Lake Capacity Study for Bright and Basswood Lakes

Prepared by

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June 29, 2011

Acknowledgement

The diligent support by the staff of Huron Shores for all aspects of the communication between the Municipality and FWR is much appreciated. We also appreciate the provision of comprehensive input data for lakeshore development.

Ray Lipinski of the Northeast Region MNR Office in Blind River provided copious support including equipment (DO meter), maps, digital information on lake bathymetry, watershed land use and hydrological information. His involvement is much appreciated. Similarly appreciated is Walter Shields of the MOE in Sault Ste. Marie whose up-beat involvement provided information including old reports and memos.

With respect to Bright Lake, the past president and founding member of the Bright Lake Association, John Milito, provided steady support and enthusiasm, which is gratefully acknowledged. Without his knowledgeable input and provision of background information and maps, the Bright Lake study (Nürnberg and LaZerte 2011) that contributes so much to the present report, would not have been possible. An Ontario Trillium Foundation grant to the Bright Lake Association provided funds for that study including support for equipment and lab analyses as well as the preparation of the Bright Lake report.

With respect to Basswood Lake, Secchi disk data were collected under the MOE Partner Program for Basswood Lake by Jon Cavanagh who provided them for inclusion in this report. John Fullerton provided his boating skills and general knowledge of Basswood Lake so that the principal author could take temperature and oxygen readings.

All this friendly support is gratefully acknowledged.

Cover Photos by GN:

Bright Lake (top) at the Milito Residence shoreline, 13 Sep 2009

Basswood Lake (bottom), 19 Sep 2010

Executive Summary

Following the request by the Municipality of Huron Shores a capacity study was performed for two lakes, (Big) Basswood or Wakwekobi Lake and Bright Lake or Pakawagamengan. Basswood Lake is a head water lake to Bright Lake and the lakes could not be more different in morphometry, water quality and land use of their immediate watersheds. Oligotrophic Basswood Lake is large, deep, stratified and has clear water, while mesotrophic Bright Lake is half the area but much shallower and polymictic with low water clarity and has sustained cyanobacterial blooms in the past.

To determine the capacity of the lakes first it was established that Basswood Lake is a designated cold water and lake trout lake. Such lakes have to comply with a MNR dissolved oxygen (DO) criterion that states that mean volume-weighted DO concentration for 15 Sep (measured between mid-Aug and mid-Sep, and adjusted if necessary) should be above 7 mg/L DO for a lake to be open for future development. DO profiles measured in Basswood's two basins on 19 Sep 2011 showed concentration above 10 mg/L at all depths. Therefore, Basswood Lake is impressively compliant with respect to the oxygen criterion and the same procedure as for Bright Lake can be used to determine its capacity.

In this approach, external and internal loads of total phosphorus (TP) are combined in a mass balance model with a predicted P sedimentation (retention) term to model growing season P and algal biomass indicators.

Whenever feasible, model input was used in accordance with the latest version of the MOE Lake Shore Capacity model (LSC 3). When more detailed information was available, like that of land use in the watershed and of internal P loading for Bright Lake, appropriate input was applied to render the model more specific. Some input with respect to shore line usage was based on the District of Muskoka Model (DMM), as it is more specific than corresponding input by the LSC.

The determination of a lake's capacity for development is based on the separation of natural and anthropogenic P loads and their application in a model that predicts ("models") growing season (summer and early fall) P concentration in the lake from these loads in combination with other lake characteristics, such as morphometry and hydrology.

Predicted lake P concentrations were compared with observed TP concentrations to validate the model. Considering the low TP concentration in Basswood Lake and the variable TP concentration and lack of historic data for Bright Lake the model adequately predicts water quality in these lakes (Table 0). Additional models (regression equations) were also used to predict algal biomass (as the pigment, chlorophyll *a*) and water clarity (as Secchi depth transparency).

Based on the present water quality and hypothetical scenarios the model can predict future water quality so that informed decisions on the extent of any future development can be made. Model results (Table 0) reveal that Basswood Lake is not at capacity (its P load is 1.21 times of its "pristine" load instead of 1.5 times, which is defined as "capacity" by the MOE) and its anthropogenic load could be increased by more than twofold, even after all vacant lots are developed.

On the other hand, Bright Lake is far above capacity, because its TP concentration is almost 4 times the pristine TP concentration (Table 0). A major reason for the exceedance is the internal P load that was estimated independently as almost equal to external load. The entire internal load

has to be attributed to anthropogenic activities. Next important is the agricultural area and a larger cleared area (>15%); the least important appears to be shoreline development.

Much of the information presented here is based on the report *Water Quality and Remediation Options for Bright Lake, Pakawagamengan* (Nürnberg and LaZerte 2011). We highly recommend consulting that report for further methodological details and background information.

Table 0. Observed lake characteristics (shaded) and model results for different scenarios

Observations & Scenarios	TP (µg/L)	Chlorophyll (µg/L)	Secchi (m)
Basswood Lake			
Observations	**4.6***	**na**	**11.3**
Model Results for Scenarios:			
Present	4.9	2.2	9.65
Vacant developed	5.1	2.2	9.49
Pristine	4.0	1.8	10.64
Capacity	6.0	2.5	8.85
Bright Lake			
Observations	**13.8**	**8.4**	**2.2**
Model Results for Scenarios:			
Present	15.1	5.7	3.36
Vacant developed	15.3	5.8	3.35
Pristine	4.0	1.8	6.14
Capacity	6.0	2.6	5.10

* Converted to growing season TP from spring TP of 3.2 µg/L according to Eq 3 of Appendix D

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1 Introduction

A lake capacity study is a tool for municipalities allowing them to determine whether present or future development may jeopardize the water quality of specific lakes in their jurisdiction. The assessment of lake capacity is a multi-step process and this report deals with the technical aspect of determining average growing season phosphorus (P) concentrations that are representative for the lake to be assessed. The implementation of the assessment falls to the municipality as outlined in the Lakeshore Capacity Assessment Handbook (Ministry of Environment 2010).

The Handbook summarizes the purpose and benefits of such an assessment in its executive summary as follows: *"Lakeshore capacity assessment … is a planning tool that can be used to control the amount of one key pollutant - phosphorus - entering inland lakes on the Precambrian Shield by controlling shoreline development. High levels of phosphorus in lake water will promote eutrophication - excessive plant and algae growth, resulting in a loss of water clarity, depletion of dissolved oxygen and a loss of habitat for species of coldwater fish such as lake trout."*

Further, the Handbook lists the following benefits for an assessment:

"Lakeshore capacity assessment enhances the effectiveness of the land-use development process in many ways:

- *It incorporates the concept of ecosystem sustainability in the planning process*
- *It is consistent with watershed planning*
- *It promotes land-use decisions that are based on sound planning principles*
- *It addresses many relevant aspects of the Provincial Policy Statement (2005), which came into effect on March 1, 2005. The Provincial Policy Statement is issued under section 3 of the Planning Act.*
- *It encourages land-use decisions that maintain or enhance water quality*
- *It encourages a clear, coordinated and scientifically sound approach that should reduce conflict among stakeholder groups*
- *It encourages a consistent approach to lakeshore capacity assessment across the province*
- *It is cost effective*

The net effect of lakeshore capacity assessment will likely be to shift development from lakes that are already well developed to those that are less developed."

The Municipality of Huron Shores was aware that Bright Lake (also called, Pakawagamengan) had previously experienced several water quality problems including toxic cyanobacterial (bluegreen) blooms and therefore considered such a study important. Water quality issues are not just a lake's problem, but reflect watershed usage and upstream water quality. Consequently the capacity study was expanded to include the upstream Basswood Lake (also called, Big Basswood or Wakwekobi Lake) and Freshwater Research was retained to determine development capacities of both, Basswood and Bright Lakes.

In this study, we applied a lake shore capacity model similar to that employed by the MOE (Version 3 of LSC) or the District of Muskoka (DMM) in order to determine the sources of phosphorus entering the lake (external P load). Such a model can also estimate pre-development water quality and determine whether any potential further development around the lake would noticeably reduce its present water quality. Internal P load, which has been determined in the Bright Lake Study independently was incorporated as described in Nürnberg and LaZerte (2004).

The determination of a lake's capacity for development is based on the separation of natural and anthropogenic P loads and their application in a model that predicts ("models") growing season (summer and early fall) P concentration in the lake from these loads in combination with other lake characteristics, such as morphometry and hydrology.

Predicted lake P concentrations have to be compared to observed concentration to validate the model with its lake specific inputs. The predicted and observed P concentrations can be further applied in additional models (regression equations) to predict algal biomass (as the pigment, chlorophyll *a*) and water clarity (as Secchi depth transparency).

Based on the present water quality and hypothetical development scenarios the model can predict future water quality so that informed decisions on the extent of any future development can be made.

Much of the information presented here is based on the report *Water Quality and Remediation Options for Bright Lake, Pakawagamengan* (Nürnberg and LaZerte 2011). We highly recommend consulting that report for methodological details and background information with respect to Bright Lake.

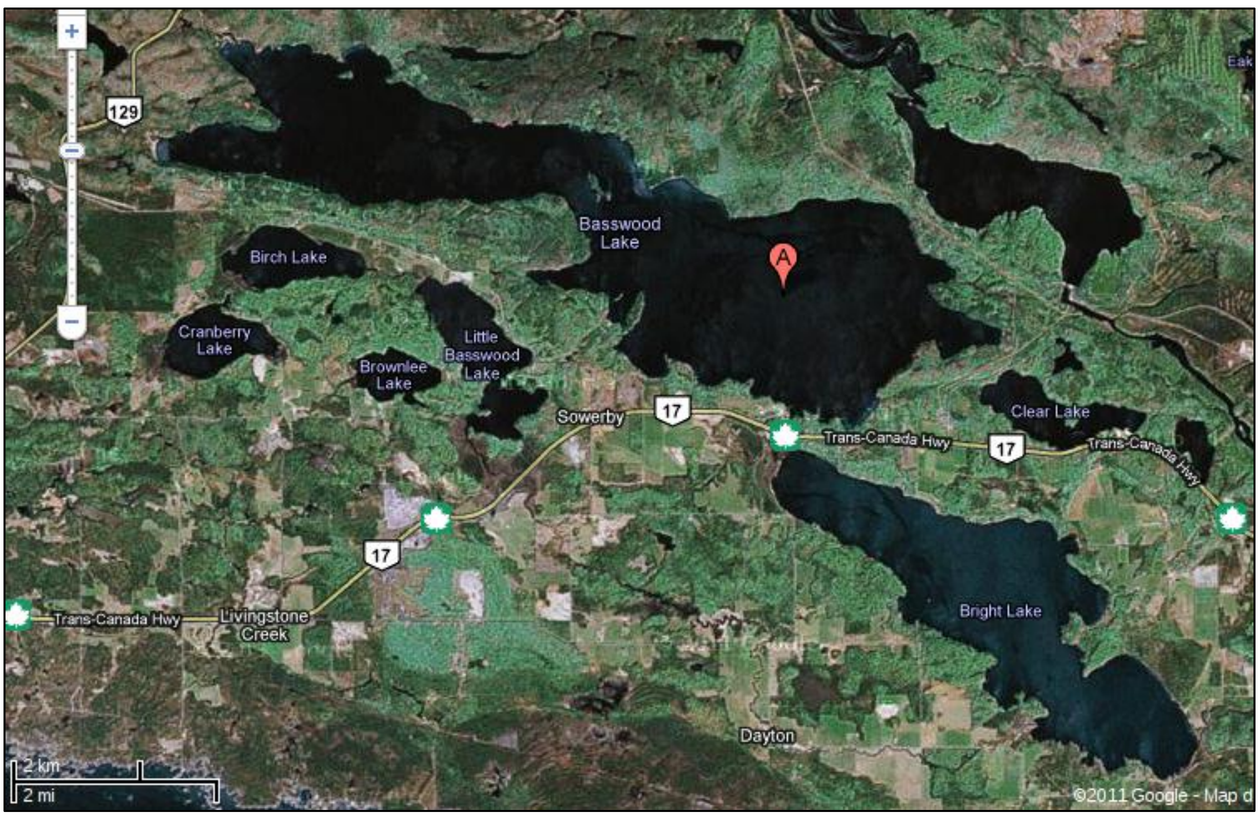

Figure 1. Satellite view of Basswood (A) and Bright Lake, from Google Map

2 Characteristics of Bright (*Pakawagamengan)* and Basswood (*Wakwekobi*) Lake

2.1 Morphometry and hydrology

The lake shore capacity model requires a certain amount of data specific to the study lakes as input into the model as well as for its evaluation and verification. Characteristics such as morphometry and hydrology can be used in the model directly, if available, and are listed in Table 1. Flushing rate and water load for Bright Lake is based on outflow volume that was estimated from runoff height for nearby regions (listed in the Hydrological Atlas updated from Canada Department of Fisheries and Environment 1978) as suggested in LSC 3. For Basswood Lake these variables could be computed from metrics provided by MNR (Appendix A).

The lakes' layer morphometry (Table 2, Table 3) is based on new GIS determinations provided by Ray Lipinski, MNR (6 Dec 2010, Figure 2 and Figure 3). The bathymetric information for the lakes reveals the morphometric differences between them. Basswood Lake is about twice as large as Bright Lake by area, but more than 18 times by volume (Table 1). The watershed to area ratio of Basswood reflects that it is a headwater lake with only little impact from the watershed, while Bright Lake's ratio is almost 7 times higher reflecting that Bright Lake drains a large area (Table 1).

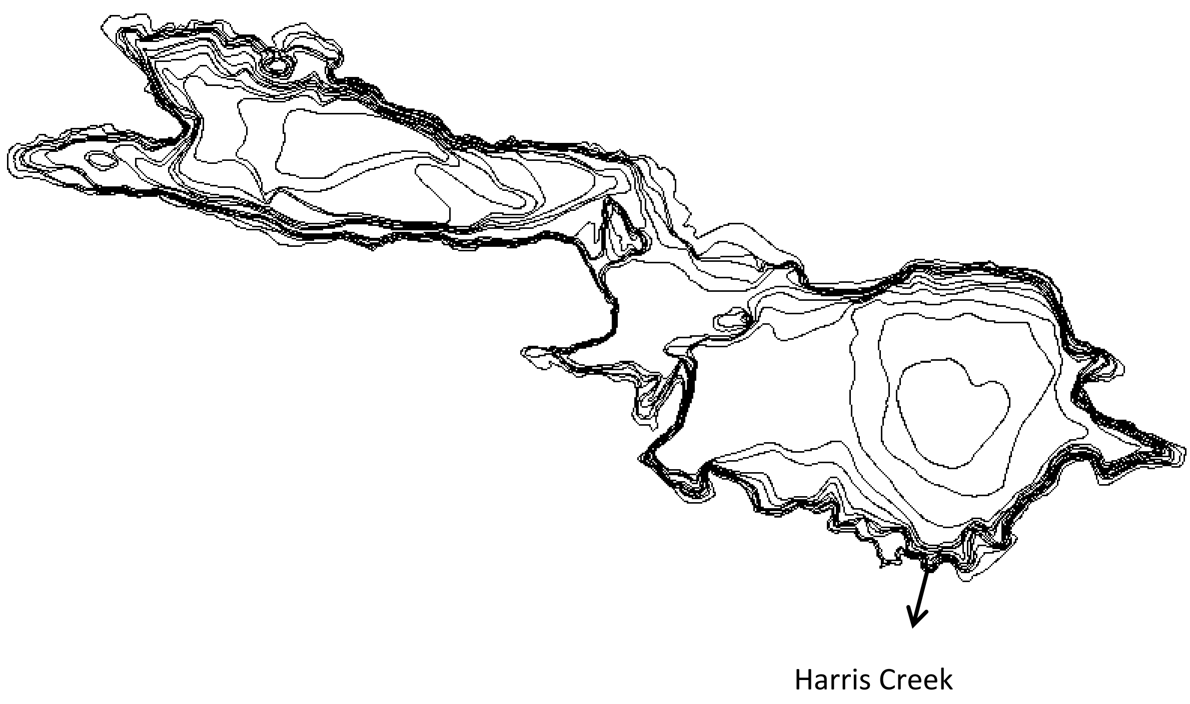

Figure 2. Basswood Lake depths contours (10 feet, 3.05 m)

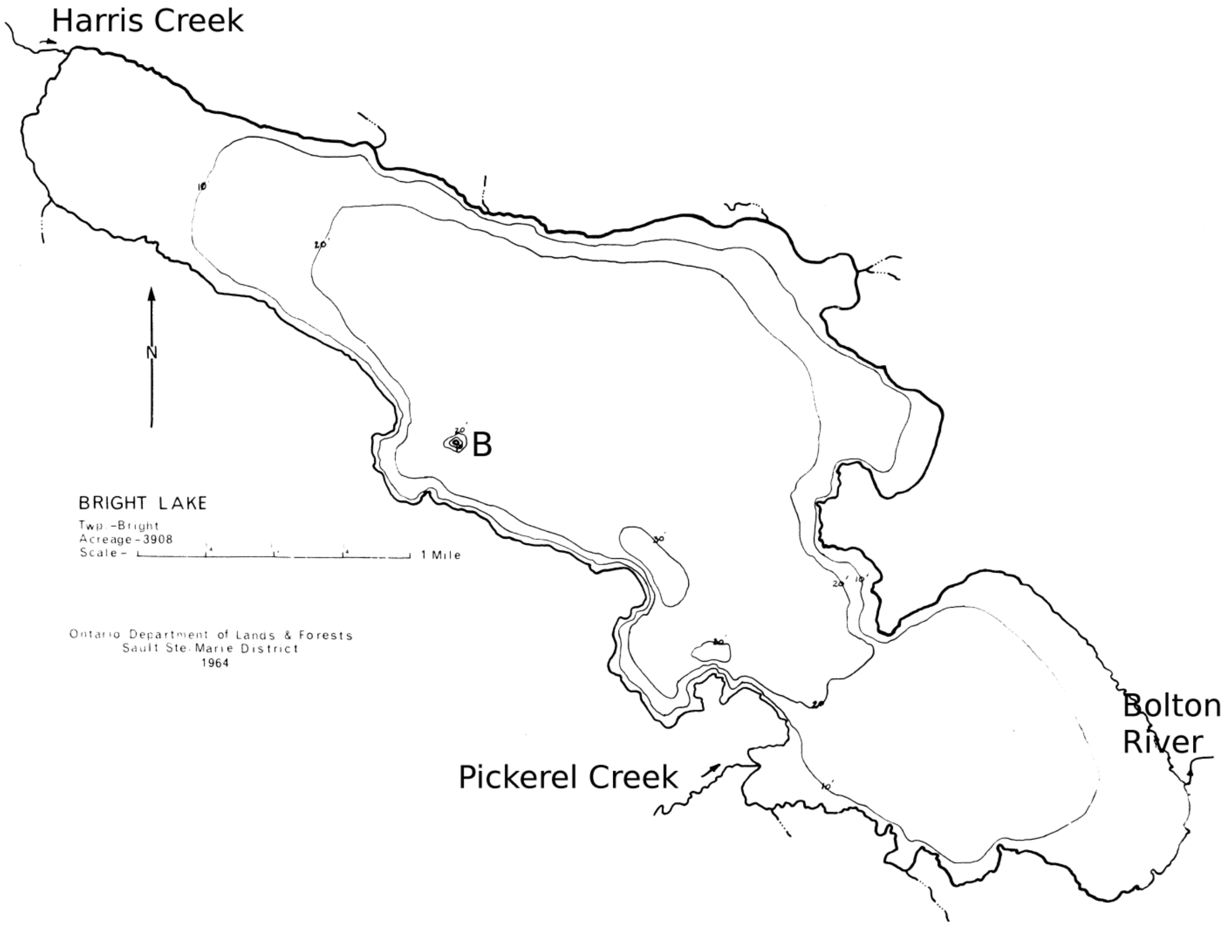

Figure 3. Bright Lake depths contours of 10 feet (3.05 m)

The main deep sampling station is indicated as "B".

Table 1. Morphometric and hydrological characteristics of the lakes

Characteristics	Bright	Basswood
Approximate location:	46°12.9' 83°12.5'	46°19' 83°22'30''
Surface Area, Ao (km²):	12.32	26.95
Watershed Area, Ad (km²):	173.76	60.89
Ratio of areas Ad/A_o:	14.10	2.26
Maximum Depth, zmax (m):	12.19	73.2
Mean Depth, z (m):	4.91	37.9
Volume (10^6 m³):	60.45	1,022.45
Annual flushing rate (per yr):	1.43*	0.047*
Annual water load (m/yr):	6.99*	1.77*
Perimeter (km)	27.46	35.2

*For Bright: based on runoff height from hydrological atlas (Canada Department of Fisheries and Environment 1978)

For Basswood: based on flow metrics provided by MNR hydrologist

Table 2. Layer-morphometry of Basswood Lake

Depth (m)	Area at upper depth (m²)	Volume interval (m³)	(%)
0 - 3.05	26,949,624	79,460,124	7.8%
3.05 - 6.1	25,199,358	75,111,223	7.4%
6.1 - 9.1	24,090,380	71,750,600	7.0%
9.1 - 12.2	22,994,319	68,615,284	6.7%
12.2 - 15.2	22,032,260	65,403,739	6.4%
15.2 - 21.3	20,888,658	117,393,393	11.5%
21.3 -27.4	17,671,061	105,825,475	10.4%
27.4-33.5	17,050,432	99,684,954	9.8%
33.5 - 39.6	15,664,397	91,010,614	8.9%
39.6 - 45.7	14,206,593	73,408,478	7.2%
45.7 - 54.9	10,000,304	78,514,640	7.7%
54.9 -61.0	7,246,390	41,310,196	4.0%
61.0 - 67.1	6,317,440	33,768,319	3.3%
67.1 - 73.2	4,796,270	20,166,371	2.0%
73.2 - 74.7	2,017,456	1,024,868	0.1%
Total		**1,022,448,278**	100%

Note: computed from GIS information provided by Ray Lipinski, 6 Dec 2010

Table 3. Layer-morphometry of Bright Lake

Depth (m)	Area at upper depth (m²)	Volume interval (m³)	(%)
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		**60,452,636**	**100%**

Note: computed from GIS information provided by Ray Lipinski, 6 Dec 2010

2.2 Watershed connectivity

Almost half of the Bright Lake watershed consists of the upstream Basswood Lake with its catchment basin. Basswood's outflow is Harris Creek that flows into the north western tip of Bright Lake (Table 4). The next largest inflow is Pickerel Creek, which drains 30% of the remaining area. Pickerel's headwaters are comprised of three lakes and a wetland: Cranberry Lake drains into Birch Lake which flows into Little Basswood or Cully Lake (Table 5, Figure 4). Pickerel Creek then passes through a wetland and under the Provincial Highway 17, after which it meanders through grass lands and agriculturally used lands to Bright Lake.

Table 4. Bright Lake sub-watersheds *(MNR 26 April 2010)*

Description	Area	
	km^2	%
Basswood Lake	27.0	16%
Basswood watershed to inflow of Bright	60.89	35%
Not accounted for	10.69	6%
Pickerel	52.67	30%
Southern shoreline	11.76	7%
Northern Shoreline	10.68	6%
Total Watershed w/o Bright Lake (A_d)	173.76	100%
Bright Lake (A_o)	12.32	
Ratio of A_o/A_d	14.1	

Table 5. Surface areas of lakes in the Bright Lake watershed

Water	Area (km^2)
Basswood	27.0
Bright	12.32
Little Basswood (Cullis Lake)	2.14
Birch	1.43*
Cranberry	1.43*
Brownlee	0.71*
Total of lakes	45.10
River, creeks, ponds	4.83
Overall total	49.93
Lake area not modelled separately	*5.72*

*Areas are estimated from maps

The three smaller upstream lakes (Birch, Cranberry and Brownlee) are not modeled separately in this study because the extent of their individual sub-watersheds and several morphometric characteristics are not known. Treating this lake area as watershed area barely affects the calculations because it only represents 3.3 % of the total Bright Lake watershed area (5.7 unknown lake area of 5.7 km^2 versus 174 km^2 watershed area, Table 4 and Table 5).

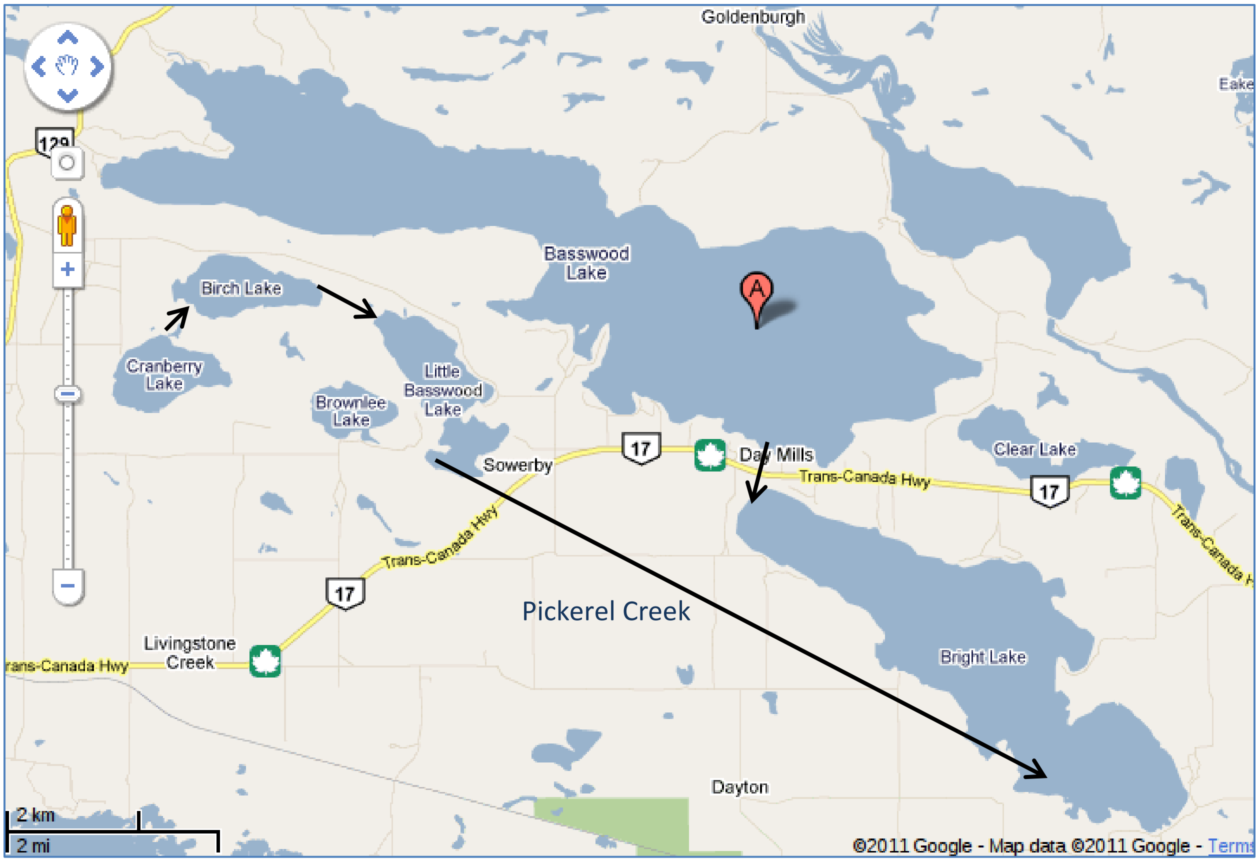

Figure 4. Schematic connections between lakes (arrows)

2.3 Water quality

The capacity assessment's main predicted variable is the summer (growing season) average total phosphorus (TP) concentration. From TP a lake specific or general regression is applied to predict the algal biomass indicators, chlorophyll *a* (the green algal pigment) and Secchi disk depth transparency (Secchi). Secchi combined with an estimate of lake water colour, is a potent predictor of algal biomass, but it stands alone as a measure of lake water quality as it appears to the naked eye of the lake user. The three variables of TP, chlorophyll and Secchi are used to determine the trophic state of lakes (Table 6).

According to the trophic state evaluation, observed long-term growing season average water quality classifies Bright Lake as mesotrophic (Nürnberg and LaZerte 2011) and Basswood Lake as oligotrophic or even "ultra-oligotrophic". The individual water quality variables are discussed in the next two sections separately for each lake.

Table 6. Trophic state categories based on summer water quality (Nürnberg 1996)

	Bright	Basswood	Oligo trophic	Meso trophic	Eu trophic	Hyper-eutrophic
Secchi Transparency (m)	2.2	11.3	> 4	2 – 4	1 – 2	< 1
Total phosphorus (µg/L)	14	4.2*	10	10 – 30	31 – 100	> 100
Chlorophyll *a* (µg/L)	6.3	NA	< 3.5	3.5 – 9	9.1 – 25	> 25

*Converted to growing season TP from spring TP of 3.2 µg/L according to Eq 3 of Appendix D;
NA, not available

2.3.1 Bright Lake

There are not many long-term water quality data available for Bright Lake and most of observed water quality is based on the study 2009 and 2010 (Nürnberg and LaZerte 2011). Highlights are presented here.

Water quality in Bright Lake was comparably good in the growing season of 2010 as there were no cyanobacterial (bluegreen) blooms. Summer average Secchi transparency at the main station was 2.2 m and decreased in the fall (Figure 5). Secchi disk readings were never below 1m, which is the Ontario guideline for contact sport. However, Bright Lake is relatively turbid considering its location on the Canadian Shield and its trophic state has to be classified as almost eutrophic (at 2 m and below) with respect to Secchi transparency (Table 6).

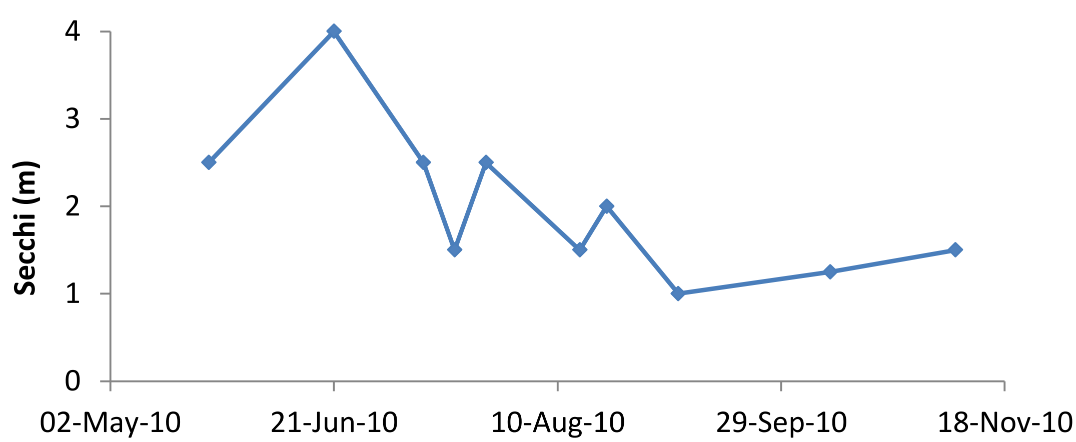

Figure 5. Secchi disk transparency at the main station in 2010

Phosphorus data are available for two growing seasons. They indicate an increasing trend of TP throughout the growing season in 2009 from 11 to 25 µg/L and in 2010 from 8 to 19 µg/L TP between 2 May and 6 Sep., if the low values of 15 Aug were not considered (Figure 6). (It is unlikely that such low values below 3 µg/L are real; they may indicate an analytical interference problem. Detection limit was 2 µg/L.) Increasing TP concentration throughout summer and early fall is often due to sediment P release that is enhanced by elevated water temperature.

In these two years the provincial water quality objective for lake water of 20 µg/L summer average TP (Ministry of Environment 1994) has not been exceeded in Bright Lake.

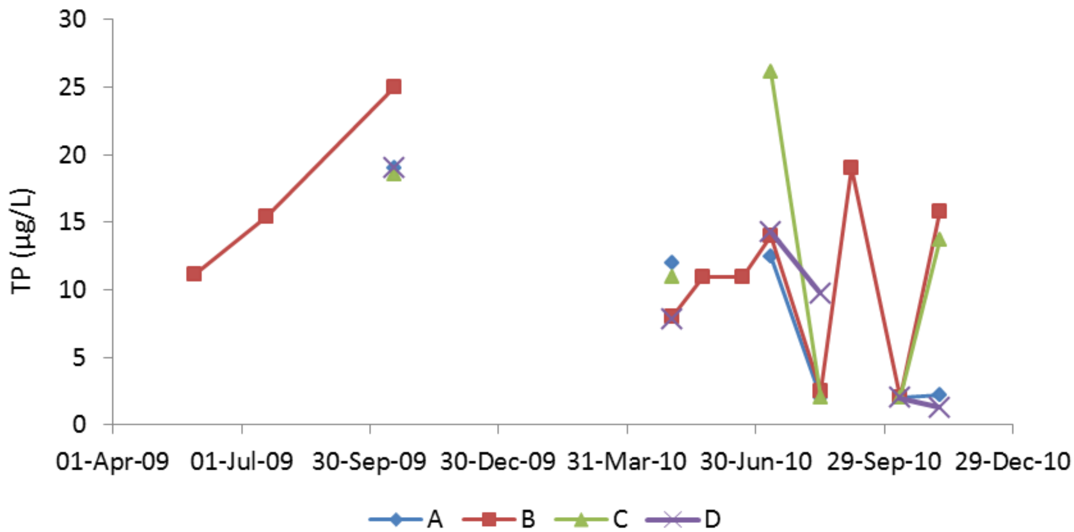

Figure 6. All available TP results in the mixed surface layer of Bright Lake

(with B, main deep station, and A,C,D at shallower sites, from Nürnberg and LaZerte 2011)

Dissolved oxygen profiles especially in summer 2010 indicate sub-saturation concentrations throughout the water column (< 6 mg/L) in Bright Lake (Figure 7). These results indicate the relative difference between upper and lower layers and a decrease of DO concentration with depth. Such a pattern is usually created by a severe sediment oxygen demand which is consistent with the overall low DO concentration and likely increased because of relatively high temperatures also in the deeper water (19-20° C during hypoxia in 2009 and 20-22° C in 2010). Occasional stratification is indicative of polymictic lakes and is typical for shallow lakes such as Bright. Occasional hypoxia is representative of mesotrophic conditions in polymictic Bright Lake.

Bright Lake is categorized as entertaining warm water fisheries so that the Provincial Water Quality Objective (PWQO) of 5 mg/L DO applies. DO concentration was below 5 mg/L at several occasions in 2009 and most of the summer 2010 at and below 8 m. Severe hypoxia starting at 6 m was measured on 18 July 2010. This means that 11% of Bright Lake (Table 3) was not acceptable to warm water biota during that period. In several previous springs, fish kill was observed in the south eastern portion of the lake (John Milito, pers. comm.) and may indicate hypoxic conditions under ice. Nonetheless, a survey by MNR on 5-9 July 2010 indicated a flourishing warm water fishery with 17 fish species, including: Longnose Gar, Bowfin, Rainbow Trout, Cisco (Lake Herring), Rainbow Smelt, Northern Pike, White Sucker, Shorthead Redhorse, Spottail Shiner, Brown Bullhead, Trout-Perch, Rock Bass, Pumpkinseed, Small- and Largemouth Bass, Yellow Perch and Walleye.

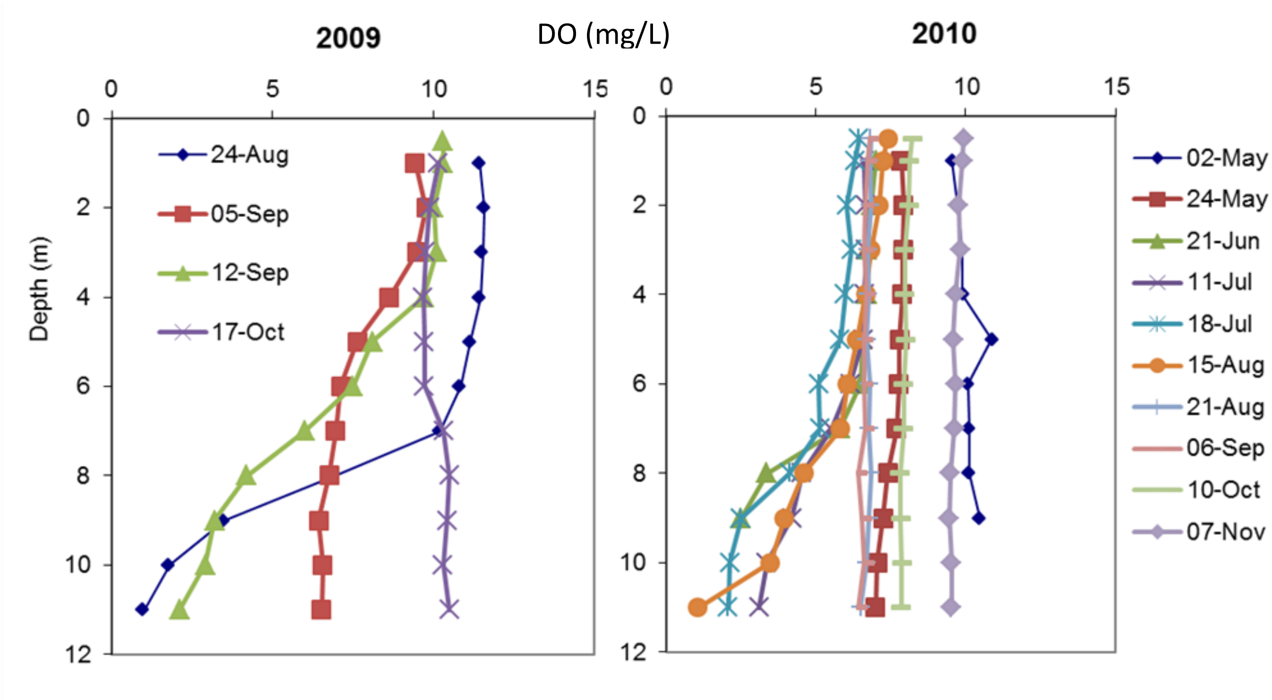

Figure 7. Dissolved oxygen profiles for 2009 and 2010 in Bright Lake

2.3.2 Basswood Lake

A long-term data set is available for Basswood Lake, as it was always considered an important cold water and trout lake. In particular, 12 years of observations are available, starting 1975 (Figure 8, Table 7). TP was measured in May shortly after ice-out as spring overturn TP and Secchi disk transparency was determined throughout the summer and early fall. Besides some early measurements by the MOE, these data were collected by volunteers, starting 1999 with the Lake Partner Program of the MOE (Appendix B).

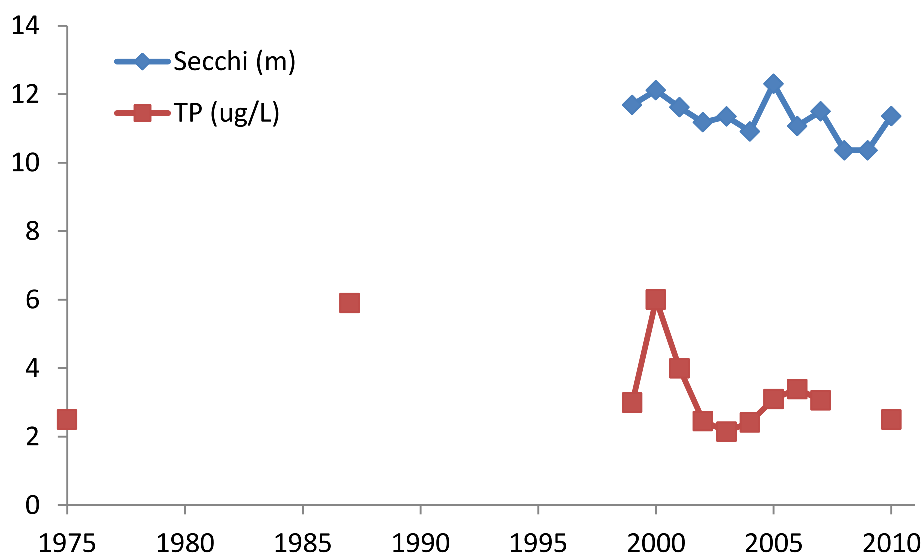

Figure 8. Secchi transparency growing season averages and Spring TP for Basswood Lake

Table 7. Secchi and TP values for Basswood Lake

Data Source	Year	Secchi (m)	TP (µg/L)	Date of TP Sampling
MOE Capacity Memo 1991	1975	NA	2.5	Spring
MOE Capacity Memo 1992	1987	NA	5.9	Spring
Lake Partner	1999	11.7	3	
Lake Partner	2000	12.1	6	
Lake Partner	2001	11.6	4	
Lake Partner	2002	11.2	2.5	28-May-02
Lake Partner	2003	11.3	2.2	15-May-03
Lake Partner	2004	10.9	2.4	12-May-04
Lake Partner	2005	12.3	3.1	08-May-05
Lake Partner	2006	11.1	3.4	23-May-06
Lake Partner	2007	11.5	3.1	08-May-07
Lake Partner	2008	10.4	NA	
Lake Partner	2009	10.4	NA	
Lake Partner	2010	11.4	2.5	16-May-10
Lake Partner	**Average**	**11.3**	**3.2**	

NA, not available

A long term spring TP concentration average of 3.2 µg/L indicates nutrient-poor water that would not sustain any nuisance cyanobacterial blooms. Secchi disk transparency is also very high with summer averages between 10.4 and 12.1 m. Individual transparency values measured throughout the growing period (Figure 9) indicate lower transparency in the spring, possibly due to spring algal blooms (which are beneficial), but clarity is often at its maximum in late summer and fall (Aug, Sep), which is opposite to mesotrophic Bright Lake, indicating no internal P load or bluegreen blooms. All these values and seasonal trends are typical for oligotrophic lakes.

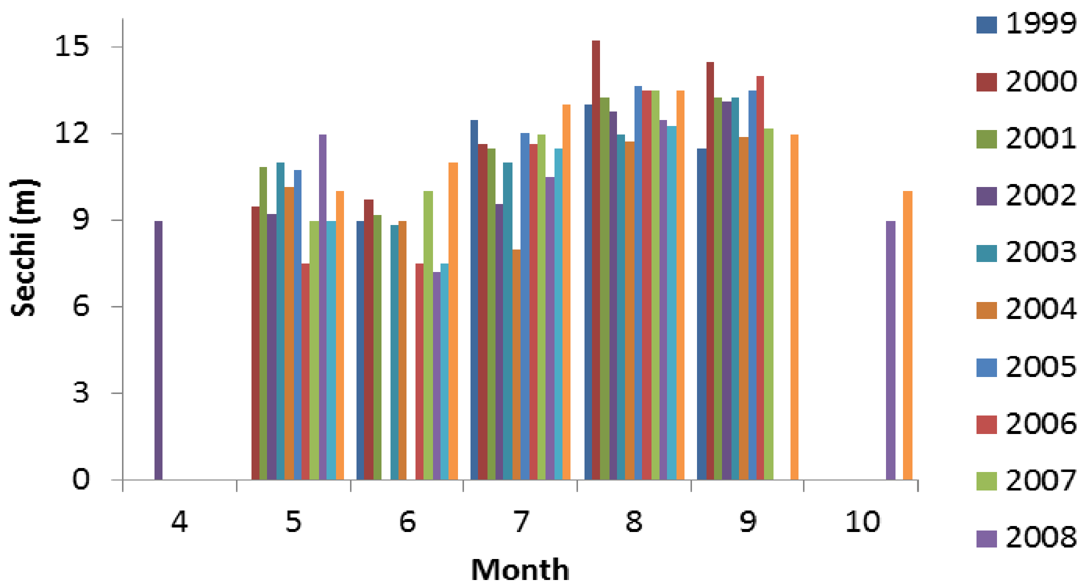

Figure 9. Monthly averages of Secchi transparency for Basswood Lake

Basswood Lake's good water quality also extends to its dissolved oxygen (DO) concentration. Temperature and DO profiles were taken once at 1 m depth intervals with a DO Meter (Hanna Instruments HI 9146 Portable Waterproof Microprocessor) borrowed from the Blind River MNR. Profiles were measured in the fall at a time when any oxygen demand would be highest and DO concentration lowest. They still reveal close to 100% saturation at values above 10 mg/L. The lowest concentration was 10 mg/L at 15 m in the eastern basin and 11.4 in the upper 2 m of the western basin (Figure 10). Temperature below the thermocline was below 10° C and therefore supports cold water fisheries. Consequently, classification with respect to fisheries is cold water, lake trout fisheries for Basswood Lake.

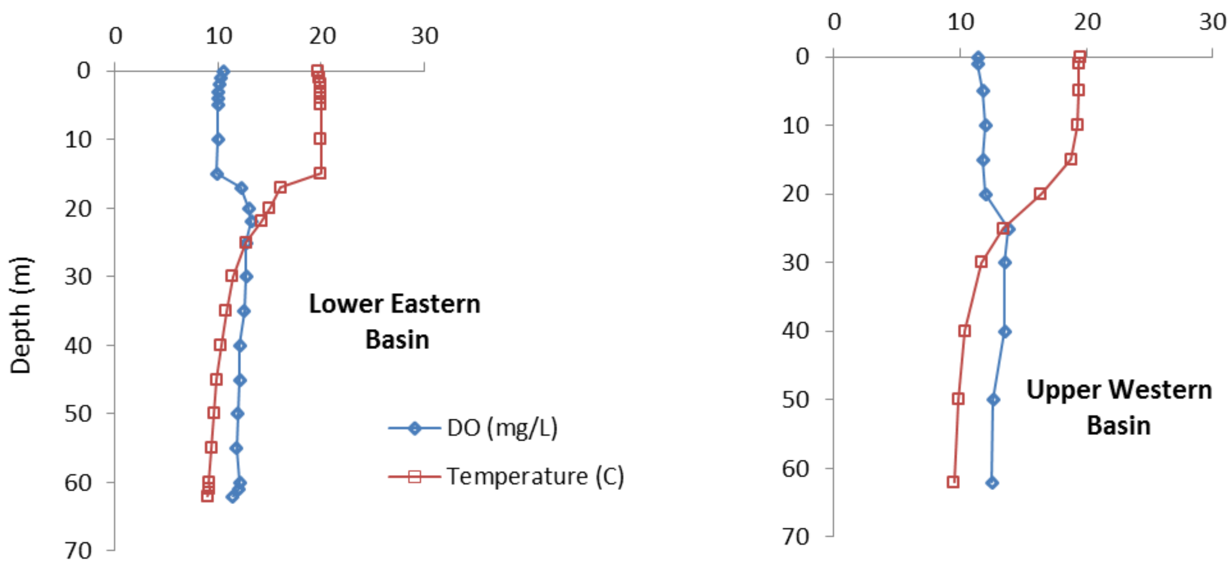

Figure 10. Temperature and dissolved oxygen profiles for Basswood Lake eastern and western basins, determined on 19 Sep 2010 by Gertrud Nürnberg.

There are provincial DO criteria to protect lakes with lake trout (*Salvelinus namaycush*). The most recent one (Ministry of Natural Resources 2006, Appendix C) states a minimum volume-weighted hypolimnetic DO of 7 mg/L measured within 2 weeks of August 31 and adjusted to Sept 15 conditions. Basswood Lake's values are far above this value at approximately 13 mg/L for the upper and 12 mg/L for the lower basin (measured at and below 25 m depth on Sep 19, Figure 10). Since Basswood is compliant with respect to the DO criterion, the evaluation of its capacity follows the same procedure as that for Bright Lake, i.e. the capacity evaluation with respect to TP loading (Appendix C).

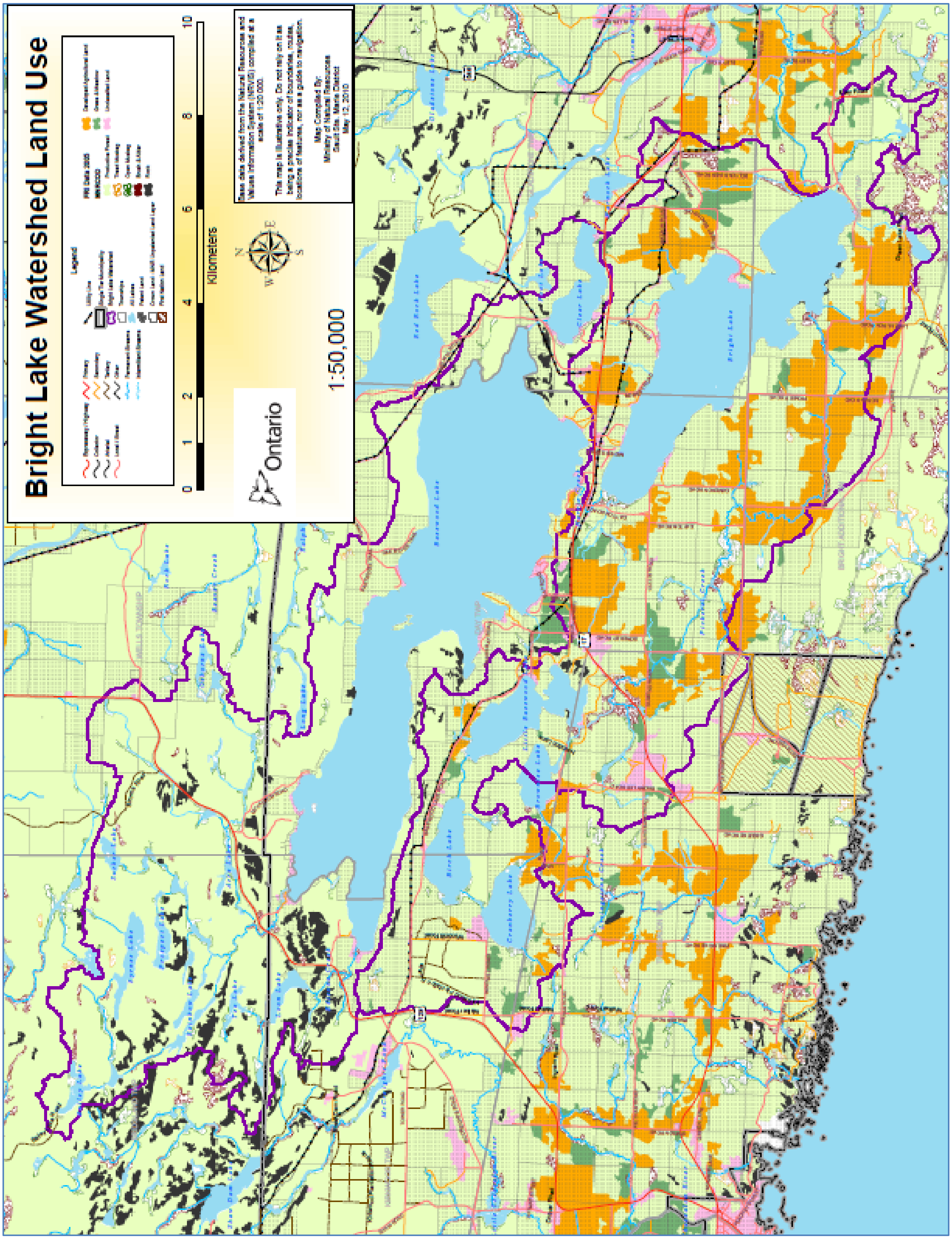

Figure 11. Bright Lake watershed land use map *(MNR 12 May 2010, an electronic map is included)*

3 Determination of P loading

Whenever feasible, model input was used in accordance with the latest version of the MOE Lake Shore Capacity model (LSC 3). When more detailed information was available, like that of land use in the watershed and of internal P loading for Bright Lake, appropriate input was applied to render the model more specific. Some input with respect to shore line usage was based on the District of Muskoka Model (DMM), as it is more specific and applicable to this region than corresponding input by the LSC (Table 8).

Table 8. General model input variables to compute external P load

Variable	Value	Source*
Precipitation (mg P m^{-2} yr^{-1})	16.7	LSC 3
Runoff (m yr^{-1})	0.35 - 0.50	[*Canada 1978*]
P-export from the watershed (mg m^{-2} yr^{-1})		
Wooded < 15% cleared areas	5.5	LSC 3
Wooded > 15% cleared areas	9.8	LSC 3
Agriculture	30	LSC 3
Urban	50	LSC 3
Lake shore lot within 300 m (dwelling, resort, campground)	22.5	DMM
Lakeshore usage figures (capita years yr^{-1})		
Seasonal cottage	0.69	LSC 3
Year-round dwelling	2.56	LSC 3
Urban lake shore dwelling	2.09	DMM
Resort unit	1.27	LSC 3
Campground, some trailers	0.37	LSC 3
Trailer park	0.69	LSC 3
P Supply from tile fields of septic systems (kg $capita^{-1}$ yr^{-1})		
Within 100 m	0.30	Calibration
Trailer & camp sites within 100m:	0.15	Assumption
Average developed areas per lot (m^2 $unit^{-1}$)**		
Cottage	2000	Survey DMM
Resort	1000	Survey DMM
Campground/Trailer park	1000	Survey DMM

*Source: LSC 3, third version of the MOE Lake shore Capacity Model (Paterson et al. 2006)
DMM, District of Muskoka Model and survey (Nürnberg and LaZerte 2004)

**Used to determine P export from lake shore lots

3.1 External sources

Based on land use information provided by the MNR (Figure 11) and applicable TP export coefficients, external load was evaluated for the lake capacity assessment of Bright and Basswood Lakes.

External P input from atmospheric and terrestrial sources in the catchment basin to Basswood and Bright Lake was estimated according to assumptions and constants of LSC (Table 8). This approach considers the amount of cleared and wetland areas (percentage of their respective watersheds Table 9, Appendix E) in addition to sources from agricultural and shoreline development.

Table 9. Watershed characteristics of the lakes, input for LSC model

(Percentages used in the LSC Model are given for the corresponding watersheds in parentheses)

	Areas (km^2)			
	Cleared	Wetland	Farms	Meadows
Designation by MNR:	*Agricultural land Grass & meadows*	*Treed & open Muskeg*	*Developed agricultural land*	*Grass and Meadow*
Basswood*	1.05 (1.7%)	0.11 (0.18%)	0.25	0.80
Bright**	19.06 (22.3%)	3.03 (3.53%)	15.50	3.56

*Separately estimated from MNR land use map

**provided by MNR

The Municipality of Huron Shores provided development information within 300 m around the shoreline of Bright and Basswood lakes (Figure 12), as assembled from tax role information by town staff (*Assessment Roll and Assessment Base Mapping*, Table 10). The seasonal units include about 20 trailers on private properties around Bright Lake and an unknown number for Basswood Lake.

Table 10. Lake shore development units, based on tax role information of Bright and Basswood Lake

Unit Description	Bright	Basswood
	(# of units or lots)	
Permanent	32	22
Seasonal	121	233
Resort	0	29
Campground	30	60
Vacant	57	76

Since Basswood is upstream of Bright Lake, only a fraction of its external load reaches Bright. A pristine lake like Basswood retains a large proportion of its external load (predicted from annual water load as 0.76 in the model, Appendix D) that does not reach Bright Lake and is considered in the calculation of Bright Lake's load. Loads for Basswood and Bright Lake and retention in Basswood are presented in Table 11. Bright Lake has a large annual TP load which is almost twice as high as Basswood's when expressed in kg and almost four times as high when expressed per lake area in mg/m^2.

Figure 12. Shoreline development on Basswood Lake (GN, 19 Sep 2010)

Table 11. Input values and loading results of the LSC approach

Description	Units	Basswood	Bright
Area	(km^2)	27	12
Runoff coefficient, r	(m)	0.543	0.392
Annual water load, q_s	(m/yr)	1.77	6.99
TP Retention (R)	proportion	0.76	0.60
Natural External Load	(kg/yr)	785	1,246
Anthropogenic Load	(kg/yr)	187	472
Present external load	(kg/yr)	972	1,718
(sum of above)	($mg/m^2/yr$)	36	139

Table 12. Bright Lake watershed land use areas, specific TP-export coefficients and computed loads

Land Type	Area (m^2)	TP-Export ($mg/m^2/yr$)	Load* (kg/yr)	Source
Water (load from Precipitation)	49,931,682	16.7	834	Precipitation, LSC
Productive Forest	103,114,224	5.5	567	Forest <15 cleared, LSC
Treed Muskeg (Wetland)	223,362	50.0	11	Wetland, LSC
Open Muskeg (Wetland)	2,920,898	50.0	146	Wetland, LSC
Brush & Alder	2,170,846	5.5	12	Forest <15% cleared, LSC
Rock	3,842,603	5.5	21	Forest <15% cleared, LSC
Developed Agricultural Land	15,749,605	30.0	472	Intensive agriculture, LSC
Grass & Meadow	4,356,863	30.0	131	Intensive agriculture, LSC
Unclassified Land	3,770,640	9.8	37	Forest >15% cleared, LSC
Shoreline Development within 300 m (8,239,500m^2, included in above)			*115*	*LSC Model*
Bright Lake	12,321,254			
Watershed w/o Bright Lake (Ad)	173,759,468			
Total	186,080,722		2,347	
Load retained in Basswood (0.76 modeled retention)			-738	
Based on Load for Basswood 972 kg/yr from LSC				
External load, total of above			1,609	

*Determined as: Load= area x export /10^6

For finer resolution of the P sources, external load to Bright Lake was also estimated from the more detailed GIS-based information on land use in the catchment basin (Figure 11). For this effort, corresponding export coefficients were taken from the same sources as those of the LSC and lake shore development input of the LSC approach was added to the external load estimate based on land use area (Table 12).

Export coefficients were not available for some of these land use categories and had to be extrapolated from available information (e.g., the export from wetlands was extrapolated to 100% peat from the equation in Fig. 4, Appendix E) or approximated from similar land use characteristics.

Partitioning external load according to the land use information in the Bright Lake watershed (Figure 13) identifies the relative importance of the various P sources and their potential effects on lake water quality. Loads from precipitation onto the lakes and creeks in the watershed are the highest single source of P (35%) followed by the extended forested area (24%), as is typical for relatively remote lakes on the Precambrian Shield. The next largest source is agriculture, which together with grass & meadows represent the extended farming activities in the watershed that together bring 25% of total external load. Wetlands contribute 8% and shoreline development of Bright Lake 6% of the P load.

Bright Lake external load estimated this way from more detailed land use information (1,609 kg/yr, Table 12) compares well to that from the LSC approach presented first (1,718 kg/yr, Table 11). The difference is due to uncertainty in some of the export coefficients applied to the land use categories and the different approaches to treating wetland and cleared lands. The LSC approach does not require many of the specific export coefficients as it only needs input on the agricultural area and the proportion of cleared land and wetland, besides the statistics for lake shore development.

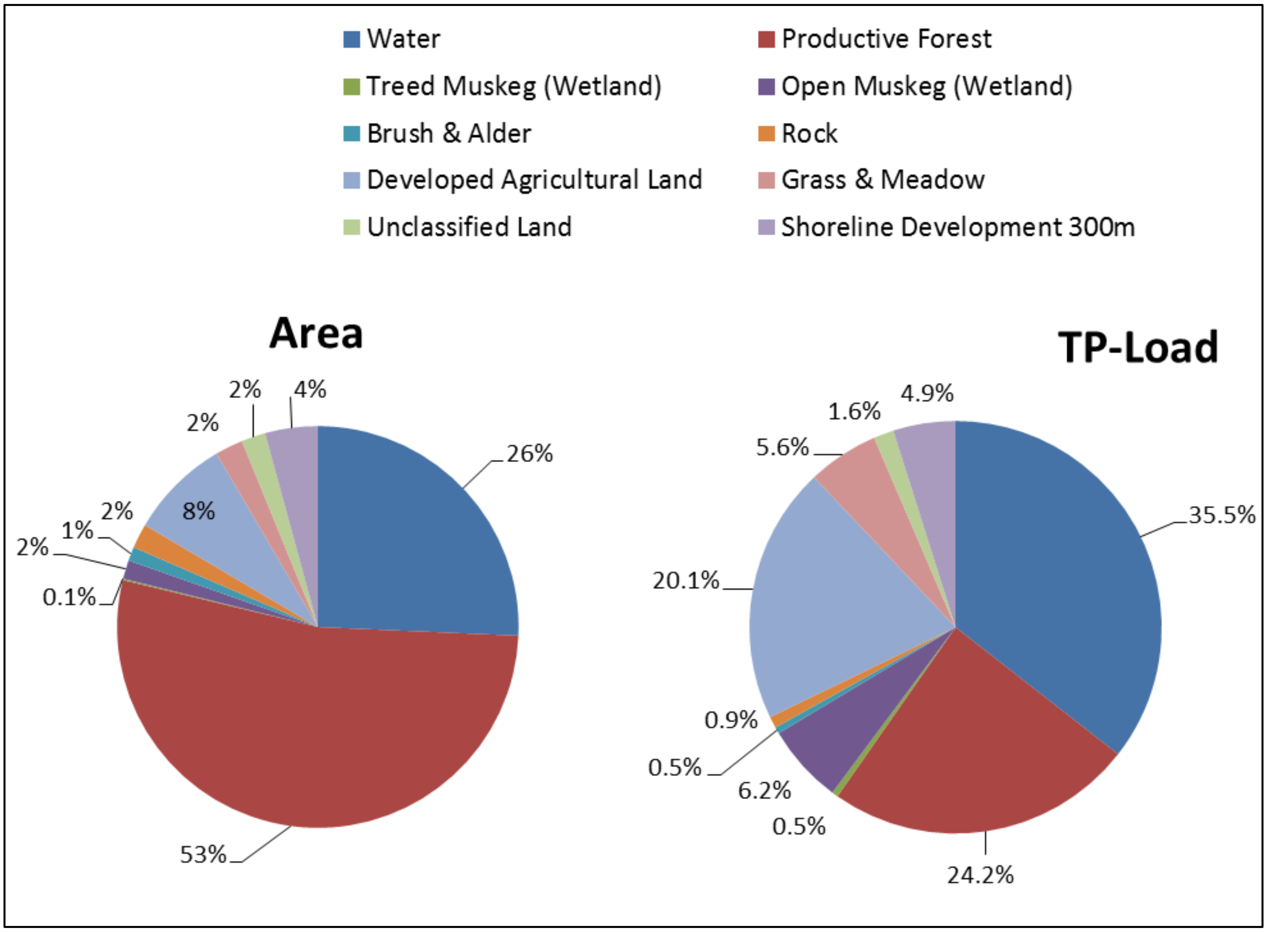

Figure 13. Watershed areal and loading proportions for Bright Lake (based on Table 12)

While the export coefficients used in this assessment represent an overall average of conditions for the specific land use that may slightly deviate in the Bright Lake watershed (for example, newly incorporated farm management practices may decrease the export from those areas), the results are distinct enough to support the following conclusions.

If it should be deemed necessary to decrease the P load to Bright Lake to achieve acceptable water quality, mainly anthropogenic loads must be considered. Natural sources like precipitation or wetland, even though beaver ponds were found to contribute a large amount of P to receiving waters (Devito and Dillon 1993; Paterson et al. 2006), can or should only be marginally managed. Of anthropogenic sources, those of development and agriculture are potentially manageable and can be decreased. For example, septic system inspection and renewal, education to minimize fertilizer applications and agricultural best management practices (BMPs) can help minimize such sources.

A more detailed discussion of management suggestions is presented in the Bright Lake Remediation Report (Nürnberg and LaZerte 2011).

3.2 Internal sources

In some lakes there are internal P sources such as chemical release from sediments, senescing macrophytes (decaying weeds), gas formation and wind action that distributes bottom and shoreline sediments. The Bright Lake Study (Nürnberg and LaZerte 2011) determined that chemical release is important in Bright Lake. Internal load as P released from bottom sediments is a difficult quantity to estimate in mesotrophic shallow and polymictic lakes, such as Bright. It is especially important to consider this P source in relatively remote lakes, because it can be the single most important "point" source of a readily available form of P, which is phosphate, as it is directly injected into the lake water where it can be used by P starved phytoplankton.

The underlying mechanism is that anoxia leads to the dissolution of iron hydroxides in sediments with concomitant release of adsorbed P (i.e., P attached to the iron surfaces) to adjacent lake water. Although internal loading mostly stems from former external inputs which are stored in sediments, it is often ignored in P mass balance studies because of difficulties in obtaining estimates. Because of its high biological availability and the timing of its release during summer stratification, internal P loading can have an immense negative effect on summer water quality of a lake. However, it is not always easy to determine the quantity of the internal load and there are many potential problems associated with separating the contribution of internal from external P sources to a lake (Nürnberg, 2009). Accordingly, a variety of independent approaches to quantify sediment derived P for as many years as possible were applied in the Bright Lake Study and are used as input in the capacity model applied here (Table 13), until more data become available.

Because Basswood Lake is a deep and stratified lake that does not show any indication of oxygen depletion as described in Section 2.3.2, it is unlikely that there is any sediment P release from its sediments. Consequently, internal load in Basswood Lake was considered to be absent in the model (Table 13).

Table 13. Internal load estimates (Bright Lake Study)

	Internal Load estimates	
	(mg/m^2/summer)	(kg/yr)
Bright Lake *(from Bright Lake Study)*		
Sediment Model estimates	44 - 127	
In situ increases estimates	129	
Proposed input for capacity study	125	1,540
Basswood Lake		
Input for capacity study	0	0

4 Lake capacity assessment

External and internal loads were combined in a mass balance model with a predicted P sedimentation (retention) term to model growing season TP and algal biomass indicators (Appendix D). More detailed results are presented in Appendix F.

The most important task of a capacity model is the prediction of water quality depending on various development scenarios. Besides the presentation of a “Present” scenario that is useful for the validation of the model (confirming that input and model structure are applicable to the specific lake), different development scenarios, including one at pre-development conditions (“Pristine”) are modeled.

4.1 Comparison of predictions with observations (model validation)

Using monitoring data and characteristics presented in Section 2 the capacity model was used to predict present conditions as well as several scenarios (Table 14). TP concentration is reasonably well predicted for Basswood Lake, considering its low concentration. Predictions for Bright Lake are also acceptable, considering that there is only one year of fluctuating TP data available. Further monitoring is suggested for Bright Lake to ascertain its TP averages.

Secchi transparency of Basswood Lake is slightly better (higher) than predicted, while chlorophyll and Secchi observations in Bright Lake are slightly worse (Secchi is lower and chlorophyll is higher) than predictions. This means that in Bright Lake long-term TP concentrations are probably higher than measured in 2010 and future measurements of TP concentration is strongly suggested (Nürnberg and LaZerte 2011). With respect to Basswood Lake all predictions appear to be on the conservative side and there is no concern about the application of the model results in a capacity assessment.

Table 14. Observed lake characteristics (shaded) and model results for different scenarios

Conditions & Scenarios	TP (µg/L)	Chlorophyll (µg/L)	Secchi (m)	Colour (Pl units)
		Basswood Lake		
Observations	**4.6**	**na**	**11.3**	**1.5***
Scenarios:				
Present	4.9	2.2	9.65	
Vacant developed	5.1	2.2	9.49	
Pristine	4.0	1.8	10.64	
Capacity (1.5 x Pristine)	6.0	2.5	8.85	
		Bright Lake		
Observations	**13.8**	**8.4**	**2.2**	**10.3**
Scenarios:				
Present	15.1	5.7	3.36	
Vacant developed	15.3	5.8	3.35	
Pristine	4.0	1.8	6.14	
Capacity	6.0	2.6	5.10	
With Basswood at capacity	15.4	5.8	3.34	

*assumed value, no data available, needed to model Secchi

Besides the uncertainty of current TP concentration for Bright Lake, its hydrology should be verified. In the assessment presented here the runoff coefficient of neighbouring areas as represented in the Hydrological Atlas of 0.38 m/yr was used (Canada Department of Fisheries and Environment 1978). Using a runoff coefficient for Bright Lake as that back-calculated for Basswood from MNR hydrology instead of this one from the hydrological Atlas (replacing 0.38 with 0.54 m) would decrease the modelled annual average TP concentration by 9%. Consequently the current model yields more conservative results.

4.2 Scenarios

The most important task of a capacity model is the prediction of water quality depending on various development scenarios. Besides the presentation of a "Present" scenario, a scenario in which the vacant lots are included as development is shown ("Vacant developed"). In both lakes this scenario only marginally increases TP concentration.

The revised PWQO (Provincial Water Quality Objectives) for lakes on the Precambrian Shield allows a 50 per cent increase in TP concentration from a modeled baseline of water quality in the absence of human influence (Ministry of Environment 2010). Consequently the lakes' capacity was modeled in scenario "Capacity" for water quality associated with 1.5 times its original (modeled as "Pristine") TP concentration, expected from conditions as they were before any anthropological influence. The Pristine scenario assumes that less than 15% of the watershed was cleared and that there is no P input from shoreline development and agriculture, and no internal load, while input via precipitation and from wetlands are not changed.

Basswood appears to be well below capacity (Table 14) and even a scenario that includes development of all vacant units ("Vacant") computes a TP concentration that is only 1.21 fold the "Pristine" TP concentration. Consequently, the current development including vacant units (and some agricultural land, Table 9) could be doubled before its capacity is reached (resulting in a predicted average TP increase of about 1 µg/L).

On the other hand Bright Lake is far above capacity, because its predicted TP concentration is almost 4 times the pristine TP concentration (Table 14). A major reason for the exceedance is the internal P load that was estimated independently as almost equal to external load (Section 3.2). Because there are no known lakes with P release on the Canadian Shield due to a general lack of releasable P in lake sediments of undeveloped watersheds (Nürnberg et al. 1986; Nürnberg 1988), the entire internal load has to be attributed to anthropogenic activities. Next important is the agricultural area and the fact that a different export coefficient for a larger cleared area (>15%) has to be assumed for "present" conditions. The least important appears to be shoreline development (Figure 13).

Even though Bright Lake is far beyond capacity, added P load from developing Basswood Lake to capacity is not predicted to have any appreciable effect on Bright Lake's TP concentration (Table 14, an increase from 15.1 to 15.4 µg/L). Therefore, it is not a limnological issue, whether Basswood Lake should be developed any further.

5 Previous evaluation of Basswood Lake capacity and septic systems by MOE

5.1 Capacity evaluation for 1987

The MOE used to determine lake shore capacity of important lakes in Ontario. A communication dated 8 Feb 1991 from the North-eastern Region (Sudbury) to the Algoma Region (provided by Walter Shields on 19 Apr 2011) lists a number of regional lakes' spring TP concentration and the development capacity determined by "Dillon's Models" (as mentioned in the title of the communication). Trophic state was determined as level "1" (<10 µg/L TP, oligotrophic), developmental capacity to reach the next trophic state level was determined as 2422 cottages and to increase spring TP by 1 µg/L was 602 cottages. Only one spring TP value was used in this model, 5.9 µg/L measured in spring 1987, despite an earlier value of 2.5 µg/L measured in spring 1975 (Table 7). No information on the number of cottages was provided.

Relationships in the capacity evaluation and development possibilities seem surprisingly similar to our assessment, despite the relatively coarse approach in 1987. Development options are only slightly higher compared to those of the capacity study presented here, where an increase in about 1 µg/L TP is predicted when the present (including vacant units and some agricultural land, Table 9) development is doubled, with about 500 (rather than 602) cottage, resort and campground units (Table 10).

5.2 Basswood cottage and septic system count in 1977

Some historical insights are gleaned from a 1977 septic system evaluation: "Cottage Pollution control programme, July 1977, Wakwekobi Lake (Big Basswood Lake) Townships of Kirkwood, Day, Day and Bright Additional, and Gladstone, District of Algoma".

Of the 164 cottages present in 1977, 123 of the owners were interviewed and their sewage disposal categorized as shown in Table 15. Several systems were reported to the Algoma Health Unit for improvement. These faulty systems included: Eight septic systems and three pit privies too close to the lake, 13 undersized septic tanks and 2 systems having insufficient drainage tile.

Table 15. Type of sewage disposal on Basswood Lake in July 1977.

(i)	pit privy	67
(ii)	septic tank	58
(iii)	chemical	8
(iv)	humus	3
(v)	holding tank	3
(vi)	porta-potti	2
(vii)	vault privy	1
(viii)	leaching pit	1
(ix)	cesspool	1
(x)	undetermined	16

6 Conclusions

Based on the present water quality and the model to assess lake capacity, it can be concluded that Basswood Lake is not at capacity. Its growing season TP concentration indicates a low oligotrophic state and its P load is 1.21 times of its "pristine" load instead of 1.5 times, which is defined as capacity by the MOE. Therefore, its anthropogenic load could be increased by more than twofold, even after all vacant lots are developed.

Bright Lake, on the other hand, is developed far beyond its capacity. Its present growing TP concentration although uncertain for various reasons, is probably at least 14 µg/L and its P load is 4 times of the load for its capacity. A major reason for the exceedance is the internal P load that was estimated independently as almost equal to external load. The entire internal load has to be attributed to anthropogenic activities. Next important is the agricultural area and a larger cleared area (>15%); the least important appears to be shoreline development.

7 References

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Appendix A: Hydrology report from MNR Nov 6, 2009, first page

DRAFT

HARRIS CREEK AT BASSWOOD LAKE DAM NATURAL FLOW METRICS DATA SHEET

Station Information	
Site ID	2CC11
River Name	Harris Creek
Site Name	Basswood L. Dam
Region	Northeast
District	Sault Ste. Marie
Drainage Area	85.45 km²
Owner	-
Plant Capacity	-
Spill Capacity	-

Flow metrics are provided for the waterpower facility based on simulated natural flows as described in the draft *Waterpower Science Transfer Report 1.0* (MNR 2003). The target metrics provided are described in the *Aquatic Ecosystem Guidelines* (MNR 2002) and the *Waterpower Science Strategy* (MNR 2002). Metrics are based on simulated natural daily flow from 1978-2001 (24 yrs). The gauges used for the natural flow simulation were: i) 02CA002, Root River at Sault Ste. Marie (weight=0.6), ii) 02CD006, Serpent River above Quirke Lake (weight=0.4).

Annual:

I. Streamflow Time Series

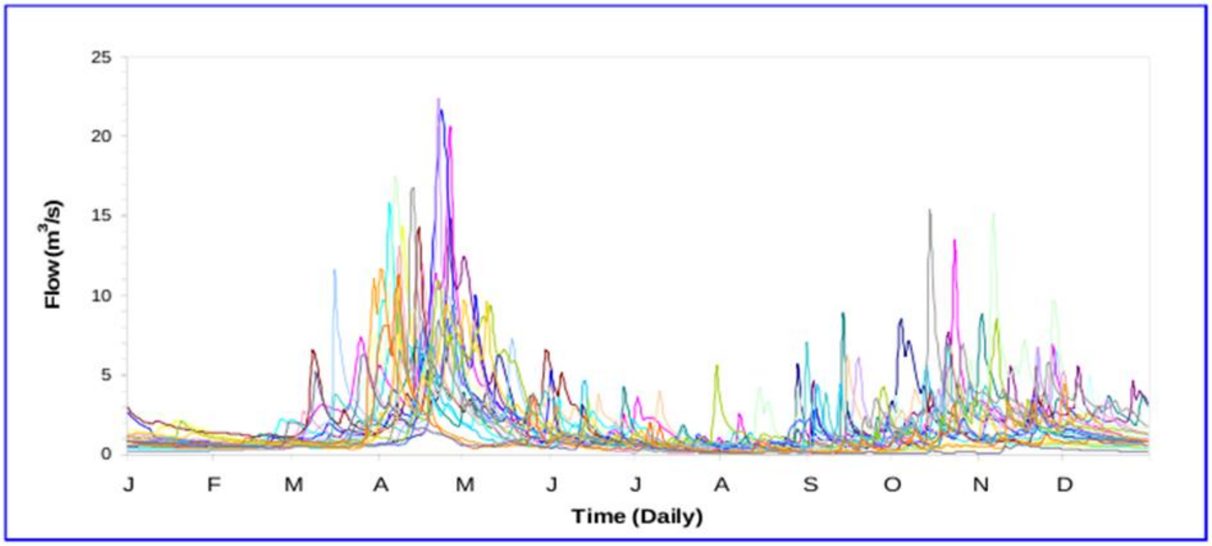

Figure 1: Annual daily flow hydrographs from 1978-2001.

Table 1: Annual flow metrics based on 24 years of data.

Descriptive Metric	Value
Mean Annual Flow	1.51 m³/s
20% Time Exceeded Flow	2.13 m³/s
Median Flow	0.86 m³/s
80% Time Exceeded Flow	0.48 m³/s
Month of Max. Median Flow	April
Month of Min. Median Flow	August
Mean Rising Rate of Change of Flow	0.68 m³/s/day
Mean Falling Rate of Change of Flow	-0.28 m³/s/day
Extreme Low Flow Conditions:	
7-day-average low flow in 2-year return period, $7Q_2$	0.21 m³/s
7-day-average low flow in 10-year return period, $7Q_{10}$	0.09 m³/s
7-day-average low flow in 20-year return period, $7Q_{20}$	0.07 m³/s
Target Metrics	**Value**
Riparian Flows (Q_2 - Q_{20})	11.9 - 21.1 m³/s
Bankfull Flows ($Q_{1.5}$ - $Q_{1.7}$)	10.1 - 10.9 m³/s

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Appendix B: Secchi disk transparency for Basswood Lake

Collected by lake volunteers with the MOE Lake Partner Program

Date	Secchi (m)	Date	Secchi (m)	Date	Secchi (m)	Date	Secchi (m)
10-Jun-99	6.5	21-Aug-01	13.8	30-May-04	10.3	08-May-07	9
27-Jun-99	11.5	27-Aug-01	13	18-Jun-04	9	10-Jun-07	10
15-Jul-99	11.5	07-Sep-01	14.5	02-Jul-04	8	24-Jun-07	10
29-Jul-99	13.5	15-Sep-01	12	07-Aug-04	12.8	16-Jul-07	11
03-Aug-99	13.5	28-Apr-02	9	18-Aug-04	11	22-Jul-07	12
15-Aug-99	12.5	09-May-02	9.5	26-Aug-04	11.4	30-Jul-07	13
22-Aug-99	13	28-May-02	9	04-Sep-04	11.2	11-Aug-07	13.5
23-Sep-99	11.5	07-Jul-02	9.2	10-Sep-04	12.8	02-Sep-07	12
28-May-00	9.5	15-Jul-02	9.5	20-Sep-04	11.5	11-Sep-07	12
06-Jun-00	10	27-Jul-02	10	27-Sep-04	12	20-Sep-07	12.5
18-Jun-00	9.5	25-Aug-02	12.5	08-May-05	10.8	10-May-08	12
06-Jul-00	10	30-Aug-02	13	18-May-05	11.5	22-Jun-08	7.2
09-Jul-00	11.5	07-Sep-02	13.2	29-May-05	10	17-Jul-08	10.5
24-Jul-00	13.5	12-Sep-02	13	10-Jul-05	11.3	03-Aug-08	12.5
05-Aug-00	15	17-Sep-02	13.2	30-Jul-05	12.8	12-Oct-08	9
25-Aug-00	15.5	28-Sep-02	13	08-Aug-05	12.8	20-May-09	9
12-Sep-00	14.5	15-May-03	11	24-Aug-05	14.5	15-Jun-09	7.5
08-May-01	11	04-Jun-03	9.2	07-Sep-05	13.5	04-Jul-09	12.5
14-May-01	11	16-Jun-03	8.5	17-Sep-05	13.52	24-Jul-09	10.5
20-May-01	10.5	13-Jul-03	11	23-May-06	7.5	24-Aug-09	12.3
07-Jun-01	8.5	14-Aug-03	12.5	06-Jun-06	7.5	16-May-10	9.5
23-Jun-01	9	20-Aug-03	11.4	02-Jul-06	11.5	30-May-10	10.5
29-Jun-01	10	30-Aug-03	12	13-Jul-06	10.5	12-Jun-10	11
30-Jul-01	11.5	05-Sep-03	13	28-Jul-06	13	10-Jul-10	13
05-Aug-01	13	13-Sep-03	13.5	12-Aug-06	13.5	10-Aug-10	13.5
18-Aug-01	13.2	12-May-04	10	01-Sep-06	14	10-Sep-10	12
						03-Oct-10	10

Appendix C: Excerpt from dissolved oxygen criterion definition (MNR)

Ministry of Natural Resources 2006: The most appropriate time for assessment of the dissolved oxygen regime in Ontario lakes is during the peak of thermal stratification (i.e., August 31 ± 2 weeks). The criterion should be compared to the mean volume-weighted dissolved oxygen concentration of the hypolimnion, adjusted to a standard date, September 15, using the lake-specific, observed rate of hypolimnetic oxygen decline. Lakes that are below the 7 mg/L criterion would have no further capacity for phosphorus loading, while lakes that exceed the criterion would have some additional capacity. The capacity for additional phosphorus loading can be determined by application of the Ontario Ministry of Environment, Lakeshore Capacity Model…

Appendix D: Phosphorus mass balance model and regression equations

Growing season TP concentration was modeled according to mass balance equations presented in detail in Nürnberg 2009. In particular, a specifically designed retention (R) model was applied that predicts only sedimentation (and not sediment release) as it was developed with a dataset of stratified lakes with no or low potential of sediment P release. The specific R-model (R_{sed}, equation 1) therefore represents the downward flux of TP due to settling and sedimentation.

$$R_{sed} = 15 / (18 + q_s), \quad (1)$$

where q_s, is annual areal water load (m/yr).

The prediction of lake TP concentration can be accomplished by adding an internal loading term to the general mass balance equation. In this way, both upward and downward fluxes are considered and specific seasonal or annual TP concentrations can be predicted in stratified and polymictic lakes according to Nürnberg (2009).

The model for average TP concentration is based on the same term of retention for both external and internal loads (areal loads, L_{int} and L_{ext}, mg/m^2/yr) and is predicted with equation (2).

$$TP = \frac{L_{ext} + L_{int}}{q_s} \times (1 - R_{sed}) \quad (2)$$

This model predicts annual average TP in stratified lakes with and without internal loading and growing season concentrations of polymictic lakes.

Observed TP concentration collected with the MOE Partner Program are usually measured during the spring turnover period. Such values are typically smaller than annual average or growing season T P and can be converted by equation (3), developed from observations of lakes in the Haliburton-Muskoka region (Clark and Hutchinson 1992).

$$\text{TP growing season average} = 0.80 \times \text{TP spring} + 2.04 \quad (3)$$

Chlorophyll and Secchi disk depth were predicted from observed and predicted (equation 2) phosphorus using equations (3) and (4) that were developed on eastern North American lakes, including many lakes on the Precambrian Shield (Nürnberg 1996). Although these relationships can be considered applicable, ideally they should be verified with lake specific data, when they become available over the years of future monitoring. At the moment such input is limited to Basswood Lake for which several years of TP and Secchi observations are available.

Log Chlorophyll = -0.27 + 0.87 log TP (n=42, R^2= 0.89, p<0.0001) (4)

Log Secchi = 1.35 - 0.455 x log TP - 0.283 x log Colour (n=38, R^2=0.89, p<0.001) (5)

Colour is a measured or assumed value of lake water (true colour) in platinum units.

Appendix E: Modeling wetlands in the LSC model

(From page 10 of Paterson et al. 2006)

In most regions, therefore, this model is not easily adapted for general use. However, a simpler version of this relationship recognizes the importance of wetlands in controlling the export of phosphorus to Precambrian lakes (Dillon *et al.* 1991, Dillon and Molot 1997). A linear regression of phosphorus export and % wetland area (expressed as % peat) was developed from 20 watersheds in central Ontario (following Dillon and Molot 1997; Fig. 4). Phosphorus export was calculated as a long-term mean from more than two decades of empirical measurement (Ontario Ministry of the Environment, Dorset Environmental Science Centre, unpublished data). Equation (2) may be used to predict the phosphorus supply from forested watersheds on the Precambrian Shield:

$$TP\ (kg \cdot yr^{-1}) = \text{catchment area}\ (km^2) * (0.47 * \%\ \text{wetland area} + 3.82) \quad (2)$$

When specific data exist for sub-watersheds, calculations should be made separately and then summed.

In addition to wetland coverage, the earliest version of the model recognized that the export coefficient may also vary significantly with land-use (Dillon and Rigler 1975). Based on experimental work and a literature survey of 69 watersheds, Dillon *et al.* (1986) determined that forested watersheds with ≥15% cleared land had a mean TP export value of 9.8 mg $TP \cdot m^{-2} \cdot yr^{-1}$, compared to 5.5 mg $TP \cdot m^{-2} \cdot yr^{-1}$ for forested watersheds where <15% of the land was cleared. Similarly, a doubling of the coefficient from 10 to 20 mg $TP \cdot m^{-2} \cdot yr^{-1}$ was used to estimate phosphorus export from forested and pasture lands, respectively, for a small watershed on sedimentary geology in southern Ontario (Winter and Duthie 2000). For forested watersheds on the Precambrian shield with ≥15% cleared or pastured land, and where the % wetland area is known, the LCM uses the following equation to calculate phosphorus export:

$$TP\ (kg \cdot yr^{-1}) = \text{catchment area}\ (km^2) * (0.47 * \%\ \text{wetland area}^2 + 3.82) * (1.8) \quad (3)$$

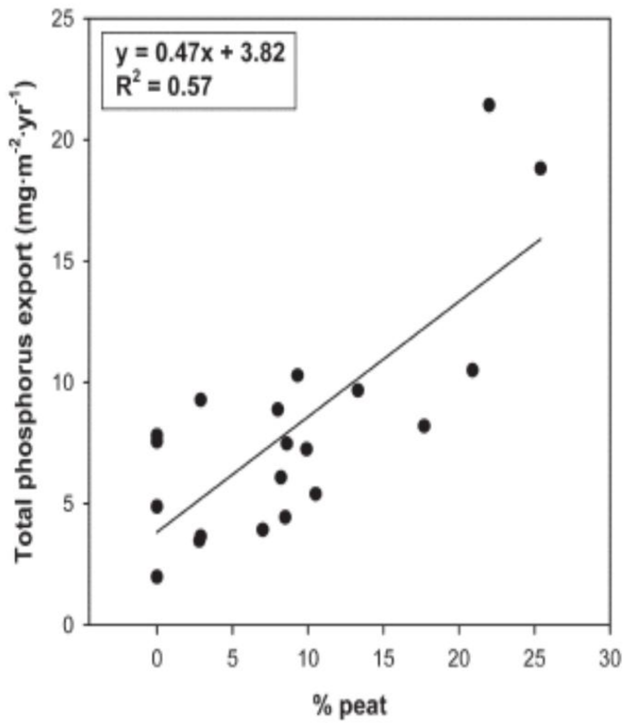

Figure 4.-Relationship between mean annual export of total phosphorus and % wetland (expressed as % peat) for 20 watersheds in south-central Ontario, Canada.

Equation (3) assumes that export from wetlands is similar for forested and cleared watersheds. A constant is applied to reflect the mean difference in export between forested and forest-pasture watersheds on the Canadian Shield (*i.e.*, $(9.8)*(5.5)^{-1}$; please see Dillon *et al.* 1986 for derivation of export coefficients).

Appendix F: Input values and results of the capacity assessment, loads and concentrations

Description	Units	Basswood	Bright
Area	(km^2)	27	12
Runoff coefficient, r	(m)	0.543	0.392
Annual water load, q_s	(m/yr)	1.77	6.99
TP Retention (R)	proportion	0.76	0.60
Natural External Load	(kg/yr)	785	1,246
Anthropogenic Load	(kg/yr)	187	472
Present external load (sum)	(kg/yr)	972	1,718
TP concentration	(µg/L)	4.92	7.97
Internal load	(kg/yr)	0	1,540
TP concentration	(µg/L)	0	7.15
Pristine total load	(kg/yr)	785	868
TP concentration	(µg/L)	3.97	4.03
At Capacity (1.5 times pristine)	(kg/yr)	1,177	1,301
TP concentration	(µg/L)	5.96	6.04