Water Quality for Caribou Lake in the Stobie Creek Watershed

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Cover Photo is taken by Nancy Maltman on 3 Sep 2009, at Caribou Lake, East North East Bay Shoreline.

Executive Summary

This evaluation of Caribou Lake's water quality is preliminary and based on available information. Its goal is to serve as a background and justification for a much needed monitoring plan including detailed data collection in the future. Comments and additions to this report are appreciated.

Caribou Lake is a typical softwater, tea-stained lake (also called "dystrophic" because of its colour) on the Canadian Shield and was probably oligotrophic with comparably little nutrient concentration and no algal or cyanobacterial ("bluegreen") blooms in the past. In the last decade water quality has apparently deteriorated and highly toxic microcystin was measured during cyanobacterial blooms. While nutrient concentrations still indicate low mesotrophic conditions and Secchi transparency is comparably high considering its tannic-rich water, cyanobacterial blooms have been occurring in late summer and fall. Because dissolved oxygen concentration (DO) is below saturation throughout the water column in the two available summer DO profiles, one explanation of the blooms is their fertilization from internal P loading from bottom sediments. To test this hypothesis specific monitoring efforts of water and sediments are recommended.

A rudimentary assessment of the importance of external versus internal P loading is presented but should be updated by a more detailed lake (capacity) model.

Specifically the following recommendations are made so that (a) the causes for the decreased water quality and increased frequency of phytoplankton blooms can be determined, and (b) remediation possibilities can be evaluated.

Recommendations for future activities:

- Septic system inspection and renovation
- Education: shoreline best management practices
- Continued journal keeping and photo documentation
- Information to be provided by MNR
    - Watershed area
    - Land use areas
- Increased monitoring in two basins
    - during the growing period (May-Oct)
    - under ice
    - total phosphorus, three nitrogen compounds, Secchi transparency
- Monitoring of the main inlet stream
- Sediment fractionation
- Phosphorus mass balance and modelling
    - External load
    - Internal load
    - Climate dependency
- Capacity study

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1 Introduction

Caribou Lake (46°22, 83°50, 237 m above surface level) and its watershed of Stobie Creek straddle the townships Johnson to the west and Plummer Additional to the east. It is one of many remote northern Ontario lakes that often experience cyanobacteria blooms (Cover photo) in late summer and fall. Local concerns about the implications for human and ecosystem health were reinforced when a surface bloom sample of the potentially toxic cyanobacterium *Anabaena (A. lemmermannii* from fall 2009 contained a high concentration of the cyanotoxin, microcystin L-R, that triggered prolonged beach closures. In 2011, the Central Algoma Freshwater Coalition requested a preliminary report be prepared based on current information to find out what is needed so that an action plan can be developed with the aim to prevent any further deterioration of Caribou Lake.

For this project, any available reports, surveys, documented communication, photos and local wisdom were inspected and the relevant information interpreted and presented. Much of the quantitative analysis of this report is based nutrient and transparency data collected in the MOE – sponsored Lake Partner Program that started in 1995.

2 General Caribou Lake characteristics

Caribou Lake (Figure 1) is located in the two townships of Johnston and Plummer Additional, about 60 km south-east of Sault Ste. Marie in the Algoma country. It drains via its outlet with a small concrete dam (Figure 2) at the southwest corner beside a public park, Suddaby Park, via Stobie Creek into Lake Huron. There are five inlets draining swamp and marsh land, with one perennial inlet in the north-eastern corner of the eastern basin (Figure 3). The inlet of this stream is weedy and shallow, but is evident from the shoreline, where a small stream enters the lake from a swampy area. Since there are no major streams connecting Caribou Lake with upstream lakes it can be classified as a headwater lake.

According to residents, Caribou Lake is a humic acid rich, tea-stained lake with a "gold-brown" colour tinged green during bloom conditions (Nancy Maltman, pers. comm.)

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

Figure 2. Outlet of Caribou Lake in the west, from Google Map

Figure 3. Inlet of Caribou Lake in the north-east, from Google Map

2.1 Morphometry and hydrology

Caribou Lake is medium-sized but shallow (Table 1), shaped like a butterfly, with the wings marking an eastern basin with a deep hole (6.2 m according to MNR map, 5.8 m verified by echo sounder) and a shallower western basin (5 m) of almost equal size (Figure 1, Figure 4). Both basins are connected by a 500 m wide water bridge. There are also four small uninhabited islands (Figure 1). Because of this shape, much of the past monitoring was done at two stations, one each in the approximate centre of each basin. Whenever possible, the limnological and water quality evaluation presented here is based on both basins separately.

Caribou Lake is not a stratified lake, but “polymictic” because of its shallowness and it is mixed most of the open water season (Section 4.2). In such polymictic lakes sediment may release P during intermittent periods of stagnant and low oxygen (hypoxic) conditions and elevated bottom temperature. Consequently, lake TP concentration can increase throughout the summer and fall in polymictic lakes with internal P loading.

Caribou’s morphometric index (mean depth/square root of surface area) is 2.5 m/km for the total lake, but higher for the individual basins (Table 1). The higher the index the more stratified and possibly stagnant conditions exist. It means that despite Caribou Lake’s shallowness, quiescent and partial stratification periods may prevail, creating hypoxic conditions and nutrient release from sediments. But these stratified periods do not last long and frequent fluxes from the bottom can fertilize surface water. Because the eastern basin is deeper with a larger morphometric index

(Table 1), it can be expected that stratified periods last slightly longer and influences from the bottom sediments (e.g., P release) may be more pronounced in this basin.

Bathymetric information that quantifies areas and volumes for the individual layers of Caribou Lake are available from MNR (Table 2). It would be useful to obtain separate values for the two basins, so that future investigations can be completed for both basins independently.

Hydrological information like annual flushing rate and water detention time (Table 1) was calculated based on an estimated watershed area, using a typical runoff coefficient for that area as proposed by MOE (Ministry of Environment 2010). More direct evaluations of Caribou Lake's hydrology would be preferable.

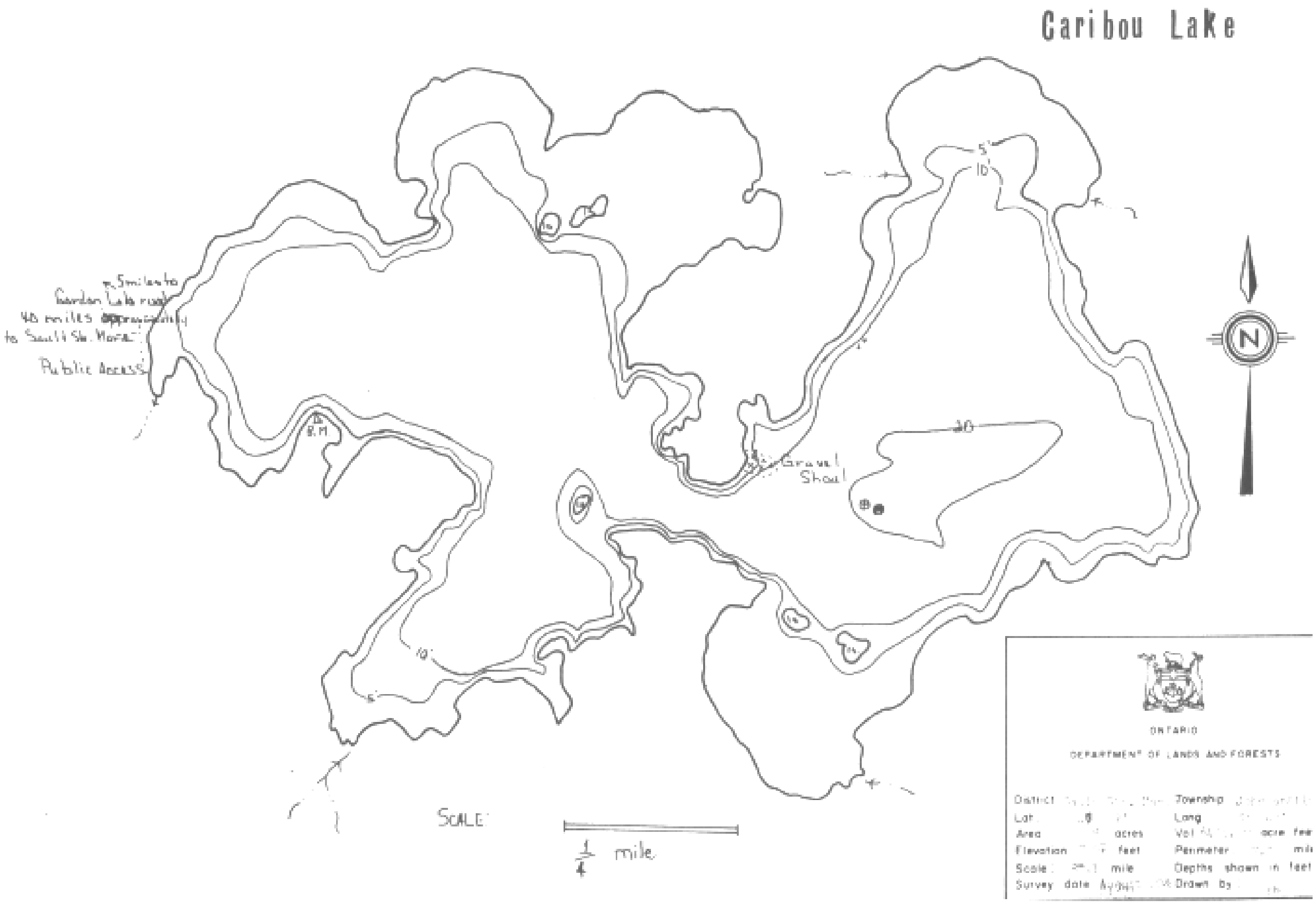


Figure 4. Bathymetric map of Caribou Lake, indicating sampling stations in the eastern basin (MNR 1973)

Table 1. Morphometric and hydrological lake characteristics

Characteristics	Total	Western*	Eastern*
Surface Area, Ao (km^2):	2.14	1.10	1.04
Maximum Depth, zmax (m):	6.2	5.0	6.2
Mean Depth, z (m):	3.7	3.44	4.01
Volume (10^6 m^3):	7.8	3.78	4.16
Annual flushing rate** (per yr):	1.43		
Annual water load** (m/yr):	6.99		
Perimeter (km)	11.6		
Morphometric Index ($z/A^{0.5}$):	2.5	3.28	3.94

*Based on contour map, except for maximum depth
** *to be confirmed*: Estimated from runoff coefficient and approximate watershed area

Table 2. Layer-morphometry based on GIS mapping (Tracey Cooke , MNR, 6 Dec 2010)

Depth	Area for upper depth	Volume interval	
(m)	(m^2)	(m^3)	(%)
0 - 3.05	12,321,254	32,495,007	54%
3.05 - 6.1	9,083,051	21,676,151	36%
6.1 - 9.1	5,308,119	6,281,478	10%
9.1 - 12.2	110,069	335,491	1%
Total	**12,321,254**	**60,452,636**	**100%**

2.2 Watershed

The watershed or catchment basin has a large influence on a lake's water quality, because most of the pollutants are flushed with the runoff to end up eventually in the lake. Caribou Lake is a headwater lake and its watershed consists only of a small area drained by its northern-eastern inflow and direct runoff from the immediate catchment basin. Consequently, the area ratio between watershed and lake is small, indicating that external load should not have a large influence on the lake. (The exact size of the catchment basin is to be provided by MNR.)

3 Water quality evaluation - Methods

There were two sampling locations established, one in the eastern and one in the western basin. Most data are based on the MOE Lake Partner monitoring of spring total phosphorus and growing season Secchi disk transparency (Table 3). This effort was supplemented by two physical profile measurements of the MNR Rangers in 2010 and further monitoring, starting 2011 by CAFC staff. General chemical composition of the water was sampled and determined once in the spring by MOE personnel (27 April 2010).

Table 3. Sampling locations and approximate sampling depths

Sampling depth (m)	Analysis	Year of sampling
Eastern basin, Main Station (Station 4)		
0.5-1	TP	1988, 1995, 2002-11
	Secchi	Between 1995-2011
0-6 as Profiles	Temperature & DO	2010-11
Composite	Background chemistry	27 Apr 2010
Western basin (Station 1)		
0.5-1	TP	2002-11
	Secchi	Between 1995-2011
0-6 as Profiles	Temperature & DO	2010-11

Temperature and dissolved oxygen (DO) profiles at 1 m depth intervals were taken with Hanna Instruments, HI 9146, Portable Waterproof Microprocessor DO Meter borrowed from the Blind River MNR.

Water samples for TP were taken and analyzed according to methods applied in the Lake Partner Program.

Secchi disk readings were taken as a measure of transparency by volunteers and on some other sampling trips. Chlorophyll *a* was not analyzed. 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. During bloom periods, occasional grab samples were taken by lake residents and analyzed by MOE labs for phytoplankton species and cyanotoxins.

4 Limnology and water quality of Caribou Lake

Ice-out happens usually around the beginning of May in the Algoma District. Therefore the summer period is defined as the period between 1 June and 30 September.

4.1 General background chemistry

Background chemistry was determined by MOE staff and labs for samples collected on 27 April 2010 at the main station in the eastern basin. Although these characteristics were only determined once at one location, they can be taken as representative, because they usually do not vary considerably with time and space.

The pH was just above neutral (7.2), alkalinity was medium (13 mg/L as $CaCO_3$) and calcium and sulfate concentrations were typical for softwater in the clay belt on the Canadian Shield (Table 4). Chloride, sodium, magnesium and potassium were at normal levels and do not display any indication of road salt effects. Silicate was high enough not to be limiting as a nutrient to algae that bloom in the spring (Diatoms). Dissolved organic carbon and colour values indicate that Caribou Lake is a tannic acid (with humic and fulvic acids) stained, softwater lake (Table 4). The colour value of 42 true colour units (TCU) is far above what is usually recognized as clear

(<10 TCU) and may be influenced by some tea-stained inlets and runoff from the surrounding wetlands.

Table 4. General background chemistry measured at the eastern basin

Compound	Value
Silicate (Si, mg/L)	0.8
Sulfate (SO_4, mg/L)	3.9
Calcium (Ca, mg/L)	4.3
Chloride (Cl, mg/L)	2.2
Sodium (Na,(mg/L)	1.5
Hardness (mg/L)	17
Conductivity (µS)	41
Alkalinity (mg/L Ca CO_3)	13.2
Dissolved organic carbon (DOC, mg/L)	8.5
Dissolved inorganic carbon (DIC, mg/L)	1.7
Colour (TCU)	42.4
pH	7.2
Total dissolved solids (TDS, mg/L)	26
Total suspended solids (TSS, mg/L)	28

"Gold-brown" colour of the tea-stained water was noted by lake residents before (Nancy Maltman). This characteristic is an important modifier of water quality (Nürnberg and Shaw 1998). For example, the light does not penetrate as deep as in clear lakes and often bacteria are more important than autotrophic, green phytoplankton. Such lakes have naturally low oxygen concentrations (hypoxic conditions in the water and the sediment surfaces) and low Secchi disk transparency, so that the Secchi-nutrient and Secchi-algal biomass relationships are modified by colour and are different from those for clear lakes.

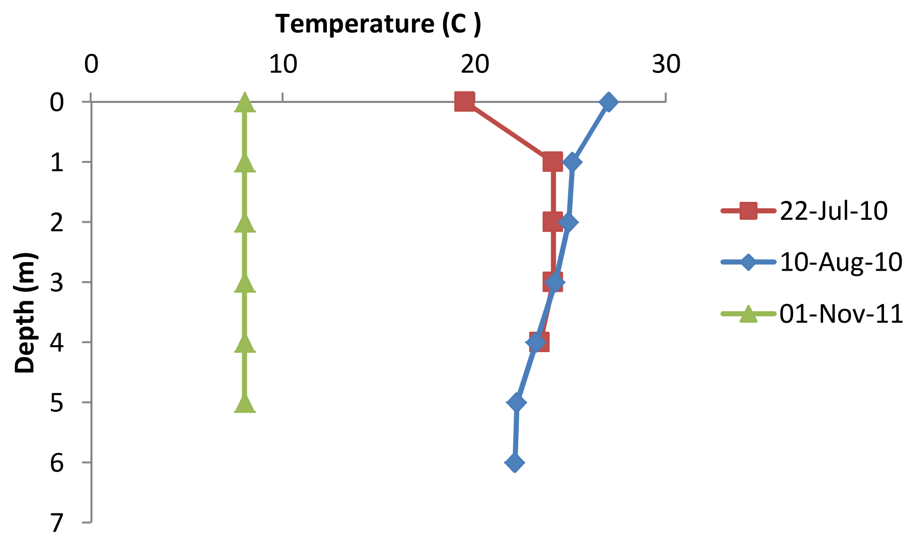
4.2 Temperature and dissolved oxygen concentration

Caribou Lake was not strongly thermally stratified at the deep station when temperature and DO profiles were taken in the summer 2010. This can be expected since the lake is so shallow and mostly less than 5 m deep (Figure 4). The largest differences between 1 and 6 m at the main station were 3 °C on 10 Aug, and 1.6 mg/L DO on 22 July (Figure 5). Oxygen concentration was between 5.5-6.9 mg/L throughout the water column, which is below saturation. The small temperature gradient and the hypoxic DO concentration indicate a possible, but short stratification period during which hypoxia can develop. (Profile data are listed in Appendix C.)

Sub-saturation concentration and decreasing DO with depth is typically created by oxygen demand at the sediment due to organic substances of decaying plankton and other organic material. Sediment oxygen demand is expected to be large in Caribou Lake because of the relatively high temperatures including those close to the bottom (22.1-23.4 C). Occasional stratification can occur even in shallow lakes such as Caribou, because of its relatively small area, and is supported by the relatively large morphometric indices for the individual basins (Table 1).

However, there are only 2 summer profiles available and a much higher monitoring frequency of at least every 2-3 weeks is required to determine whether Caribou Lake ever becomes hypoxic (i.e. below 3 mg/L DO). If occasional hypoxia can be confirmed in future summer monitoring, it would indicate the likelihood of sediment release of phosphorus (internal load) in Caribou Lake. In addition, profiles determined under ice in the winter may shed light on the potential of hypoxia at short periods even during the open water season.

Caribou Lake is categorized as entertaining warm water fisheries so that the PWQO of 5 mg/L DO applies. DO concentration was above 5 mg/L for the two measured occasions in summer 2010 but more data have to be collected to verify compliance.



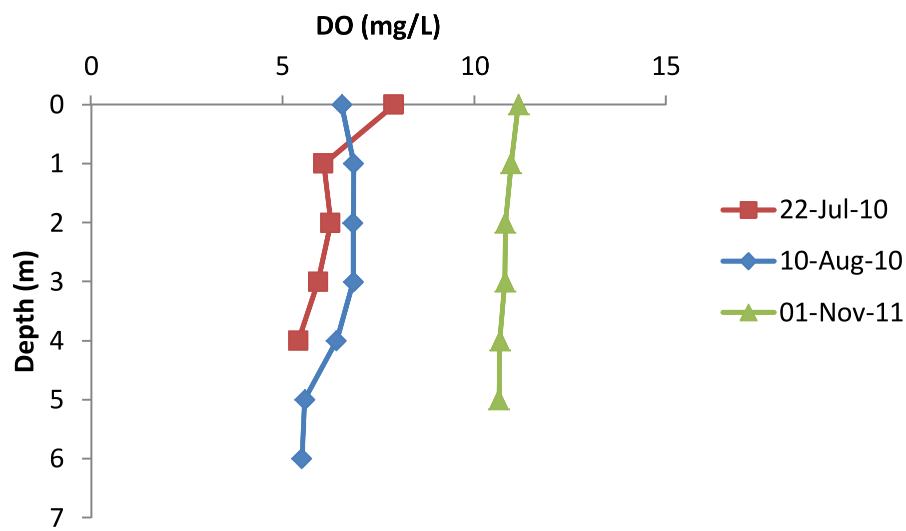


Figure 5. Temperature (top) and dissolved oxygen profiles (mg/L) profiles

Note that the zero depth location in the July and August profiles actually represents conditions measured in the air.

4.3 Apparent water quality, water clarity measured as Secchi disk transparency and colour

Secchi disk transparency readings are available since 1995 and permit a long-term evaluation of water quality trends in Caribou Lake (Figure 6, Table 5). Even though there is not a consistent collection of Secchi data every month and every year, it appears that transparency is lower in the last decade, compared to readings before 2002.

In particular, summer average Secchi transparency was 2.7 m in the western and 2.6 m in eastern basin after 2002 (ranging 2.0 – 3.0 m in the western and 2.2 – 3.1 m in the eastern basin) and classifies Caribou Lake as mesotrophic (Table 11). In both basins the 2011 readings were the lowest ever recorded with a summer average of 2.0 and 2.2 m for the western and eastern basin respectively. In comparison, the 1995-2001 summer Secchi readings were consistently higher with averages (and ranges) of 3.6 m (3.3 – 4.1m) in the western and 2.8 m (2.7 - 2.9 m) in the eastern basin.

There are not many fall readings available for recent years (Table 5) to determine whether there was a seasonal pattern and whether algal biomass increased in the fall. However, for 2011 August and September Secchi readings are clearly lower than most measured before. Such Secchi decreases in the fall can be associated with increased algal biomass due to internal P loading and was found in Bright Lake, Iron Bridge, for example (Nürnberg and LaZerte 2011a).

Despite the coloured water, Secchi disk readings were never below 1m, which is the Ontario guideline for contact sport.

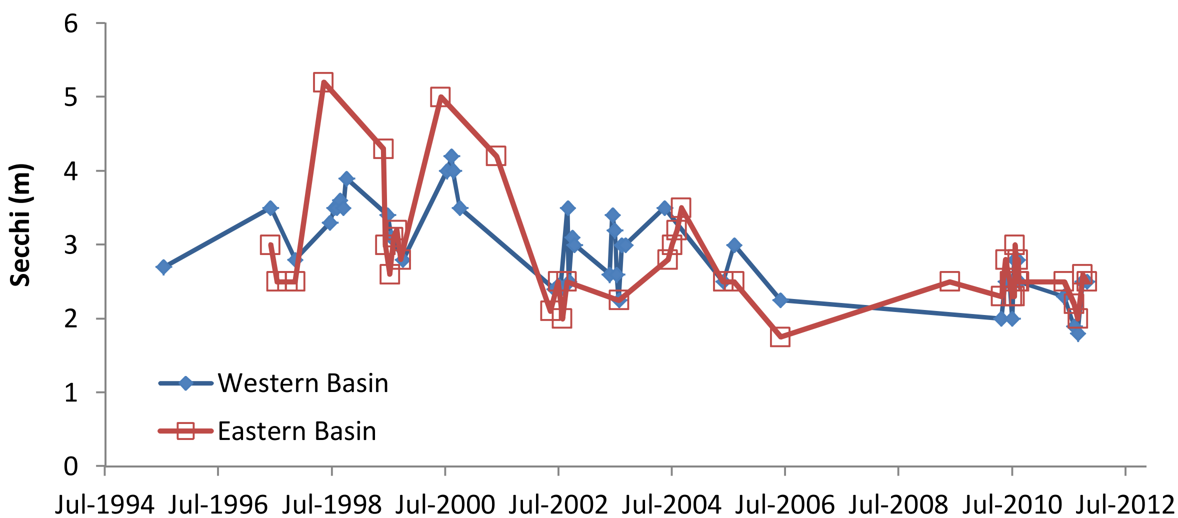


Figure 6. Secchi disk transparency readings since 1995

Table 5. Monthly Secchi disk transparency averages determined between 1995 and 2011

Year	Month								
	4	5	6	7	8	9	10	11	**Jun-Sep***
Western Basin									
1995				2.7					
1997			3.3					2.8	
1998			3.3	3.5	3.6	3.5	3.9		**3.5**
1999			3.4	3.1			2.8		**3.3**
2000				4.0	4.1		3.5		**4.1**
2002			2.4	2.4	3.5	2.8	3		**2.8**
2003		2.6	3.4	2.7	3.0	3.0			**3.0**
2004		3.5							
2005		2.5			3.0				**3.0**
2006			2.3						
2010	2.0	2.5	2.5	2.4	2.7			2.5	**2.5**
2011			2.3		1.9	1.8	2.5	2.5	**2.0**
1997-2001*			**3.3**	**3.3**	**3.8**	**3.5**	**3.4**		**3.6**
2002-2011*		**2.8**	**2.6**	**2.5**	**2.8**	**2.5**	**2.8**		**2.7**
1997-2011*		2.8	2.9	3.0	3.1	2.8	3.1		**3.0**
Eastern Basin									
1997			3.0	2.5		2.5		2.5	**2.7**
1998		5.2							
1999		4.3	3.0	2.6	3.2	2.8			**2.9**
2000			5.0						
2001		4.2							
2002		2.1		2.3	2.5				**2.4**
2003				2.3					
2004			2.8	3.0	3.2	3.5			**3.1**
2005		2.5			2.5				
2006			1.8						
2009		2.5							
2010	2.3	2.8	2.5	2.5	2.6				**2.5**
2011			2.5		2.2	2.0	2.6	2.5	**2.2**
1997-2001*		**4.6**	**3.7**	**2.6**	**3.2**	**2.7**			**2.8**
2002-2011*		**2.5**	**2.4**	**2.5**	**2.6**	**2.8**			**2.6**
1997-2011*		3.4	2.9	2.5	2.7	2.7			2.6

*Only averages of more than 1 reading are given

4.4 Phytoplankton and cyanobacteria blooms

Lake shore residents noticed problems in the water quality due to phytoplankton since the beginning of this century. They often collected water samples containing the bloom organisms for identification and analysis by MOE labs, kept a journal (Table 6) and recorded blooms photographically (e.g., Title Photo).

In this way it was determined that in 2005-2006 an obvious bloom was caused by the algae *Chrysochromulina breviturrit*a (belongs to Prymnesiophyceae or "Chryptophytes" according to MOE protocol), which is known for its taste and odour problems. While this alga bloomed in summer, fall and spring, all known more recent blooms occurred in the fall and were created by cyanobacteria. In 2009 and 2010, Microcystin analysis indicated a severely toxic concentration on Oct 2009, and below toxic but detectable concentrations in Oct 2010. The cyanobacterium *Anabaena lemmermannii* was probably the toxin producer, although also other cyanobacteria were identified in the samples, including *Woronichinia naegeliana, Microcystis* and *Oscillatoria (*possibly *Planktothrix spec.*). Detailed reports by the MOE are presented in Appendix B.

Table 6. Evidence of algal blooms

Year	Season	Problem	Cause	Sample site
2002-04	No known blooms			
2005	Summer-fall	Odour	*Chrysochromulina breviturrita*	
2006	Spring-summer	Odour	*Chrysochromulina breviturrita*	
	October	Thick blanket of "blue-greens" in the North East bay, dispersed with a wind change later the same day.		
2007	No known blooms			
2008	October	Thick blanket of blue-greens at the Public Park area, dispersed by following day.		
2009	10-Sep	Toxic	100.5/70 µg/L Microcystin-LR/ -LA	Lake Dock
2010	04-Oct		1.06 µg/L Microcystin-LR	Beach front, Eastern basin
2011	30-Oct		Blue-greens, not analyzed	Beach front, Eastern basin

Background information for *Chrysochromulina breviturrita*

A bloom of the odour producing algae is something of a rarity, and its characteristics are investigated in more detail here to determine the potential trigger and causes of such blooms.

Production of odour ("rotten cabbage") by *C. breviturrita* was first recorded in 1978-80 in one New Hampshire and several Muskoka lakes where it reached bloom densities (Nicholls et al. 1982). The alga was recorded at lower densities in more than 40 Ontario lakes with relatively low alkalinity (1 to 10 mg $CaCO3/L$), pH (5.9 to 6.9) and calcium concentration. In other words, *C. breviturrita* appears to prefer softwater lakes (potentially on the Canadian Shield) and it was not prevalent in hardwater lakes of southern Ontario.

The five lakes with reported blooms in the seventies were small (<95 ha) and ranged in maximum depth from 7 to 25 m. Specific conductance (28-60 Mhos/cm), colour (10-40 Hazen units), total nitrogen (300-500 µg/L) and total phosphorus (8-13 µg/L) levels were typical of many lakes on the Precambrian Shield. Caribou Lake's characteristics are similar to these observations, as it is a softwater lake on the Canadian Shield, similar in size, depth, and chemistry (Table 1, Table 11, and Table 4).

Odour development does not seem to be directly related to algal density, but more to water temperature. Surface water temperatures of all five lakes during odour production ranged between 18 and 25 °C, while similar concentration did not produce any smells at 5 °C in November samples.

There are no toxic reports for *C. breviturrita* and bioassays based on mice did not show any effects (Nicholls et al. 1982). However, a closely related species, *Chrysochromulina parva*, has been repeatedly associated with fish mortality, for example in a small Danish lake (Hansen et al. 1994) and any signs of potential toxicity should be investigated.

A field and laboratory culture study revealed that *C. Breviturrita* requires ammonium (NH_4) as nutrient, because it cannot use nitrate nor nitrite compounds, and the only organic compound it can use, inefficiently, is urea in the presence of nickel (Wehr et al. 1987). Ammonium is a sign of hypoxic conditions in a lake and such sub-saturation conditions have been observed in Caribou Lake when DO profiles were taken in summer 2010 (Section 4.2).

It can be concluded that the conditions for odorous blooms of *Chrysochromulina breviturrita* are favorable in Caribou Lake and are even more so with climate change related temperature increases. Nutrient abatement that would decrease the potential for hypoxic conditions and hence the prevalence of reduced N compounds in particular, NH_4, would also reduce the potential of such blooms.

4.5 Nutrient concentration

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. TN and TP are often closely correlated, but generally algae biomass (expressed as the green pigment, chlorophyll a concentration) is better correlated with TP rather than TN. For this reason and because phosphorus can more easily be controlled than nitrogen, management and restoration efforts typically concentrate on the reduction of phosphorus.

Nutrients were analysed to determine (a) their possible sources and (b) their impact on nuisance algal blooms. It can be expected that Caribou Lake is P limited like most temperate lakes, and the Lake Partner program by the MOE analyzes TP from spring samples collected by volunteers (Apr to early June). Nonetheless nitrogen is a nutrient too, and especially inorganic N compounds are indicative of bluegreen blooms. In particular, inorganic nitrogen concentration (nitrate-nitrite and ammonia concentrations) can decrease to below 50 μg/L levels while bluegreens proliferate (Nürnberg 2007). Because several cyanobacteria species have the ability of fixing nitrogen that they need for their growth, they can outcompete other phytoplankton at these conditions.

4.5.1 Total Phosphorus

Most TP data that are available are from the spring period late April to early June. Average long-term spring concentration is 11 µg/L in the western basin and 10 µg/L in the eastern basin (Table 7, Figure 7, Appendix D). There appears to be a long-term trend of slightly increasing spring TP concentration, because there is an average increase of 2.5 µg/L from the past to the recent period in both basins (Table 7).

Spring TP concentration is supposed to be representative of the whole lake TP in stratified lakes because at this time the lake mixes from top to bottom, rather than is stratified with warmer temperature on the top. However, Caribou Lake is not a stratified lake but “polymictic” and is mixed most of the open water season in summer and fall, as well as in the spring. In such polymictic lakes sediment may release P during intermittent periods as explained above (Section 2.1) and consequently, lake TP concentration can increase throughout the summer and fall with internal P loading.

Currently there is no increasing trend throughout the growing season detectable. But that may be because there are not enough data available to test this hypothesis (Appendix D). Therefore, increasing water sampling throughout the open water season is recommended so that it can be determined whether there is any seasonal trend for lake TP.

The amount of release depends on the releasable fraction in the sediment. If the redox-sensitive P-fraction in the bottom sediment is large, it can be released as internal P load and fertilize the open water. Therefore, it is important to determine this fraction so that release rates can be estimated from models based on studies in other lakes (Nürnberg 1988).

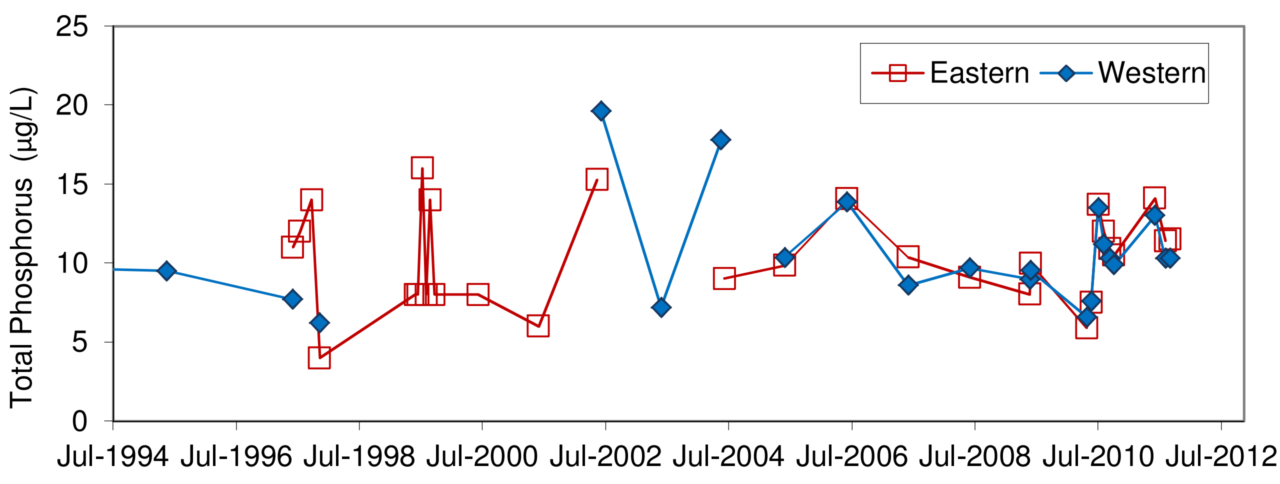


Figure 7. All available TP concentration in the western and eastern basins

Note: One early value for 20-May-88 of 10.2 µg/L in the Western basin is not shown

Table 7. TP concentration in the western and eastern basin sampled in the spring

	Spring TP (µg/L)		
	Western	Eastern	Average
1988	10.2		10.2
1995	9.5		9.5
1997	7.7	11	9.4
1999		8	8
2000		8	8
2001		6	6
2002	19.6	15.3	17.4
2003	7.2		7.2
2004	17.8	9.0	13.4
2005	10.4	9.9	10.1
2006	13.9	14.1	14.0
2007	8.6	10.4	9.5
2008	9.7	9.1	9.4
2009	9.3	9.0	9.1
2010	7.1	6.7	6.9
2011	13.0	14.1	13.6
1988-2001	**9.1**	**8.3**	**8.5**
2002-2011	**11.6**	**10.8**	**11.1**
1988-2011	11.1	10.0	10.1

Note: Starting 2002 data are precise to 0.7 µg/L, based on an analytical improvement by MOE labs.

With respect to trophic state, Caribou Lake can be classified as oligotrophic to mesotrophic based on the average TP summer concentration of the two basins that were 11.9 and 10.9 µg/L in 2010 and 2011 (based on 3 and 2 sampling dates each, Figure 7, Appendix D, Table 11). In all years with available data the provincial water quality objective for lake water of 20 µg/L summer average TP (Ministry of Environment 1994) has not been exceeded. However, the western basin spring TP was close, at 19.6 µg/L in 2002 (Figure 8, Appendix D).

4.5.2 Nitrogen compounds: nitrate and nitrite, total N

Nitrogen compounds were determined once by MOE staff and labs on 27 April 2010 at the main station in the eastern basin.

The inorganic fractions nitrate and ammonium were relatively high (Table 8) as is typical for spring conditions. It is expected that nitrate would decrease throughout the summer and may be approaching detection limits when cyanobacteria proliferate. Conversely it can be expected that ammonium concentration would increase in late summer and fall, caused by hypoxic conditions in the water column. It is recommended to analyse the nitrogen compounds throughout the growing season.

Total nitrogen, computed as the sum of total Kjeldahl and nitrate/nitrite fractions was 0.591 mg/L, which is relatively high for a lake on the Canadian Shield and represents mesotrophic conditions, leaning towards eutrophic conditions (Table 11).

Table 8. Nitrogen compounds in the eastern basin (27 April 2010)

Compound	(mg/L)
TN	0.591
NH4	0.041
Nitrite	0.002
Nitrate	0.109
TKN	0.480

4.6 Bottom sediments

Sediments that accumulate on the bottom of lakes document the past, but can also affect the current water quality. There is no information about sediment chemical composition in Caribou Lake available and it is highly recommended to do a chemical analysis of sediment cores at the deep location in the eastern basin, including sediment TP, redox-dependent P fraction and the organic fraction (loss on ignition) (Section 6.1.3).

4.7 Fisheries and clams

There were several fish surveys conducted by the MNR in Caribou Lake. The last one was done in Aug 2005 (Table 9) and reflects the previous stocking of walleye and small mouth bass (Table 10).

Table 9. Fish survey by MNR on 17 Aug & 14 Sep 2005

	Caught	Size (cm)	Weight (g)
Walleye	58	28-65	340-3500
Northern Pike	33	28-60	na
Smallmouth Bass	208	14-47	na
Perch	3	14-16	na
Brown Bullhead	201	22-40	na
Pumpkinseed	1	12	na
Bowfin	17	45-68	na
Rock Bass	8	6-15	na

na, not available

Table 10. History of fish stocking and surveys by MNR

1932: 75,000 Walleye fry
1939: 200,000 Walleye fry
1940: 5 million Walleye fry
1941: assessment indicated that Walleye stocking had failed
1949: Small Mouth Bass fingerlings
1962: 81 adult Walleye were introduced, adult plant successful
1973: lake survey found Northern Pike, Walleye, Yellow Perch, Small Mouth Bass, Rock Bass, Pumpkinseed
1995: MNR Fish survey
2005: MNR Fish survey (Table 9)

The number of observed fish species (species richness) of 8 (Table 9) is small compared to that predicted from a model that takes into consideration the lake surface area and observed anoxia. Using Caribou Lake's total area of 214 ha and an observed anoxia (anoxic factor) of 0 d/yr a species richness of 13.5 is predicted according to equation (1), (n=52, R^2= 0.51, p<0.001, Nürnberg 1995). It is not clear, whether the survey underestimated fish abundance or whether there are really less fish species in Caribou Lake, perhaps because of its tea-stained water and associated hypoxia.

$$\text{Number of fish species} = -\,1.53 \times \log(AF+1) + 5.38 \times \log(A_o \times 100) + 0.97 \qquad (1)$$

Observations by the resident, Nancy Maltman, suggest that clams used to be abundant on the north eastern shore in 2000, but have almost disappeared since then.

4.8 Trophic state classification and water quality of Caribou Lake – Summary and Conclusions

Based on several water quality variables a lake can be classified with respect to its trophic state (Table 11). Clean pristine and clear lakes are called oligotrophic and have high Secchi disk transparency, and low nutrient and algae concentrations, while 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 for extended periods. In shallow lakes (polymictic lakes), such as Caribou Lake, stagnant conditions are rare, often prohibiting extended oxygen deficits independent of the trophic state.

As shown in the previous sections, Caribou Lake's trophic state is oligotrophic to mesotrophic for the investigated variables. Mesotrophy is an intermediate state that is relatively enriched for a lake on the Canadian Shield and often indicates anthropogenic disturbances.

Because of the high colour Caribou Lake has a lower Secchi disk transparency than is typical for its TP concentration. But when considering its colour, the lake fits the general and trophic state relationships well, with respect to routinely measured phosphorus and Secchi transparency (Table 12). On the other hand, nitrogen concentration, which was measured only once, appears to be elevated and is close to the eutrophic level (Table 11).

Dissolved oxygen profiles are difficult to interpret in polymictic lakes and the high organic acid content of the coloured lake creates a natural oxygen demand. Sub-saturation concentrations were found throughout the water column in the two available profiles of summer 2010 at the deep station and can be classified as mesotrophic.

Table 11. Trophic state categories based on summer water quality (Nürnberg 1996)

	Caribou Eastern Basin*	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
Secchi Disk Transparency (m)	2.6	> 4	2 – 4	1 – 2	< 1
Total phosphorus (µg/L)	11	10	10 – 30	31 – 100	> 100
Total nitrogen (µg/L)	591**	< 350	350 – 650	650 – 1 200	> 1 200
Chlorophyll *a* (µg/L)	na	< 3.5	3.5 – 9	9.1 – 25	> 25
Anoxia in polymictic lakes	na	none	none	occasional during summer stratification	

Note: *For explanation see Section 4
**TN was analyzed only once, on 27 Apr 2010
na, not available or measured too infrequently to provide representative values

Table 12. Relationships between phosphorus and Secchi transparency

Characteristic	Value
TP (µg/L)	11.0
Colour	42.4
Secchi (m):	
Measured	2.57
Predicted*	2.60

*Secchi = 1.35-0.455 x log P-0.283 x log Colour (Nürnberg 1996)

The occurrence of odorous algal (*Chrysochromulina Breviturrita* in 2005-06) and cyanobacterial blooms (since 2008) may mean that Caribou Lake is in transition. As it is a headwater lake with only a small catchment basin and because of its location on the Canadian Shield relatively good water quality is to be expected. A phosphorus mass balance analysis in a lake capacity model would more exactly determine the likely pre-development water quality. Anthropogenic nutrient input in this small watershed consists mainly of lake shore residencies and inefficient wastewater treatment may have caused an increase in phosphorus. It is likely that during this process nutrients accumulated in the bottom sediments and started to become released, when hypoxic periods occurred, caused by high sediment oxygen demand from naturally enriched organic acids. (For further discussion see Appendix D.)

Anthropogenic effects on the lake are obvious also in other ways. There was one microbiological incident of a beach closure on 2006: July 28, APH posted Suddaby Park unsafe for swimming, as it exceeded bacteriological safe swimming and bathing guidelines. That was the first time of a closure according to lake residents.

The water quality in the summer of 2010 was unusually good in many Ontario lakes and in the Algoma region in particular. For example, Desbarats Lake, also in Johnson Township and less than 5 km distant and Bright Lake, Iron Bridge (Nürnberg and LaZerte 2011a) did not experience any algal bloom as they did in previous years. The reasons for the generally better water quality in Ontario lakes are not clear, but an extreme weather pattern may be responsible. Snow melt and ice-out were extremely early and a warm spring was followed by a relatively hot and dry summer. Nonetheless, Caribou Lake displayed a cyanobacteria bloom in October 2010, when apparently the entire surface was covered and low-level toxins were detected (Table 6). The recent blooms suggest that Caribou Lake's water quality is deteriorating at a faster pace than that of lakes in the vicinity.

5 Phosphorus mass balance

A P mass balance is to be assembled so that the relative importance of different P sources can be determined. Any available information is summarized here, but a more complete evaluation like in a lake capacity study is recommended. Preliminary modeling suggests that perhaps up to half of the lake water P concentration is derived from internal P loading and the remainder from external load. Any P derived internally has a much greater and more immediate effect on the water quality than that from external sources, because it happens at a time when algae and cyanobacteria need nutrients most, which is the summer and fall. Further, sediment released P is in the chemical form of phosphate that is highly biologically available, while externally derived P is typically not more than 30% biologically available.

It is recommended to quantify both loads in more detail using several approaches. Land use information will be provided by the MNR based on their map (Figure 8). Together with applicable TP export coefficients external load can then be evaluated as done in the lake capacity assessment for Bright and Basswood Lakes (Nürnberg and LaZerte 2011b). In particular the influence of development on TP concentration in Caribou Lake could be estimated and loads computed from numbers of current units (Table 13).

Available information shows that the south and east of the eastern basin are most densely developed. In other locations, there are cabins in the south and a resort with seasonal and year-round cabins and a campground in the north of the western basin. Septic systems in the eastern development are classified to be of various ages, dating back to the seventies, with only few systems constructed after 2000 (Nancy Maltman, pers. comm). Consequently, a thorough septic system inspection with mandatory renovations is recommended.

A recreational park is located at the beach just north of the outflow and includes a boat launch, change rooms and toilets, a swimming and a picnic area. Because of its location so close to the outflow, its influence on the water quality of Caribou Lake can be considered negligible.

Table 13. Lake shore development

Unit Description	2011	1995
Permanent	9	11
Seasonal	24	17
Resorts:	2	1
Year-round cabins	8	0
Seasonal cabins	3	7
Trailers	8	0
Camping	number unknown	
Recreational Park	1	1
Vacant	6	NA

Source: Nancy Maltman

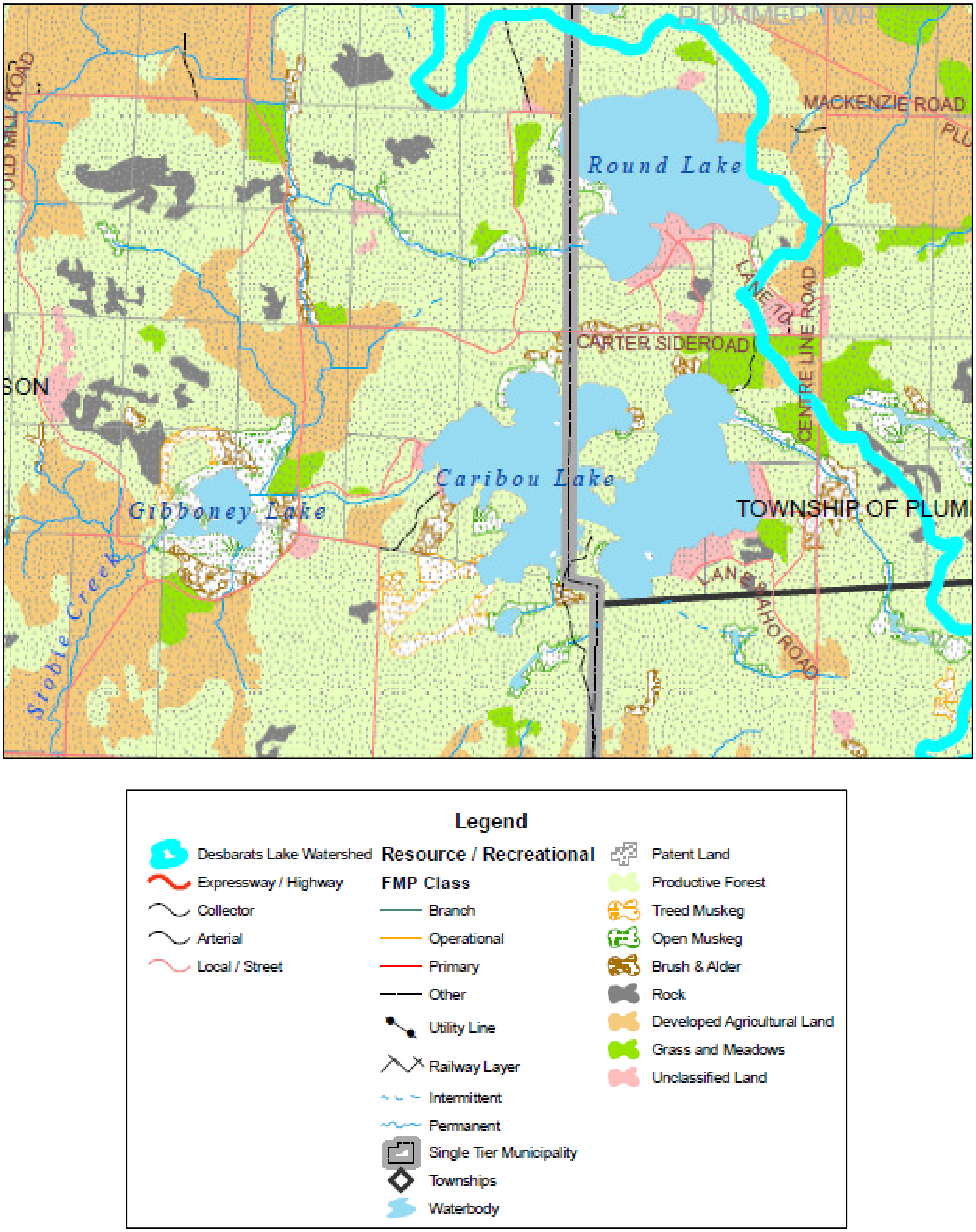


Figure 8. Land use around Caribou Lake *(based on electronic map provided by MNR 21 Oct 2011)*
Note: This map does not show the watershed boundaries of Caribou Lake

6 Needed Information and Recommendations

If the data assembled so far are representative it appears that external input (from wetland runoff, lake shore development and precipitation) induce slightly elevated TP concentration and that hypoxic conditions triggers algal blooms. In particular, hypoxia provided the nutrient ammonia for the odorous algae *Chrysochromulina*, and highly bio-available P by internal load from bottom sediments for cyanobacteria. The recommendations listed here are to support these hypotheses and help quantify the various effects.

6.1 Limnological information

Because Caribou Lake consists of two similarly large basins, all analysis would be best completed for both basins. Consequently, separate bathymetric information for the basins would be useful and could be provided by MNR.

For external load quantification the total watershed area (catchment) and the separate land use areas are needed and promised by MNR.

Hydrological information like annual water detention time was calculated based on an assumed watershed area, using a typical runoff coefficient for that area as proposed by MOE (Ministry of Environment 2010). More direct evaluations of Caribou Lake's hydrology would be preferable.

6.1.1 Algae and cyanobacteria

Any blooms by the algae *Chrysochromulina breviturrit*a should easily be noted, because of its obnoxious taste and odour. Because a closely related species, *Chrysochromulina parva*, was repeatedly associated with fish mortality in other lakes, any signs of potential toxicity should be investigated.

The presence of cyanotoxins (microcystin) could be crudely determined by volunteers or CAFC staff using commercially available kits, for example by *Abraxis* (http://www.abraxiskits.com). However, it may be preferable to collect samples during blooms and send them to MOE for toxin analysis and phytoplankton identification.

Photo documentation of any blooms is always useful. A journal that also includes notes on the duration and location of any bloom conditions similar to that of Nancy Maltman, should be continued.

6.1.2 Water quality monitoring

There is one inflow creek to the north eastern bay and its chemistry should be monitored occasionally (monthly, May – Oct). In particular, the amount of nutrients should be measured and colour value determined.

The investigation of internal loading processes is important as it can be expected to vary annually with flow, water level and other conditions. Consequently, profiles measurements of DO, temperature and TP should be conducted routinely at the deep stations throughout the growing season.

Therefore, increasing water sampling throughout the open water season is recommended so that it can be determined whether there is any seasonal trend for lake TP and Secchi transparency. There are not many fall readings available to determine whether there was a seasonal pattern and whether algal biomass increased in the fall. Any Secchi decreases in the fall can be associated with increased algal biomass due to internal P loading. Similarly, increases in TP are a sign of internal load. To determine any such indication, Secchi transparency and TP measurements should be continued throughout the fall (May – Oct, every 2-4 weeks).

Further one winter sampling under ice, as late as possible before ice-out would indicate any winter internal load. Anoxia and elevated TP concentration above the bottom in late March would not only indicate that internal load may provide nutrients for a spring bloom, but it also would indicate that sediment oxygen demand is high enough to provide low DO concentration in bottom sediments and P release throughout the summer.

It is expected that nitrate would decrease throughout the summer and may be approaching detection limits when cyanobacteria bloom. Conversely, it can be expected that ammonium concentration would increase in late summer and fall, due to increasing hypoxic conditions in the water column. Therefore, it is recommended to analyse three nitrogen compounds (Nitrate, total Kjeldahl-N, ammonia) throughout the growing season.

6.1.3 Sediment analysis

If the redox-sensitive P-fraction in the bottom sediment is large, it can be released as internal P load and fertilize the open water. Therefore, it is important to determine this fraction so that release rates can be estimated from models based on studies in other lakes (Nürnberg 1988). Such rates can then be used to estimate internal P load.

Bottom sediment is best collected by a device that keeps the layers intact. In this way distinct sediment depths can be analyzed by specialized commercial labs (0-5 cm and 5-10 cm, as described in Nürnberg and LaZerte 2011a).

6.2 P Mass balance & lake capacity model

A phosphorus mass balance analysis in a lake shore capacity model would determine the different parts of external loading, including the natural background load and the lake shore development load to predict the likely pre-development and current water quality. Such an approach was commissioned by the Township of Huron Shores in a lake capacity study for Bright and Basswood Lake (Nürnberg and LaZerte 2011b).

Once sediment and seasonal P data are available, internal load can be determined with several different approaches based on sediment P fractions, on TP changes in the water throughout the growing season and on a mass balance.

When both external and internal loads are quantified, a lake capacity study can be conducted to determine whether the lake is at capacity with respect to future development.

6.3 Climate, hydrology and water level

Patterns of precipitation and flows affect the water quality of lakes in various ways and have to be considered in a limnological assessment. However, there are no observations about water level changes and other climate related characteristics in the Caribou watershed available. Since it is a headwater lake, its dependence on precipitation and runoff is immediate. It may be useful to compare long term precipitation and runoff conditions with available annual water quality characteristics, such as Secchi transparency and spring TP.

Further, summer temperature, ice out date and duration of warm weather may be correlated with internal load effects and bloom conditions. Even if no historic observations exist for Caribou Lake, perhaps such data are available for lakes in the vicinity and could be applied.

6.4 Prevention and stewardship

6.4.1 Septic system inspection

Septic systems are classified to be of various ages, dating back to the seventies, with only few systems constructed after 2000 (Nancy Maltman, pers. comm). Consequently, a thorough septic system inspection with mandatory renovations is recommended.

6.4.2 Shoreline best management practices

Education and provision of incentives for using best management practices in the watershed and especially around the shore of Caribou Lake is further encouraged, similar to activities presently conducted by CAFC.

7 Conclusions

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 (TP in particular), as excessive algal growth is ultimately the result of fertilization from external sources like agriculture, field and lawn runoff, septic and sewage outflows. Specifically in the Caribou Lake watershed septic system inspection and renovation and shoreline best management practices like those proposed by CAFC are recommended.

The following recommendations are made so that (a) the causes for the decreased water quality and increased frequency of phytoplankton blooms can be determined, and (b) remediation possibilities can be evaluated.

Recommendations for future activities:

- Septic system inspection and renovation
- Education: shoreline best management practices
- Continued journal keeping and photo documentation
- Information to be provided by MNR
    - Watershed area
    - Land use areas
- Increased monitoring in two basins
    - during the growing period (May-Oct)
    - under ice
    - total phosphorus, three nitrogen compounds, Secchi transparency
- Monitoring of the main inlet stream
- Sediment fractionation
- Phosphorus mass balance and modelling
    - External load
    - Internal load
    - Climate dependency
- Capacity study

8 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: SooToday.com: "Blue-green algae bloom confirmed in area lake"

By SooToday.com Staff
SooToday.com
Thursday, September 10, 2009

NEWS RELEASE

ALGOMA PUBLIC HEALTH

****

Blue-green algae bloom confirmed at Caribou Lake, located between Plummer Additional and Johnson townships, north of Bruce Mines

The Ontario Ministry of Environment collected algae samples from the lake on September 2, 2009.

Initial laboratory analysis of these samples indicated that there was Cyanobacteria in the sample, toxin test results are pending.

Signs have been posted at the public boat launch notifying users not to use the water during an algae bloom.

Algoma Public Health advises that you can protect your health and that of your family, friends and pets during a blue-green algae bloom by avoiding the use of the water for drinking or activities that involve direct contact with it such as swimming, water skiing, and showering.

There are several necessary conditions for an algae bloom to occur.

These conditions include: high levels of nutrients (particularly phosphorous, and also nitrogen), calm water, low or no flow, strong sunlight, relatively clear water (which allows sunlight to penetrate), high air and water temperatures, shallow water (which heats up quickly).

Certain blue-green algae have air sacs that allow them to float to the surface for sunlight and sink to the bottom for nutrients.

This explains why blooms can appear, disappear and reappear quickly.

The blooms can persist for several weeks.

Toxins produced by certain forms of blue-green algae can affect your health in two ways.

Skin contact with the algae through washing or swimming can cause itchy, irritated eyes and skin.

Drinking water contaminated with the toxins can cause nausea, vomiting, abdominal pain and diarrhoea.

Liver or nervous system disease can also develop if toxins are consumed over a long period of time.

The occurrence of symptoms and the severity of illness depend on the amount of water consumed.

If illness results after drinking or bathing in the water of lakes with a blue-green algae bloom, see your doctor as soon as possible.

To help protect the lake, property owners should avoid using lawn and garden fertilizers, increase naturalization of the shoreline, prevent soaps and shampoos from going into the lake during bathing, dishwashing, laundry, and cleaning, and inspect all sewage and waste systems such as septic tanks and tile fields, outhouses, and leaching pits to ensure they are functioning properly and conform to the standards.

Suspect algae blooms can be reported to your local Ontario Ministry of the Environment office.

Algoma Public Health routinely monitors public beaches in Algoma, testing them weekly for the presence of E.coli bacteria.

If water at a public beach is found to have high levels of bacteria or the presence of blue-green algae, signs will be posted at the beaches advising residents and users of the warnings.

The public is also encouraged to visit the Beach Warnings section on our website to view an interactive map that shows which beaches have been posted as unsafe for swimming.

Hyperlink: http://sootoday.com/content/news/full_story.asp?StoryNumber=41569

Appendix B: 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

Ministere de l'Environnement
Direction de la surveillance environnementale
125, chemin Resources
Toronto ON M9P **3V6**
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Ontario

Water Monitoring & Reporting
Section Sport Fish &
Biomonitoring Unit

September 15, 2009

MEMORANDUM

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

FROM: Lynda Nakamoto
technologist - phytoplankton

RE: algae identification of grab samples taken September 2, 2009 from Caribou Lake

Both samples indicated a bloom of the potentially cyanotoxin producing filamentous cyanobacterium *Anabaena (A. lemmermannii).* The water column sample CBL1 was not nearly as dense as the bloom sample CBL2. The large green specks seen floating throughout sample CBL1 were large clumps of *Anabaena lemmermannii.* Both samples also contained colonies of the cyanobacterium *Woronichinia naegeliana,* a common component of blooms. The colonial cyanobacterium *Microcystis* (a potential hepatotoxin producer) was observed in CBL2. ELISA was positive for microcystins for both samples with the bloom sample having a much higher concentration than the water column sample. As always, caution should be exercised when a cyanobacteria bloom occurs.

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Ministère de l'Environnement
Direction de la surveillance
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Ontario

Water Monitoring & Reporting Section
Sport Fish & Biomonitoring Unit

October 12, 2010

MEMORANDUM

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

FROM: Lynda Nakamoto
technologist - phytoplankton

RE: algae identification of grab sample from Caribou Lake beachfront (179 Aho Rd.), Tarbutt Additional Tp., Algoma Dist. taken October 4, 2010

There were some potentially toxin producing cyanobacteria in the sample but it was not a very dense bloom. The water actually had a yellowish tinge rather than a blue-green colour. I did observe a small blue-green patch of algae floating at the surface of the sample (mostly the colonial cyanobacterium *Woronichinia naegeliana*) and blue-green particles visible to the naked eye were dispersed throughout the sample. *Woronichinia naegeliana* was the dominant type of algae. This species' status as a toxin producer is not certain but it is often considered a potential toxin producer. It is frequently a component of blooms containing other toxin producing species of cyanobacteria. In this sample, fragments of the filamentous cyanobacterium *Anabaena* were common, including a few clusters of *A. lemmermannii*. There were also a couple of colonies of the cyanobacterium *Microcystis* present in the 2 mL aliquot of well mixed sample examined. However, when I looked at a drop of the floating "green patch" under the microscope, there was a lot more *Microcystis* as the colonies tend to float. Both *Anabaena* and *Microcystis* are known to be cyanotoxin producers. ELISA showed that a small quantity of microcystins was present but it was below the guideline for microcystin LR in drinking water. I saw one other filamentous cyanobacterium (*Oscillatoria*) and a few taxa of small colonial cyanobacteria.

The sample contained algae from a number of other classes including flagellates from the Dinophyceae, Cryptophyceae and Euglenophyceae. Chrysophyceae or golden brown algae were common, especially the tiny flagellate *Chrysochromulina parva*. A number of single celled (including desmids), filamentous and colonial green algae, along with several taxa of diatoms, were also present.

Appendix C: Temperature and dissolved oxygen data

Dissolved oxygen and temperature profiles for 2010 & 2011

Date	Weather	Time	Total Depth (m)	Depth (m)	Temperature (C)	DO (mg/L)	Sampler
				Eastern Basin (Main Station)			
22-Jul-10	overcast	9:20	6	air	19.5	7.9	Rangers
22-Jul-10	mild breeze			1	24.1	6.06	
22-Jul-10				2	24.1	6.25	
22-Jul-10				3	24.1	5.92	
22-Jul-10				4	23.4	5.4	
22-Jul-10				5	-	<4.0 sediment	
10-Aug-10	sunny	14:10	6	air	27	6.54	Rangers
10-Aug-10	strong wind & waves			1	25.1	6.85	
10-Aug-10				2	24.9	6.83	
10-Aug-10				3	24.2	6.84	
10-Aug-10				4	23.2	6.4	
10-Aug-10				5	22.2	5.57	
10-Aug-10				6	22.1	5.5	
01-Nov-11	clouds	10:45	6	air	6.5	13	Lindsey P.
01-Nov-11	overcast			surface	8	11.14	
01-Nov-11	wind			1	8	10.95	
01-Nov-11				2	8	10.8	
01-Nov-11				3	8	10.79	
01-Nov-11				4	8	10.66	
01-Nov-11				5	8	10.63	
				Western Basin			
01-Nov-11	clouds	10:10	6	air	8	12.3	Lindsey P.
01-Nov-11	overcast			surface	7.9	11.13	
01-Nov-11	windy			1	7.9	11	
01-Nov-11				2	7.8	10.96	
01-Nov-11				3	7.8	10.95	
01-Nov-11				4	7.8	10.95	
01-Nov-11				5	7.8	11.01	
01-Nov-11				6	bottom		

Appendix D: Total phosphorus data for the western and eastern basins

	TP (µg/L)		
	Western	Eastern	Average
20-May-88	10.2		10.2
15-May-95	9.5		9.5
01-Jun-97	7.7	11.0	9.4
13-Jul-97		12	12
21-Sep-97		14	14
08-Nov-97	6.2	4	5.1
30-May-99		8	8
13-Jun-99		8	8
11-Jul-99		16	16
03-Aug-99		8	8
25-Aug-99		14	14
19-Sep-99		8	8
04-Jun-00		8	8
29-May-01		6	6
12-May-02		15.3	15.3
05-Jun-02	19.6		19.6
28-May-03	7.2		7.2
16-May-04	17.8		17.8
07-Jun-04		9.0	9.0
29-May-05	10.4	9.9	10.1
04-Jun-06	13.9	14.1	14.0
02-Jun-07	8.6	10.4	9.5
01-Jun-08	9.7	9.1	9.4
24-May-09	9.0	8.0	8.5
29-May-09	9.5	10.0	9.8
27-Apr-10	6.6	5.9	6.3
24-May-10	7.6	7.5	7.6
04-Jul-10	13.5	13.7	13.6
05-Aug-10	11.2	12.0	11.6
11-Sep-10	10.3	10.9	10.6
05-Oct-10	9.9	10.5	10.2
05-Jun-11	13.0	14.1	13.6
08-Aug-11	10.3	11.4	10.9
02-Sep-11	10.3		10.3
05-Sep-11		11.5	11.5

Appendix E: Internal load in Cottage Country

NEWSLETTER Canadian Society of Environmental Biologists

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

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

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

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

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

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

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

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

Important phosphorus forms

Phosphorus (P): Usually means total phosphorus, which is all phosphorus that can be analysed in a water sample. It includes phosphate, particulate forms, and other forms not easily available to be used by algae. Much external loading is comprised of all these forms.

Phosphate: A proportion of phosphorus that is directly available to plankton (algae, bacteria) in the water; it is usually below analytical detection limits in lakes on the Canadian Shield, except where internal loading occurs.

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

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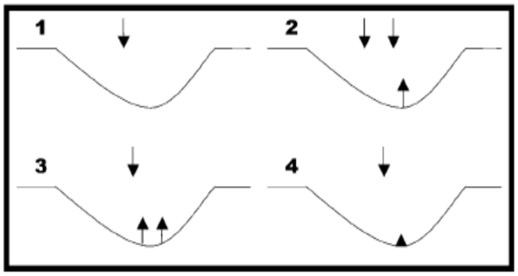

Figure 1. Presumed stages during the eutrophication process in lakes with respect to internal P load from the lake bottom (upwards arrow) in response to external load (downwards arrow). During Stage 1, external load happens, but no internal load. Even if the hypolimnia may be anoxic, there is not enough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

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

Further Reading: Nürnberg, G.K. 2001. Eutrophication and Trophic State - Why does lake water (quality) differ from lake to lake? LakeLine (North American Lake Management Society) 21(1), 29-33.

Nürnberg, G.K., and LaZerte, B.D. 2004. Modeling the effect of development on internal phosphorus load in nutrient-poor lakes. Water Resources Research. 40, (1), W01105, DOI:01110.01029/02003WR002410.

Nürnberg, G.K. 2007. Internal phosphorus loading in Ontario Cottage Country or "the devil is in the sediments". Canadian Society of Environmental Biologists, Newsletter 64 (4), 11-12.