-12	9.8	22					Upstream of a series of Beaver dams (700 m above 6-1)
STR6-1	08-Aug-11		66	16	11	661	672	Downstream of a series of beaver dams with human disturbance
	23-Oct-12	10.6	12					Downstream of a series of beaver dams, no disturbance
STR16	16-Apr-12	6.9	51					Downstream of wetland with beaver ponds
	23-Oct-12	11.6	23					
IN3								
STR2	08-Aug-11		36	49	14	546	560	Upstream of beaver pond/dam
STR3	08-Aug-11		29	23	13	467	480	In beaver pond - stagnant water (signs of algae scum on surface)
STR4	08-Aug-11		25	20	17	448	464	Below beaver dam - flowing water
STR5	08-Aug-11		22	12	45	374	419	At culvert of road - water flows well here in to forested area
IN4								
IN4-1	23-Oct-12	9.5	22					Westerly and easterly branches above newly installed culverts
	21-Nov-12		53					
IN4-2	23-Oct-12	9.7	38					
	21-Nov-12		55					

5.2.1 Inflow Stream IN1

Stream IN1 follows Puddingstone Road going upstream from STR7 that is close to the inflow, to STR10 (Figure 24). Samples of 31 Aug 2011 show a variable pattern of comparably high nutrient concentrations that is probably affected by developmental influences along the road and cattle with access to the creek. The most upstream site, STR10, indicates hypoxic conditions (low DO concentration at 3 mg/L) and has a low flow rate. Such low DO is worrisome because it could mean that there may be hypoxia during for extended periods in the upstream wetlands. During these times release phosphorus can be released from organic particles and sediments and hence add highly available nutrients to the stream and lake. Because of the high nutrient and the low DO concentration further monitoring of these sites is recommended.

Sites STR12 to STR15 (Figure 25) were monitored to determine the influence of beaver ponds and dams on nutrient concentration. There were two dams with locations sampled up-and downstream of each dam. At both dams, TP concentration increased substantially in the one spring sample available, while DOC concentration remained the same (Table 14). Concentration was very high (75 µg/L) below Dam 1 and about half of that below Dam 2. This pattern perhaps indicates spring anoxia under ice and internal load in the beaver pond. Elevated P export out of beaver ponds were observed especially in winter and spring peak snowmelt in Canadian Shield ponds (Devito and Dillon 1993).

5.2.2 Inflow Stream IN2

At a beaver dam on IN2, the downstream site (STR6 = STR6-1, Figure 24) produced less TP concentration than the upstream site (STR6-2), when there was no obvious disturbance on 23 Oct 2012. Downstream TP concentration was substantially increased when human inflicted brushes and branches were distributed throughout the creek on 08 Aug 2011. It can be concluded that human disturbance outweighed natural disturbance at this site in creek IN2.

STR 16 (Figure 25) is downstream of a wetland area with beaver ponds and was sampled twice. As with other results, TP is higher during the spring sample on 16 Apr 2012 and DOC is lower compared to the fall sample on 23 Oct 2012. Such a temporal pattern is typical for an organic acid-rich wetland environment, where higher concentration favour higher DOC content in the fall, but the high runoff volume in the spring coincides with high TP concentrations.

5.2.3 Inflow Stream IN3

The sequence of sampling sites STR2 to STR5 of IN3, starting upstream a beaver pond and following through and downstream, (Figure 24) shows a pattern of decreasing TP and most nitrogen compounds (except for nitrate) collected on 8 Aug 2011. This pattern demonstrates the beneficial impact of an intact beaver pond that can successfully trap and retain nutrients in the summer, although it probably increases TP export in the long-term.

5.2.4 Inflow Stream IN4

The TP concentrations were high, above 50 µg/L on 21 Nov 2012 in both arms of inflow creek IN4. However, TP was quite variable and an earlier sample of 23 Oct 2012 revealed just about half of the amount.

5.3 Upstream water quality - response to the questions

1. Are there any obvious nutrient sources (“hotspots”) upstream of Desbarats Lake?
2. If such hotspots exist, in which of the four inflow creeks are they located?

The most polluted and nutrient-rich inflow is IN1, which is both influenced by anthropogenic and natural sources, i.e., development along Puddingstone Road, cattle grazing and beaver ponds. At its most upstream location, STR10, hypoxic conditions were observed that could mean internal P loading.

The TP concentration in IN2 increased drastically downstream of a disturbed beaver dam.

IN3 was generally less polluted and had the lowest consistent TP concentrations of 22-36 µg/L.

TP concentrations of IN4 were highly variable. In most cases, measurements made at different times indicated seasonality and high variability of TP concentration in these small wetland creeks. Agricultural practice may have contributed to the higher concentration here. According to a lake resident, "after decades of non-pasturing cattle, this practice was re-introduced in 2012 on lands along the stream entering the lake at inlet 4".

3. Is it possible to determine whether the source is natural or anthropogenic? *and*
4. How are beaver ponds and wetlands influencing nutrients and water quality problems in Desbarats Lake?

Beavers, development and cattle grazing as well as destruction of beaver dams appear to increase TP concentration and may contribute to the high TP in Desbarats Lake. Despite uncertainty in the results because of the high variability, management options to address TP sources are available (Section 7.1).

Figure 26. Cattle grazing close to streams *(Photo by Hugh Coverley)*

6 Recommendations

6.1 Future monitoring of water quality and internal P load

Desbarats Lake clearly is not at equilibrium and future monitoring is recommended to support the decreasing trend of the trophic state variables. Water transparency as Secchi depth and nutrient concentrations (TP, nitrate, total Kjeldahl-N) should be monitored from May to October at the deep Station 3. In addition DO, temperature and TP profiles should be taken. More emphasis should be put on phytoplankton so that cyanobacterial abundance would be measured even before obvious blooms. Because chlorophyll did not seem to be correlated with blooms, identification and semi-quantification of cyanobacteria, in particular *Aphanizomenon* is required to follow their abundance.

It is not clear whether internal P load from sediment surfaces is an important P source in Desbarats Lake and triggers cyanobacterial blooms. Because Desbarats Lake is oligomictic, the internal load influence could change from year to year. It may have occurred in 1995 and 2010, based on *in situ* increases throughout the growing season and TP depth profiles (Section 4.6.1). Sediment P fractionation, which can quantify releasable P, could be repeated with the collection and analysis of more sediment cores.

The effect of the inflow streams on Desbarats Lake should be explored further. For example, the most upstream site (STR10) of the stream IN1 exhibited hypoxic conditions once (low DO concentration at 3 mg/L) that could mean internal P loading in upstream ponds. Because of this potential TP source, further monitoring of these sites is recommended. Similarly, the influence of cattle grazing close to the creeks (IN1 and IN4) should be investigated further.

6.2 Quantification of external P load and capacity study

To determine a lake's development capacity external load has to be estimated and lake P concentration predicted in a mass balance model. Such a lake shore capacity assessment was done for the Algoma lakes, Bright and Basswood south east of Desbarats Lake (Nürnberg and LaZerte 2011a).

In such an assessment, external load can be evaluated from land use information commonly available from the MNR (2010) and TP export coefficients available from the literature and MOE. The nutrient source areas are multiplied by P export for the entire watershed. Partitioning external load according to the land use information in the specific watershed identifies the relative importance of the various P sources and their potential effects on lake water quality.

The P mass balance model requires specific morphometric and hydrological input, which is not complete or potentially unreliable (Table 1) and should be reviewed.

In particular, following important variables should be reviewed:

- Watershed area and land use, including past and present agriculture
- Layer morphometric areas and volumes (hypsographic information)
- Hydrological information, i.e., long-term annual average flushing rate

7 Potential management options

In general, the most apparent water quality issue often conflicting with lake use and health is an overabundance of algae. However, Lake Desbarats was light limited in study year 2010 and very murky with extremely low transparency and high TP concentration. In the next two following study years these conditions improved, but cyanobacterial blooms occurred. Desbarats Lake clearly is not at equilibrium, but nonetheless some general recommendations can be made and are presented below.

The control of algal growth and especially cyanobacterial blooms in lakes can be accomplished in several ways. The most common is to reduce the nutrient inputs (phosphorus, in particular), as most excessive algal growth is the result of fertilization from external sources like agriculture, field and lawn runoff, septic and sewage outflows, and wetlands containing beaver activity. In addition to external loading, treatment must sometimes involve measures to decrease internal loading from the sediments, however usually the external sources have to be addressed first.

7.1 External load abatement

Even though the estimation of external load is not the subject of this report, some recommendations can be made that would decrease these nutrient sources.

Typical remedial options are displayed in Table 15. Many of the suggestions are documented and addressed by the Eastern Algoma Stewardship Council and the Freshwater Quality Public Outreach of the Central Algoma Freshwater Coalition. A Guide to Stewardship of Ontario's Waters (Federation of Ontario Cottagers' Associations (FOCA) 2009) and the *Watershed* chapter in the North American Lake Management Society's (NALMS) publication on managing lakes and reservoirs (Holdren et al. 2001) provide further information.

Table 15. External load remedial options and techniques *(BMP, best management practice)*

- Source control
  - Identify and renovate leaky septic systems
  - Minimize erosion
  - Minimize impervious area & Maximize infiltration
  - Diminish runoff from agricultural non-point sources (BMPs)

- Manage beavers
  - Monitor beaver activity in the watershed
  - Have licenced trappers remove beavers and key dams

- Reduce agricultural impact
  - Prevent livestock access to creeks
  - Optimize timing of tilling, fertilizer application
  - Improve agricultural operation by further BMPs
  - Educate farmers

- Reduce loading from lake shore
  - Stabilize the shoreline; protect the riparian zone
  - Maintain vigorously growing shrubs and trees next to water surface
  - Stabilize eroding shoreline
  - Route drainage away
  - Establish vegetation
  - Educate lake shore residents and lake users

7.1.1 Anthropogenic sources: lake shore residents and lake users, agriculture

Any runoff from shore line residencies (Figure 27) affects the lake water quality immediately because of its steep slopes. 90% of the terrain around Desbarats Lake was found to have a steep sloping gradient starting no more than 10 meters off the shoreline (Normandeau et al. 2012). Verdone (2010) reported that only 19 of 65 lake shore residents have a sewage disposal permit. Compliance of septic systems is of utmost importance. All waste water systems should be inspected and decommissioned if not adequate. Compliant waste disposal has to be proven also for any trailers on the lake. Accessory buildings, including workshops, sheds, saunas and boat houses, to existing residences are most harmful if they create additional nutrient loading. A development moratorium would prevent any increase of shoreline development loads and was proposed by CAFC and supported by Freshwater Research in fall 2011 (Appendix F).

Fertilizer runoff from grassed areas of lake shore development can contribute a significant amount of nutrients, especially if combined with irrigation, which flushes nutrients and pollutants into the lake. However, in Desbarats Lake only 1.9% within a 100 m strip around the shoreline is grassed area and a lake resident survey revealed that fertilizer use is minimal (Normandeau et al. 2012).

Other pollutant input was observed from ice fishing. An educational program encouraging anglers to use the toilet facilities at the boat launch may minimized this nutrient source.

Agricultural influences can greatly affect the nutrient status in a lake. The practice of letting livestock have access to inflow streams likely increases nutrient loading from inflow 1 and 4 to Desbarats Lake and should be discontinued. For example, this nutrient source is being addressed in another Algoma lake, Bright Lake, by providing farmers with funds for the installation of fences and pumps.

Figure 27. Cottages along south side of lake towards outlet *(Photo by Gertrud Nürnberg, 14 April 2010)*

7.1.2 Natural sources: wetlands and beavers

The potentially major past natural pollutant load stems from unmaintained beaver dams (Błędzki et al. 2011). Although retention of water by dams generally increases sedimentation and hence may help prevent P from reaching the lake, the beaver dams are not permanent structures and are not always maintained. Instead, breakage during extreme flow events flushes polluted sediments into downstream lakes. There is circumstantial evidence in at least two different lakes where an upstream breach probably induced water quality problems involving cyanobacterial blooms (Gertrud Nürnberg, unpublished data).

A survey and inventory of these wetlands respective old and maintained beaver dams is recommended. Beavers could be managed by trapping or discouraging their dam construction. In this way P export from wetlands may be decreased. However, removal of beavers is controversial and care has to be exercised not to destroy any wetland areas. Removal of dams would have to be conducted in such a way as to minimize downstream pollution. Target streams have to be carefully selected so they are most beneficial in reducing nutrient load to the lake.

7.2 Avoidance of non-native species introduction

Any introduction of non-native species is potentially harmful, and should be avoided and monitored, if possible. Public outreach and education by the Central Algoma Freshwater Coalition should be continued and information posted at the boat launch and marinas (Figure 28). In particular the following species may be relevant to the Desbarats Lake environment:

- Plants:
  - Eurasian Milfoil (*myriophyllum spicatum*),
  - Purple loose strive (*lythrum salicaria*),
  - Water Soldier (*stratiotes aloides*),
- Animals:
  - Rusty crayfish (*Orconectes rusticus*)
  - Molluscs
    - Zebra mussel (*dreissena polymorpha)*
    - Quagga mussel (*dreissena rostriformis bugensis*)
  - Zooplankton:
    - Spiny Waterflea (*bythotrephes longimanus*),
    - Fishhook Water Flea (Cercopagis pengoi)

This list is not complete and more information is available at the websites of several institutions. The Ontario Federation of hunters and Anglers: http://www.invadingspecies.com; the Invasive Species Research Institute (ISRI) on the Algoma University campus: http://www.isri.ca/Sections/Index and the NSERC Canadian Aquatic Invasive Species Network II (CAISN): http://www.caisn.ca/

Figure 28. Poster already applied *(Photo by Gertrud Nürnberg, 14 April 2010)*

8 Conclusions

Desbarats Lake is severely eutrophied with trophic state variables indicating meso- to hyper-eutrophic conditions, implying low water quality. High trophic state and concomitant blooms of cyanobacteria started in the early nineties (and blooms perhaps existed in the sixties) and have since varied annually. Even though trophic state variables (TP, TN and Secchi transparency) have improved since 2010 they were still worse than the monitoring results of 1995, and blooms are still frequent.

The remediation of remote lakes is especially important when draining via a Provincially Significant Wetland (PSW) into the Great Lakes. Desbarats Lake drains via its outlet, the Desbarats (or Walker) River, and the Kensington PSW into the North Channel of Lake Huron. Average TP outflow concentration varied from 46 µg/L in fall 2010 to 15 µg/L in fall 2012, despite fall blooms in 2012. Further monitoring should verify whether this promising trend is sustained.

Based on the available information, several recommendations are made in this report. Because the most apparent water quality issue conflicting with lake use and health is an overabundance of algae, the control of algal growth and especially cyanobacterial blooms should be attempted. The most common method is to reduce the nutrient inputs (in particular of P), as most excessive algal growth is the result of fertilization from external sources like agriculture, field and lawn runoff, septic and sewage outflows. Specifically in the Desbarats Lake watershed, continued septic system inspection and renovation, shoreline best management practices and the prevention of cattle access to inlet creeks are recommended. The low Secchi transparency and associated high TP concentration in 2010 and the increased blooms in the nineteen-nineties may have been caused by upstream beaver dam ruptures. Therefore, a survey and inventory of these wetlands including the number, extent and status of the dams is recommended.

More detailed investigations of shoreline development and land use within the immediate catchment basin is advisable. For example, past agricultural practices and current cattle pasture with access to two inflow streams (IN1 and IN4) may contribute to nutrient loading.

Preliminary P mass balances could then be established similar to those done by lake shore capacity studies (e.g., Ministry of Environment 2010, Nürnberg and LaZerte 2011a).

In general it is recommended to

- Apply best management practices in the watershed wherever possible. For example, livestock access to inflow streams and the lake should be minimized, buffer zones around water ways respected.
- Ensure septic system compliance (inspection, maintenance, renovation, installation)
- Continue education to insure environmentally friendly lifestyles (selection of cleaners and detergents; low impact ice fishing, boating and bathing; etc.)
- Continue future monitoring to verify improvement in trophic state variables (especially, TP, Secchi depth transparency and dissolved oxygen) and to corroborate the observed patterns of cyanobacteria blooms.
- Review morphometric and hydrological characteristics of the lake and land use patterns of the watershed.
- Examine the potential impact from upstream beaver activity in more detail.
- Prepare a lake shore capacity assessment.

9 References

For education and general information there is a lot of material available from governmental and non-governmental organizations. For example, suggestions are documented and addressed by the Freshwater Quality Public Outreach of the Central Algoma Freshwater Coalition, the Kensington Conservancy, and the Federation of Ontario Cottagers' Associations (FOCA), which also published A Guide to Stewardship of Ontario’s Waters (2009).

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Appendix A: Analytical detection limits

Group	Parameter	units	ADL	Laboratory
Nutrients	Total Phosphorus	µg/L	0.2	Trent
	Ammonium	µg/L	2	Trent
	Nitrate/Nitrite	µg/L	2	Trent
	TKN	µg/L	2	Trent
DOC		mg/L	0.5	Trent
TOC		mg/L	0.5	Trent
Chlorophyll a		µg/L	0.5	Testmark
Total suspended solids (TSS)		mg/L	0.4	Testmark

Appendix B: Results of MOE spring sample event 27 Apr 2010

DES-1 Lilian Keene, MOE
C176018-0006
2010WS17-00515

27-Apr-10
DESBARATS LAKE 0.6M SECCHI DEPTH COMP

Name	Value	Units
Nitrogen; ammonia-ammonium	0.034	mg/L
Nitrogen; nitrite	0.012	mg/L
Nitrogen; Nitrate-nitrite	0.14	mg/L
Phosphorus; phosphate	0.0153	mg/L
Phosphorus; total	0.034	mg/L
Nitrogen; total Kjeldahl	0.42	mg/L
Solids; suspended (TSS)	6	mg/L
Solids; total	36	mg/L
Solids; dissolved	30	mg/L
Colour; true	58	TCU
Carbon; dissolved organic	4.6	mg/L
Carbon; dissolved inorganic	2.5	mg/L
Silicon; reactive silicate	4.16	mg/L
Chloride	1.9	mg/L
Sulphate	4.7	mg/L
Calcium	4.81	mg/L
Magnesium	1.76	mg/L
Sodium	1.6	mg/L
Potassium	0.727	mg/L
Conductivity	46	uS/cm
pH	7.39	none
Alkalinity; total fixed endpoint	14.8	mg/L CaCO3
Hardness	19	mg/L

Appendix C: MOE algal identification 2009 & 2010

Ministry of the Environment
Environmental Monitoring and
Reporting Branch
125 Resources Road
Toronto ON M9P 3V6
Tel.: 416 327-2881
Fax: 416 327-6519

Ministère de l'Environnement
Direction de la surveillance
environnementale
125, chemin Resources
Toronto ON M9P 3V6
Tél. : 416 327-2881
Téléc. : 416 327-6519

Water Monitoring & Reporting Section
Sport Fish & Biomonitoring Unit

September 21, 2009

MEMORANDUM

TO: Walter Shields
Sault Ste. Marie Area Office
Northern Region

FROM: Kaoru Utsumi
technologist - phytoplankton

RE: algae identification of surface samples from Desbarats Lake boat launch (Johnson Tp.) taken September 9, 2009

The two samples from Desbarats Lake, DBL1 and DBL 2 contained a thick algal bloom of the potentially cyanotoxin producing filamentous cyanobacterium *Aphanizomenon* (*A. flos-aquae*).

ELISA was negative for the presence of microcystins; however, *Aphanizomenon* is known to produce neurotoxins which ELISA does not test for. These can only be determined by mass spec. analysis.

Ministry of the Environment
Environmental Monitoring and
Reporting Branch
125 Resources Road
Toronto ON M9P 3V6
Tel.: 416 327-2881
Fax: 416 327-6519

Ministère de l'Environnement
Direction de la surveillance
environnementale
125, chemin Resources
Toronto ON M9P 3V6
Tél. : 416 327-2881
Téléc. : 416 327-6519

Water Monitoring & Reporting Section
Sport Fish & Biomonitoring Unit

April 29, 2010

MEMORANDUM

TO: Lilian Keen
Sault Ste. Marie Area Office
Northern Region

FROM: Lynda Nakamoto
technologist - phytoplankton

RE: algae identification of surface grab sample taken April 27, 2010 from Desbarats Lake boat launch (Johnson Tp.), 3 feet from shore

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Overall there wasn't a great deal of algae in the sample and nothing that would account for the reported "pea soup" colour of the water. It was not due to cyanobacteria as there was almost none in the aliquot I examined. I noted a filament of *Limnothrix* and a small colony of *Gloeocapsa* in 2 mL of sample. One small cluster of *Anabaena* fragments was seen but the quantity was so small that toxicity was not an issue. An *Anabaena* bloom may potentially be toxic but there was no bloom in this sample. Cyanobacteria tend to bloom later in the season when the water is warm. There was a large amount of fine particulate matter in the sample and although the water had no colour, it had a milky appearance. Perhaps the suspended material contributed to the way the water looked.

There was an assortment of biflagellate algae from the families Cryptophyceae, Dinophyceae and Chrysophyceae (golden brown algae). The flagellate *Cryptomonas* (Cryptophyceae) was the most numerous but there were several chrysophyte taxa present, mostly colonial but also single cells. There were several colonies of the chrysophyte *Synura*. *Synura* can cause taste and odour problems when it blooms but this is not the case here. There was also a wide variety of diatoms – single cells, colonies and centric diatoms. Protozoa, fungi and pine pollen were also seen.

Ministry of the Environment
Environmental Monitoring and
Reporting Branch
125 Resources Road
Toronto ON M9P 3V6
Tel.: 416 327-2837
Fax: 416 327-6519

Ministère de l'Environnement
Direction de la surveillance
environnementale
125, chemin Resources
Toronto ON M9P 3V6
Tél. : 416 327-2837
Téléc. : 416 327-6519

Water Monitoring & Reporting Section
Sport Fish & Biomonitoring Unit

July 30, 2010

MEMORANDUM

TO: Lilian Keen
Sault Ste. Marie Area Office
Northern Region

FROM: Kaoru Utsumi
Technologist - phytoplankton

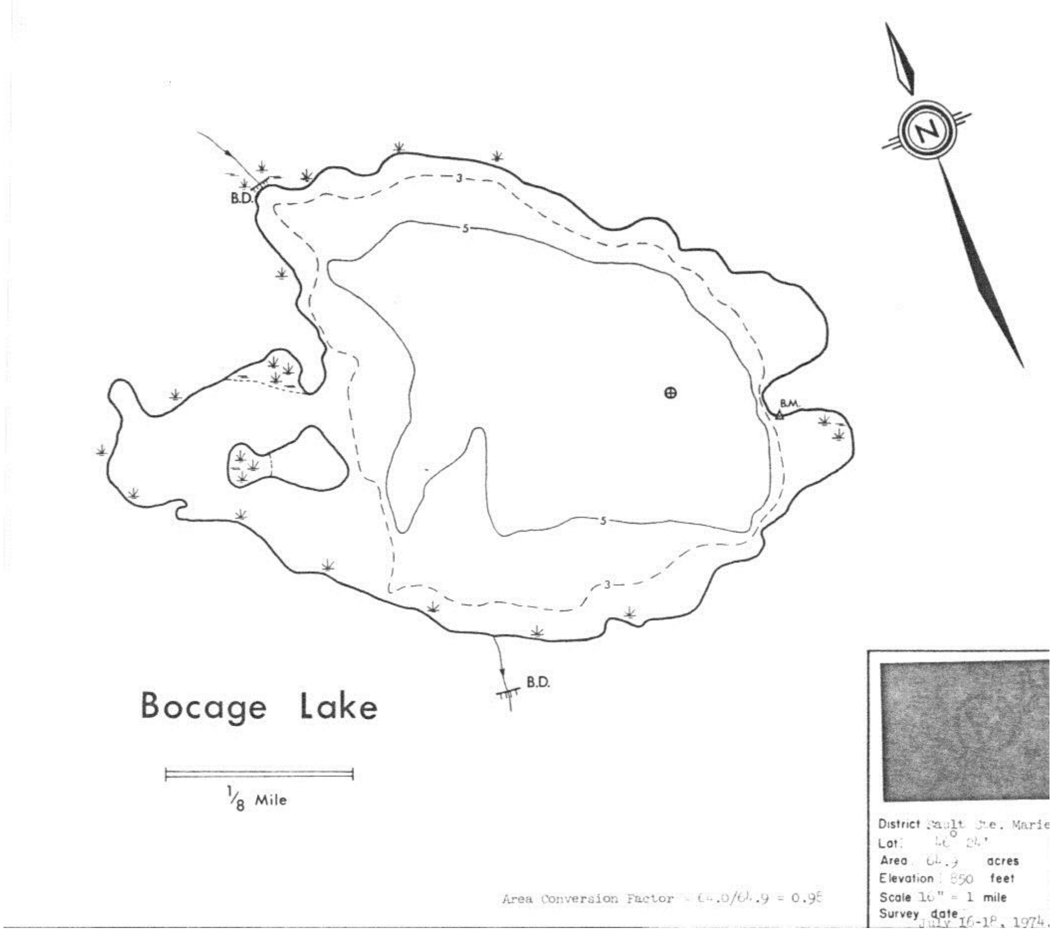
RE: Algae identification of the raw water sample from Desbarats Lake (inlet #3) taken on July 14, 2010

The sample from Desbarats Lake (inlet #3) contained the potentially toxin-producing filamentous blue-green alga (cyanobacterium), *Aphanizomenon flos-aquae*. However, the amount of *A. flos-aquae* found in the sample was little; therefore, it did not cause a bloom. In addition, the ELISA result was negative for the presence of microcystins; however, *Aphanizomenon* is known to produce neurotoxins which ELISA does not test for. These can only be determined by mass spectrometry analysis. *A. flos-aquae* occurs frequently as a component of water blooms particularly in ponds and lakes of high pH. Typically, several filaments of *A. flos-aquae* are oriented parallel to one another and are united into fascicles (bundles). Fascicles can be observed in grass-clipping appearance even with the naked eye. Fascicles float on the surface of the water.

The sample also contained a small amount of colonial green algae (*Chlorophyceae*) such as *Gloeocystis* and *Eudorina*. They do not produce toxins. Moreover, a colonial *Synura* (*Chrysophyceae*) and a single-celled flagellate *Cryptomonas* (*Cryptophyceae*) were present in the sample. They are not known to produce toxins. *Synura* is well known to cause taste and odour problems but the amount found in the sample was negligible. Finally, diatoms, protozoa, bacteria and debris were present in the sample as well.

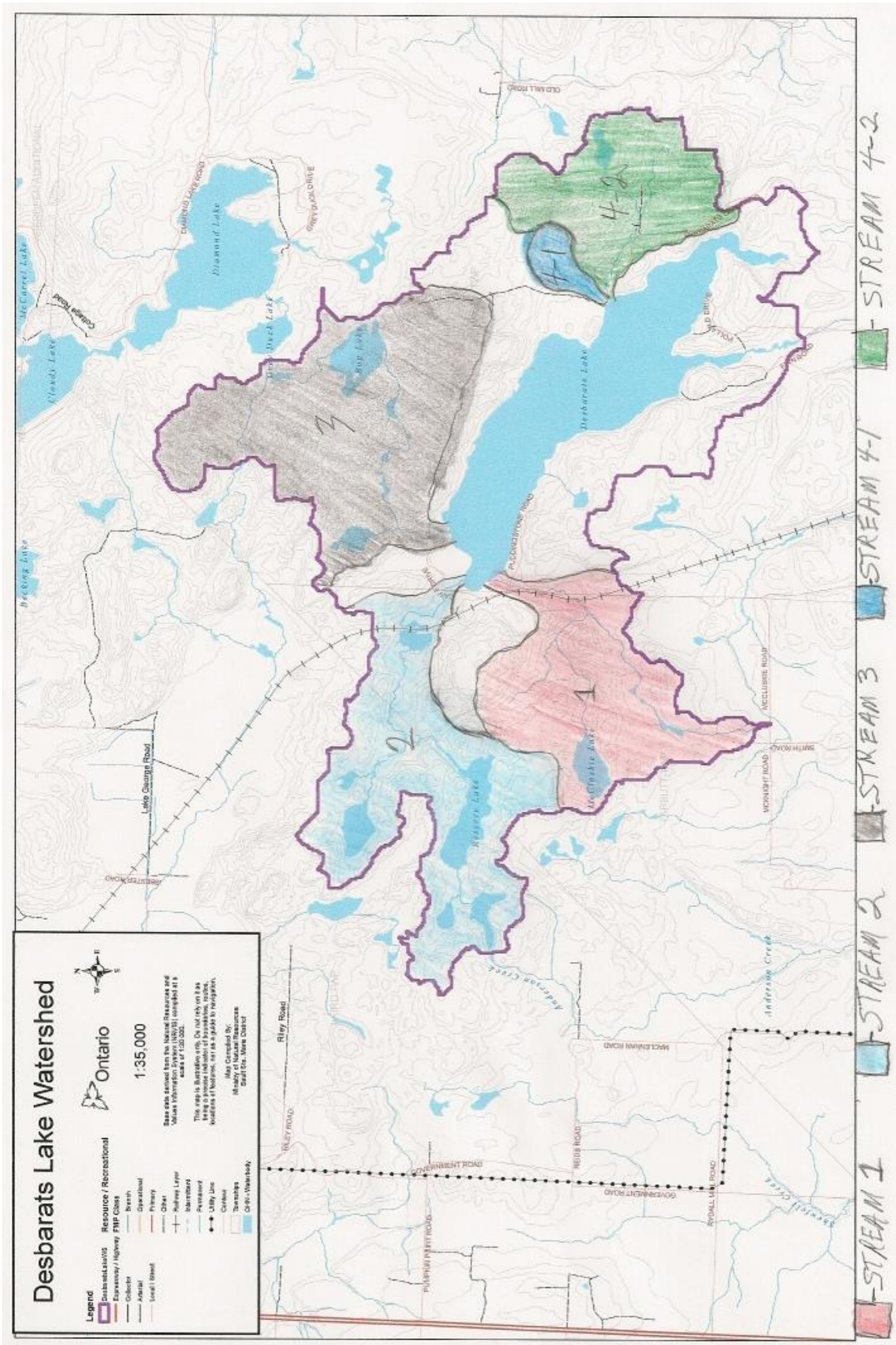
Appendix D: Available information for an upstream lake

Bocage or Bog Lake (MNR, August 1971)



Appendix E: Proportions of inflow streams to Desbarats Lake

(Peter Pollard, pers. comm.)



Appendix F: Letter to Township of Johnson

15 Nov 2011

Ruth Kelso Clerk/CAO
Township of Johnson
1 Johnson Dr., Desbarats ON
POR 1EO

RE: Proposed “Holding Zone” for Desbarats Lake

Dear Mr. Hicks,

The Central Algoma Freshwater Coalition brought to my attention the possibility of putting development on Desbarats Lake “on hold” until a capacity study can be conducted in the future.

As you are aware Freshwater Research is presently involved with the Central Algoma Freshwater Coalition to determine water quality aspects and remediation options of Desbarats Lake (a “*Monitoring Study*” started in spring 2010) and accordingly I have some insight in present and past water quality of the lake.

Without going into detail, it appears that Desbarats Lake is at a turning point where it is quite sensitive to any more disturbance and increases in nutrient loading. In past years since the mid-nineties there were extended nuisance algal (cyanobacteria) blooms every 2-5 years. The last two years of intensive monitoring (2010, 2011) were without major blooms, but worse conditions are expected in the future. While the study is examining the pattern of this variation in water quality to determine its immediate causes, it is already clear that the main reason is too much of the nutrient phosphorus in Desbarats Lake. Its phosphorus concentration has increased since the nineties about three fold and is now more than five times higher than can be expected for a lake in your area on the Canadian Shield.

For these reasons I welcome the recommendation that a hold be put on new development on Desbarats Lake until a Lake Capacity Study can be conducted. Such a moratorium would keep further disturbance in the Desbarats Lake nutrient budget at bay until a detailed and quantitative assessment of nutrient sources can be made. Of course, meanwhile any existing sources throughout the watershed should be addressed as well (see Coalition website for details).

Accessory buildings, including workshops, sheds, saunas and boat houses, to existing residences are most harmful if they create additional nutrient loading. I would propose that only those structures not requiring additional plumbing be permitted during the “Holding” period.

Sincerely yours,

Gertrud Nürnberg, Ph.D.
CC: Central Algoma Freshwater Coalition