Lakeshore Capacity Assessment Handbook

Protecting Water Quality in Inland Lakes on Ontario's Precambrian Shield

May 2010

Ontario

Lakeshore Capacity Assessment Handbook

Protecting Water Quality in Inland Lakes on Ontario's Precambrian Shield

May 2010

Prepared by:

Ministry of the Environment
Ministry of Natural Resources
Ministry of Municipal Affairs and Housing

Cette publication hautement spécialisée n'est disponible qu'en anglais en vertu du règlement 441/97, qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère de l'Environnement au 416-327-1851.

For more information:
Call 705-766-2951
www.Ontario.ca/Environment

Ontario

Table of contents

Appendices

Figures

Tables

Preface

This ***Lakeshore Capacity Assessment Handbook*** has been prepared by the Ministry of the Environment in partnership with the ministries of Natural Resources and Municipal Affairs and Housing. It was developed to provide guidance to municipalities and other stakeholders responsible for the management of development along the shorelines of Ontario's inland lakes within the Precambrian Shield. While municipalities are not required to carry out lakeshore capacity assessment, this planning tool is strongly recommended by the Ontario government as an effective means of being consistent with the Planning Act, the Provincial Policy Statement (2005), the Ontario Water Resources Act and the federal Fisheries Act.

This document is based on the scientific understanding and the government policies in place at the time of publication. Questions about planning issues should be directed to the Ministry of Municipal Affairs and Housing. Scientific or technical questions dealing with water quality should be directed to the Ministry of the Environment. Questions concerning fisheries should be directed to the Ministry of Natural Resources.

Acknowledgements

This handbook is the outcome of more than three decades of scientific research and policy development. Lakeshore capacity assessment in Canada began in the 1970s with research conducted by Peter Dillon and F.H. Rigler. Researchers who contributed to the subsequent refinement of lakeshore capacity assessment and the development of the Lakeshore Capacity Model include B.J. Clark, P.J. Dillon, H.E. Evans, M.N. Futter, N.J. Hutchinson, D.S. Jeffries, R.B. Mills, L. Molot, B.P. Neary, A.M. Paterson, R.A. Reid and W.A. Scheider.

The preparation of the handbook was overseen by an inter-ministerial steering committee which included:

> ***Ministry of the Environment***: Victor Castro, Peter Dillon, Les Fitz, Fred Granek, Ron Hall, Bruce Hawkins, Heather LeBlanc, Gary Martin, Wolfgang Scheider (Chair), Doug Spry, Shiv Sud (past Chair);
>
> ***Ministry of Natural Resources***: John Allin, John Connolly, David Evans, Gareth Goodchild, Fred Johnson;
>
> ***Ministry of Municipal Affairs and Housing***: Kevin Lee

Many other provincial staff, too numerous to name individually, contributed to the development of this handbook. Technical writing assistance for the handbook was provided by Joanna Kidd from Lura Consulting and editorial assistance was provided by Carol Crittenden from Editorial Offload.

This version of the Handbook has been revised to reflect comments received during its posting on Ontario's Environmental Registry in 2008. Thanks also go to the municipal staff and the members of organizations who assisted in the review of the handbook and provided many comments on its scope and contents. Their participation helped greatly to improve the document. These reviewers included:

Judi Brouse	District Municipality of Muskoka
Peter Bullock	City of North Bay
Cliff Craig	Rideau Valley Conservation Authority
Randy French	French Planning Services Inc.
Roger Hogan	Former Township of Cardiff (amalgamated into the Municipality of Highlands East)
Gerry Hunnius	Federation of Ontario Cottagers' Associations
Neil Hutchinson	Hutchinson Environmental Sciences Ltd.
Alex Manefski	Urban Development Institute
Pat Martin	Municipality of Dysart et al
Patrick Moyle	Association of Municipalities of Ontario
Ron Reid	Federation of Ontario Naturalists
Lorne Sculthorp	District Municipality of Muskoka

Executive summary

Purpose

This handbook has been prepared by the Ministry of the Environment in partnership with the Ministries of Natural Resources and Municipal Affairs and Housing to guide municipalities carrying out lakeshore capacity assessment of inland lakes on Ontario's Precambrian Shield.

About lakeshore capacity assessment

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

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

Benefits of lakeshore capacity assessment

Use of lakeshore capacity assessment by municipalities (along with proactive land-use controls) and enforcement of water-related regulations and bylaws will help to ensure that the quality of water in Ontario's inland lakes is preserved. The protection of water quality will also protect environmental, recreational, economic and property values.

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.

Carrying out lakeshore capacity assessment

A lake's capacity for development is assessed with the Lakeshore Capacity Model. The model, first developed in 1975, quantifies linkages between natural sources of phosphorus to a lake, human contributions of phosphorus from shoreline development, water balance, the size and shape of a lake and the resultant phosphorus concentrations. The model uses a number of assumptions about phosphorus loading, phosphorus retention and usage figures.

The model allows the user to calculate how the quality of water in a lake will change in response to the addition or removal of shoreline development such as cottages, permanent homes and resorts. It predicts an important indicator of water quality: the total phosphorus concentration. The model can be used to calculate undeveloped conditions of a lake, how much development can be added (in terms of the number of dwelling units) without altering water quality beyond a given endpoint, and the difference between current conditions and that endpoint.

Land use planning application and best management practices

Best management practices (BMPs) are planning, design and operational procedures that reduce the migration of phosphorus to water bodies, thereby reducing the effects of development on water quality. These BMPs apply to all lots, vacant or developed.

The maintenance of shoreline vegetation, installing vegetative buffers and minimizing the amount of exposed soil helps to reduce phosphorus loading - that is, the amount of phosphorus entering a body of water. Use of a siphon or pump to distribute septic tank effluents to the tile bed can also reduce phosphorus loading. Moreover, phosphorus loadings from septic systems can be reduced by avoiding the use of septic starters, ensuring that all sewage waste goes into the septic tank, pumping the tank out every three to five years and reducing water use.

Monitoring water quality

The predictions made by the Lakeshore Capacity Model should be validated by monitoring the quality of water in a lake. Water quality measurements should include total phosphorus, water clarity, and measurements at discrete depths of water temperature and dissolved oxygen concentrations at the end of summer. The Ministry of the Environment's Lake Partner Program can help municipalities fulfill their monitoring requirements. Through partnerships with other agencies and a network of volunteers, the program currently collects water quality samples from more than 1,000 locations across the province.

1.0 INTRODUCTION TO LAKESHORE CAPACITY ASSESSMENT

1.1 Purpose of the handbook

For many people, the image of Ontario is synonymous with the image of our northern lakes. When they think of our province, they think of anglers casting for walleye in the early morning mist, children leaping from docks into clear, sparkling waters and the rugged, tree-lined shores made famous by the Group of Seven. There are more than 250,000 inland lakes that dot Ontario's Precambrian Shield and these are an invaluable legacy for the residents of the province. Some people experience their beauty year round as residents. Others return every summer — some of them travelling great distances — for canoe tripping, fishing, cottaging, or to experience the solitude and the spiritual renewal that can be realized in these spectacular natural settings.

This handbook has been prepared as a tool to help protect the water quality of Ontario's Precambrian Shield lakes by preventing excessive development along their shores. It has been developed by the Ministry of the Environment (MOE) in partnership with the Ministry of Natural Resources (MNR) and the Ministry of Municipal Affairs and Housing (MMAH), with input from a diverse group of stakeholders. The advice in this handbook is intended for municipalities on the Precambrian Shield that have inland lakes within their boundaries. As such, it will be most useful to municipal planners, technical staff and consultants working on water quality in inland lakes. Nevertheless, cottagers' associations, residents living on lakes, conservation authorities and proponents of development should also find it informative.

The *Lakeshore Capacity Assessment Handbook* is a guide and resource for municipalities. Lakeshore capacity assessment will help municipalities meet their obligation under the Planning Act to be consistent with the Provincial Policy Statement (2005).

This handbook also incorporates a revised provincial water quality objective for phosphorus, and references a dissolved oxygen criterion developed by the Ministry of Natural Resources to protect lake trout habitat in inland lakes on the Precambrian Shield.

The handbook will become the basis for training resource managers in municipalities, the private sector and within MOE, MNR and MMAH. This will help to ensure consistent use and interpretation of lakeshore capacity assessment policies, the Lakeshore Capacity Model and its assumptions.

Outline of the handbook

The *Lakeshore Capacity Assessment Handbook* is organized so that more general material is presented at the beginning of the handbook and an increasing level of detail is found as one proceeds through it. The early sections are therefore suitable for general audiences, while the later chapters are targeted at more technical audiences. The greatest level of detail is found in the appendices.

Section 1.0: Provides an introduction to lakeshore capacity assessment and outlines why it is needed, what it will achieve, and what effect it will have on future lake development in the province.

Section 2.0: Examines the relationship between phosphorus, dissolved oxygen and water quality. It outlines the rationale for and approach used in the revised provincial water quality objective for phosphorus and contains a brief description of the dissolved oxygen criterion for the protection of lake trout habitat.

Section 3.0: Presents the basics of lakeshore capacity assessment. This includes a discussion on where it may be applicable, when it should be considered, what it will tell the user and what is needed to carry it out.

Section 4.0: Presents more detail on lakeshore capacity assessment and outlines how to apply the Lakeshore Capacity Model, the recommended provincial assessment tool for lakeshore capacity planning. It also addresses the updated and standardized technical assumptions used in the model, the steps involved in running it and the expected results.

Section 5.0: Provides a brief overview of land use planning application and best management practices, what they can achieve and why they are useful to municipalities (or residents and cottagers' associations) for protecting lake water quality. It also briefly addresses phosphorus abatement technologies.

Section 6.0: Focuses on monitoring water quality: why it is important, what to monitor and how to do it. It also provides an overview of MOE's Lake Partner Program.

Section 7.0: A brief conclusion.

The appendices to the handbook contain the rationale for a revised provincial water quality objective for phosphorus for Ontario's inland lakes on the Precambrian Shield, a list of resources, and MOE technical bulletins on water quality monitoring.

1.2 What is lakeshore capacity assessment?

At its simplest, lakeshore capacity assessment is a planning tool that is used to predict how much development can take place along the shorelines of inland lakes on the Precambrian Shield (**Figure 1**) without impairing water quality (i.e., by affecting levels of phosphorus and dissolved oxygen).

Figure 1. Ontario's Precambrian Shield (shaded area)

Development is defined herein as any activity which, through the creation of additional lots or units or through changes in land and water use, has the potential to adversely affect water quality and aquatic habitat. Development includes the addition of permanent residences, seasonal or extended seasonal use cottages, resorts, trailer parks, campgrounds and camps, and the conversion of forests to agricultural or urban land.

Lakeshore capacity assessment can be used in two major ways:

1. To determine the maximum allowable development (in terms of number of dwelling units) that can occur on a lake without degrading water quality past a defined point.
2. To predict the expected effect of future development.

The goals of lakeshore capacity assessment are to help maintain the quality of water in recreational inland lakes and to protect coldwater fish habitat by keeping changes in the nutrient status of inland lakes within acceptable limits. Lakeshore capacity assessment can be carried out on any inland lake on the Precambrian Shield, although its accuracy may decrease for lakes that don't stratify during the summer months (i.e., shallow lakes), or for lakes that fall beyond the calibration range of the model (see Section 4.3 for further details).

The goals of lakeshore capacity assessment are to help maintain the quality of water in recreational inland lakes and to protect coldwater fish habitat by keeping changes in the nutrient status of inland lakes within acceptable limits.

Lakeshore capacity assessment is based on controlling the amount of one key pollutant — phosphorus — entering a lake by controlling shoreline development. Phosphorus is a nutrient that affects the growth of algae and aquatic plants. Excessive phosphorus can lead to excessive algal and plant growth, which in turn leads to unsightly algal blooms, the depletion of dissolved oxygen and the loss of habitat for coldwater fish such as lake trout — a process known as eutrophication.

As outlined in Section 2.0, phosphorus comes both from natural and human sources. In the absence of significant agricultural or urban drainage, or point sources such as sewage treatment plants, the primary human sources of phosphorus to Ontario's Precambrian Shield lakes are sewage systems from houses and cottages. Shoreline clearing, fertilizer use, erosion and overland runoff can also be important sources of phosphorus to inland lakes. Lakeshore capacity assessment helps planners understand what level of shoreline development can take place on an inland lake without appreciably altering water quality (i.e., beyond water quality guidelines or objectives for levels of phosphorus and dissolved oxygen).

MOE's mandate to protect water quality allows it to establish maximum phosphorus concentrations for individual lakes and to express these limits in terms of an allowable phosphorus load from shoreline development. Nutrient (phosphorus) enrichment may also reduce the amount of cold, well-oxygenated water available for fish requiring high levels of dissolved oxygen, such as lake trout. Development planning must protect fish habitat in accordance with the requirements of the federal Fisheries Act and the Department of Fisheries and Oceans policy for the management of fish habitat[1], and the Provincial Policy Statement.

Lakeshore capacity assessment is a planning tool that will help municipalities achieve a consistent approach to shoreline development on inland lakes across the province. As noted previously, MOE recommends that municipalities use lakeshore capacity assessment to ensure sustainable development of the inland lakes in their region.

Lakeshore capacity assessment alone won't guarantee good water quality and healthy fish populations.

There are many other pollutants — such as mercury, fuel, and wastewater from pleasure boats, which includes dish/shower/laundry water (grey water) and sewage (black water) — and other land uses — such as industrial use, urbanization, and intensive timber harvesting and agriculture — that can degrade water quality. To protect water quality, municipalities and lake users need to have regard for federal, provincial and municipal water-related laws, bylaws and policies. Municipalities also need to develop proactive land-use controls.

Handbook users should remember that lakeshore capacity assessment, while effective at protecting some aspects of water quality, is by no means a panacea for all water quality problems in inland lakes.

Water quality is only one of many factors that influence the development capacity of inland lakes.

In some cases, water quality may not be the most critical factor in determining whether a lake has reached its development capacity. The development capacity of a lake is also influenced by fish and wildlife habitat, the presence of hazard lands, vegetation, soils, topography and land capability (the suitability of land for use without permanent damage). Other factors that influence development capacity include existing development and land-use patterns, as well as social factors such as crowding, the number and type of boats in use, compatibility with surrounding land-use patterns, recreational use and aesthetics. Lakeshore capacity assessment does not address these other factors.

The technical process of carrying out lakeshore capacity assessment will not, in and of itself, protect water quality — implementation is required.

The information obtained from lakeshore capacity assessment — for example, the maximum number of lots or dwelling units permitted on a lake or the names of lakes that have been determined to be at development capacity — needs to be incorporated into the policies of a

[1] Department of Fisheries and Oceans. 1986. The Department of Fisheries and Oceans policy for the management of fish habitat. Department of Fisheries and Oceans. Ottawa. 28 p.

municipality's official plan. The implementation of lakeshore capacity assessment is addressed in Section 3.4.

Lakeshore Capacity Assessment and Drinking Water

The outcome of the lakeshore capacity assessment will confer benefits on water quality that may, if a lake or watershed provides drinking water, also limit inputs of chemicals and pathogens to this drinking water source. A comprehensive strategy for the protection of drinking water supplies is under development. The Clean Water Act, passed into law in October 2006, takes a science and watershed-based approach to drinking water source protection as part of the Ontario government's Source-to-Tap framework.

1.3 Why we need lakeshore capacity assessment

The inland lakes on Ontario's Precambrian Shield are a major environmental, recreational and economic resource for the province. We need lakeshore capacity assessment as a tool for at least three reasons:

1. To help protect environmental resources
2. To help protect recreational and economic resources
3. To help municipal planning authorities meet their obligations under the Planning Act

Protecting environmental resources

Like other ecosystems, freshwater lakes are dynamic systems with an inherent resilience to stress — that is, they possess the ability to self-regulate and repair themselves. But, again like other ecosystems, inland lakes have a carrying capacity (limit) to the amount of stress they can tolerate. The near collapse of the Lake Erie ecosystem in the 1960s due to excessive phosphorus levels is one such example: a coordinated, basin-wide strategy was needed to reduce phosphorus levels and begin restoring the lake's health.

An important water quality concern related to development on Ontario's Precambrian Shield is eutrophication, which is caused by a high amount of phosphorus entering a lake. Unlike most pollutants, phosphorus isn't toxic to aquatic life. In fact, it is an essential nutrient that is supplied to the aquatic system from natural sources such as rainfall and runoff from the watershed. However, when the amount of phosphorus entering a water body is excessive, it sets off a chain reaction. First, algae proliferate causing a loss in water clarity — the lake user may see this as greener or more turbid water, which is less aesthetically-appealing. In some cases, algal growth is dense and localized — this is called a bloom. Next, the algae die off and settle to the bottom of the lake, where bacteria begin the process of decomposition. This process consumes oxygen which, in turn, reduces the level of dissolved oxygen in the bottom waters and reduces the amount of habitat available for sensitive aquatic life such as lake trout. Lakes undergoing eutrophication may lose populations of lake trout and experience shifts in fish populations to more pollution-tolerant species.

Lakeshore capacity planning has been practiced for about 30 years in Ontario. During this time, MOE regional staff have modeled or accumulated files on more than 1,000 inland lakes. About 45 per cent of the lakes that have been determined to be at capacity to date are lake trout lakes in which a cold, well-oxygenated fish habitat is threatened by further shoreline development.

Lakeshore capacity assessment will help municipalities protect lakes that are at capacity against a further deterioration in water quality. It will also help to protect the water quality of lakes that have remaining development capacity, and help lakes to sustain healthy fisheries.

Protecting recreational and economic resources

Lakeshore capacity assessment will help to protect the significant economic values that are associated with Ontario's inland lakes:

- Ontario residents own approximately 1.2 million recreational boats.[2]
- Anglers spend approximately $1.7 billion annually in Ontario on a range of goods and

[2] Great Lakes Regional Waterways Management Forum. 1999. The Great Lakes: A waterways management challenge. Harbor House Publishers, Inc. Michigan.

services related to recreational fishing.[3]

- Ontario's Great Lakes and inland lakes support one of the largest commercial fisheries in the world, with a landed value of more than $40 million annually.[4]
- Crown lands and waters encompass approximately 87 per cent of Ontario's land mass. Many visitors engage in resource-based tourism activities on these lands including, for 1999, more than 5.6 million Canadian, American and overseas visitors. These resource-based visitors spent almost $1.1 billion in Ontario.[5]
- Of the 5.6 million resource-based trips in Ontario in 1999, 4.8 million (86 per cent) were overnight trips. Many of these visitors were engaged in water-related activities: 50 per cent participated in water sports (including swimming); 39 per cent went hunting or fishing.[6]

The Planning Act and the Provincial Policy Statement

Protection of matters of provincial interest is now a responsibility that is shared between the Ontario government and municipalities. MOE and other Ontario government agencies no longer assess all development applications. As a result, municipalities need better tools to meet their obligations under the Provincial Policy Statement (PPS) to protect water quality and fish habitat and to evaluate the effect of developments on the local environment. Lakeshore capacity assessment is one such tool that will help municipalities meet these obligations. Under the 2004 amendments to the Planning Act all planning approval authority decisions made “shall be consistent with” the PPS, which came into effect on March 1, 2005 following an extensive consultation and review. This replaced the previous wording of the Planning Act which stated that approval authorities, when making decisions “shall have regard to” the PPS. Copies of the PPS (2005) are readily available online and directly from the Ministry of Municipal Affairs and Housing.

It is always important to remember that the PPS (2005) must be read in its entirety. With that in mind, land-use planners must consider many matters to reach a decision that is consistent with the PPS (2005). For lake trout lakes or any other water bodies, decisions shall be consistent with, among other PPS (2005) policies, its water quality policies and fish habitat policies, including any definitions where they apply.

---

[3] Ontario Ministry of Natural Resources. 2003. 2003 Recreational Fishing Regulations Summary. Queen's Printer for Ontario.

[4] Office of the Provincial Auditor of Ontario. 1999. 1998 Annual Report. Queen's Printer for Ontario.

[5] Ontario Ministry of Tourism and Recreation. 2002. An Economic Profile of Resource-Based Tourism in Ontario, 1999. Queen's Printer for Ontario.

[6] Ontario Ministry of Tourism and Recreation. 2002. An Economic Profile of Resource-Based Tourism in Ontario, 1999. Queen's Printer for Ontario.

1.4 What lakeshore capacity assessment will achieve

Lakeshore capacity assessment is a useful planning tool that will enhance the effectiveness of the land-use planning and development process in a number of ways. It incorporates the concept of ecosystem sustainability into the planning process.

Lakeshore capacity assessment is built upon the knowledge that inland lakes have a finite and measurable capacity for development. Central to the province's ecosystem approach to land-use planning is the concept that "everything is connected to everything else". Degradation of one element of an ecosystem (in this case, degradation of water quality) will ultimately affect other elements of the same ecosystem. Lakeshore capacity assessment is one tool that can assist in protecting the quality of water in inland lakes in the future. Protecting the quality of water in a lake will also help to protect its aquatic communities, coldwater fish habitat and the quality of water in downstream systems.

Lakeshore capacity assessment is consistent with watershed planning.

The Ontario government recommends watershed planning as the preferred approach to water resource planning. Watershed planning takes a broad, holistic view of water resources and considers many factors including water quality, terrestrial and aquatic habitat, groundwater, hydrology and stream morphology (form and structure). Although lakeshore capacity assessment is more narrow in focus (as it considers only water quality), it is consistent with watershed management in that it considers upstream sources and downstream receptors when assessing the development capacity of a lake (e.g., PPS policy 2.2.1. a) which directs that planning authorities shall protect, improve or restore the quality and quantity of water by using the watershed at the ecologically meaningful scale for planning). It is a tool that will enable municipalities sharing a watershed to work together to protect the resource.

Lakeshore capacity assessment is consistent with the strategic shifts outlined in the report, *Managing the Environment: A Review of Best Practices*[7].

Lakeshore capacity assessment fits well with the strategic shifts outlined in the *Managing the Environment* report, commissioned by the Ontario government and issued in January 2001. Specifically, lakeshore capacity assessment reflects the shift towards:

- Place-based management using boundaries that make ecological sense
- Use of a flexible set of regulatory and non-regulatory tools
- A shared approach to environmental protection that includes the regulated community, non-governmental organizations, the public and the scientific/technical community

Lakeshore capacity assessment promotes land-use decisions that are based on sound planning principles and helps to address many relevant aspects of the Provincial Policy Statement (2005).

The implementation of lakeshore capacity assessment, together with the implementation of best management practices, will demonstrate sound planning principles at the municipal level by reflecting the land-use policies in a municipality's official plan. As outlined in Section 1.3, lakeshore capacity assessment supports the protection of provincial interests identified in the Planning Act and the Provincial Policy Statement (2005). This includes protecting water quality, natural heritage features and communities.

[7] Executive Resource Group. 2001. Managing the Environment: A Review of Best Practices, Volume 1.

Lakeshore capacity assessment encourages land-use decisions that maintain or enhance water quality.

While the Ontario government maintains jurisdiction and legislative authority for water quality and quantity under the Ontario Water Resources Act and the Environmental Protection Act, municipalities are strongly encouraged to consider more restrictive procedures and practices to safeguard water resources. Lakeshore capacity assessment is a proactive method by which municipalities can determine the sustainability of shoreline development on inland lakes with respect to water quality. It will help protect or enhance water quality so that permanent and seasonal residents can continue to enjoy good water clarity. It will also help to protect fish habitat and fisheries.

Lakeshore capacity assessment encourages a clear, coordinated and scientifically sound approach that will be beneficial to stakeholder groups and may avoid or reduce land use conflicts.

Lakeshore capacity assessment is grounded in science that has been used for many years. It was developed by the Ontario government to guide municipalities with their planning responsibilities. It will help municipalities determine their lakeshore development capacity as they develop or update their official plans. Municipalities will then be able to set long-term planning policies before development expectations are generated and investments are made in property acquisition and subdivision design.

Lakeshore capacity assessment encourages a consistent approach across the province.

The Ontario government is promoting the use of this handbook and the Lakeshore Capacity Model to encourage a consistent approach across the province.

Lakeshore capacity assessment is cost effective.

Duplication of effort is avoided when municipalities carry out lakeshore capacity assessment and then develop general policies that are expressed in official plans and zoning bylaws. This is also the case when a development proposal requires a proponent to deal with more than one municipality.

1.5 What the effect will be on future lake development

There are currently more than 220,000 residential and cottage properties on Ontario's inland lakes.[8] Cottage development is sporadic and therefore difficult to predict. Annual demand for new lakeshore properties may increase somewhat in the future, but isn't expected to reach the high levels encountered in the late 1980s because of changes in disposable income and growing interest in recreational and retirement properties in warmer climates[9].

Municipal use of lakeshore capacity assessment — in conjunction with the revised provincial water quality objective for phosphorus for inland lakes on the Precambrian Shield — may allow

[8] Cottage Life Magazine. 2004. Cottage Life Advertising Brochure.

[9] Ontario Ministry of the Environment (Economic Services Branch). 1997. Economic Analysis of the Proposed Lakeshore Development Policy: Socio-economic value of water in Ontario. Queen's Printer for Ontario.

for fewer new residential and cottage lots on some lakes and more on others, as compared to the existing assessment procedure. The net effect is likely to be a redirection of development from lakes that are already well developed to lakes that are less developed.

2.0 PHOSPHORUS, DISSOLVED OXYGEN AND WATER QUALITY

2.1 Link between phosphorus and water quality

Phosphorus is an essential nutrient that is supplied to aquatic systems from natural sources such as rainfall and overland runoff, as well as human sources. Unlike most aquatic pollutants, phosphorus isn't toxic to aquatic life. High levels of phosphorus, however, can set off a chain of events that can have serious repercussions on the aesthetics of recreational waters and the health of coldwater fisheries.

The phosphorus concentration of a lake is one measure of the desirable attributes we wish to protect as the lake's shoreline is developed. These attributes include clear water for recreation and a well-oxygenated habitat for coldwater fish.

For Ontario's inland lakes on the Precambrian Shield, trophic (nutrient) status is determined by the level of phosphorus in the water (**Table 1**). Most lakes in the province of Ontario can be broadly characterized as being oligotrophic (low in nutrients) or mesotrophic (moderately nutrient-enriched), and most can accommodate small increases in phosphorus levels. However, all lakes have a finite capacity for nutrient assimilation, beyond which water quality is impaired. Excessive phosphorus loadings to a lake promote the growth of algae, sometimes leading to algal blooms on or beneath the lake's surface. The proliferation of algae reduces water clarity, which lessens a lake's aesthetic appeal. More serious effects may occur after the algae die and settle to the bottom. When this takes place, bacteria levels increase to decompose the algae and collectively their respiration consumes more oxygen in the water column. This means a loss of the cold, well-oxygenated habitat that is crucial to the survival of coldwater species such as lake trout. The ultimate outcome can be extirpation (local extinction) of the species.

Table 1. Total phosphorus and its relationship to trophic status

Trophic status	Total phosphorus range (µg/L)
Oligotrophic	<10
Mesotrophic	10-20
Eutrophic	>20

The main human sources of phosphorus to many of Ontario's recreational inland lakes are sewage systems from houses and cottages. Clearing the shoreline of native vegetation, use of fertilizers, stormwater runoff and increased soil erosion also can contribute significant amounts of phosphorus to a lake.

MOE's mandate for protection of water quality allows it to establish maximum phosphorus concentrations for individual lakes and express these limits in terms of the allowable phosphorus load from shoreline development. Since nutrient enrichment can also reduce the amount of cold, well-oxygenated water used by fish such as lake trout, MNR has developed a new criterion for dissolved oxygen to protect lake trout habitat.

Development planning must protect fish habitat in accordance with the requirements of the federal Fisheries Act and Fisheries and Oceans Canada policy for the management of fish habitat[10]. Projects that may alter fish habitat fall under the jurisdiction of Fisheries and Oceans

[10] Department of Fisheries and Oceans. 1986. The Department of Fisheries and Oceans policy for the

Canada for review under section 35 of the Fisheries Act. Fisheries and Oceans Canada has negotiated agreements with some conservation authorities to carry out these reviews at varying levels, depending on the capability of the conservation authority. Fisheries and Oceans Canada has a similar agreement with Parks Canada to carry out section 35 reviews for projects in national parks, marine conservation areas, historic canals and historic sites.

2.2 Provincial water quality objective for phosphorus

This section of the handbook provides an overview of the relationship between phosphorus and water quality and outlines the rationale for and approach used for the development of a revised provincial water quality objective for phosphorus. More detail is found in Appendix A, *Rationale for a revised phosphorus criterion for Precambrian Shield lakes in Ontario*.

Existing approach

The Ontario government's goal for surface water management is "to ensure that the surface waters of the province are of a quality which is satisfactory for aquatic life and recreation".[11] The existing PWQO for total phosphorus was developed by MOE in 1979.[12] It was founded on the trophic status classification scheme of Dillon and Rigler[13], and was designed to protect against aesthetic deterioration and nuisance concentrations of algae in lakes, and excessive plant growth in rivers and streams.

In 1992, the PWQO for total phosphorus was given interim status. This reflected both the uncertainty about the effects of phosphorus, and the fact that phosphorus isn't toxic to aquatic life. The interim PWQO doesn't explicitly distinguish between lakes in different regions of Ontario (*i.e.,* Precambrian Shield versus southern Ontario). Instead, it sets different targets for lakes depending on whether they have naturally low productivity (total phosphorus less than 10 µg/L) or naturally moderate productivity (total phosphorus greater than 10 µg/L) (*see sidebar*).

In summary, the intent of the interim PWQO for total phosphorus in lakes is to:

Interim Provincial Water Quality Objective for total phosphorus (1979)

Current scientific evidence is insufficient to develop a firm objective at this time [*i.e.,* 1979]. Accordingly, the following phosphorus concentrations should be considered as general guidelines which should be supplemented by site-specific studies:

- To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L.
- A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 µg/L or less. This should apply to all lakes naturally below this value.
- Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 µg/L.

---

management of fish habitat. Department of Fisheries and Oceans. Ottawa.

[11] Ontario Ministry of Environment and Energy. 1994. Water management: Policies, guidelines, Provincial Water Quality Objectives of the Ministry of Environment and Energy. Queen's Printer for Ontario.

[12] Ontario Ministry of Environment and Energy. 1979. Rationale for the establishment of Ontario's Provincial Water Quality Objectives. Queen's Printer for Ontario.

[13] Dillon, P.J. and F.H. Rigler 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *J. Fish. Res. Bd. Can.* 32: 1519-1531.

- Protect the aesthetics of recreational waters by preventing losses in water clarity
- Prevent nuisance blooms of surface-dwelling algae
- Provide indirect protection against oxygen depletion

Need for a revised approach

The need to revise the approach for managing phosphorus stems from an improved understanding of the relationship between phosphorus concentrations in water and the resulting plant and algal growth in lakes and rivers. It also reflects an improved understanding of watershed processes, biodiversity and the assessment of cumulative effects. A revised approach would ensure adoption of these considerations in the water management process.

Although the existing, two-tiered guideline for total phosphorus in lakes has performed well for more than 30 years, it fails to protect against the effects of cumulative development. Further, it doesn't protect the province's current diversity in lake water quality and its associated biodiversity. As illustrated in **Figure 2**, there is a wide range of nutrient levels in Ontario's inland lakes, with a prevalence of oligotrophic lakes.

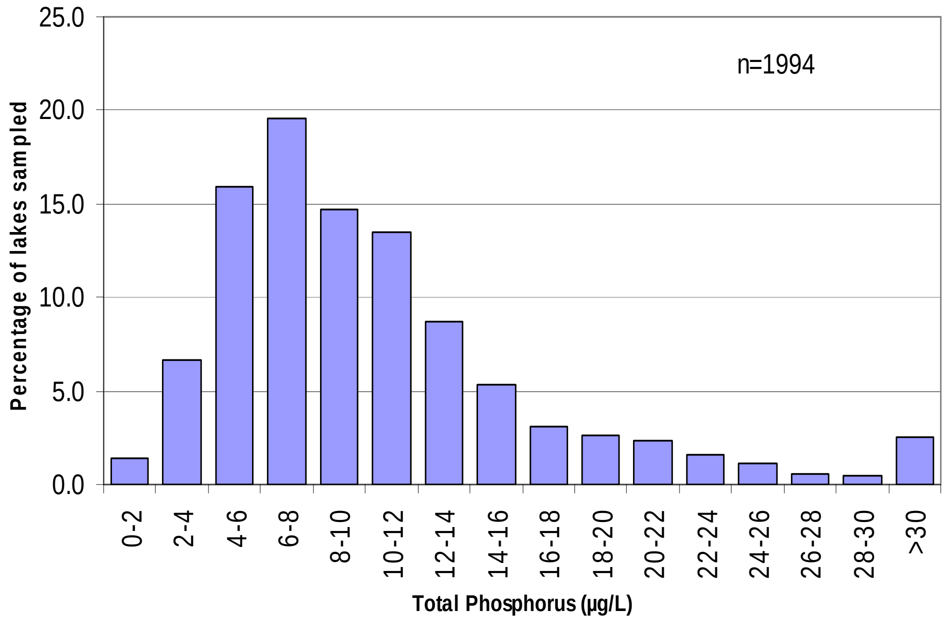


Figure 2. Distribution of total phosphorus concentrations in sampled Ontario lakes (source: MOE Inland Lakes database, March 2004)

The logical outcome of the application of the Ontario government's two-tiered 1979 phosphorus objective is that, over time, the quality of water in recreational lakes will converge on each of the two water quality objectives. This will produce a cluster of lakes slightly below 10 µg/L, and another slightly below 20 µg/L, thus reducing the diversity of water quality among lakes and, with it, the diversity of the associated aquatic communities.

Revised approach

The revised PWQO for lakes on the Precambrian Shield allows a 50 per cent increase in phosphorus concentration from a modeled baseline of water quality in the absence of human influence.

The revised approach has the following advantages:

- Each water body would have its own water quality objective, described with one number

(*i.e.*, 'undeveloped' or 'background' plus 50 per cent)

- Development capacity would be proportional to a lake's original trophic status
- Each lake would remain closer to its original trophic status classification. A lake with a predevelopment phosphorus level of 10 µg/L could be developed to 15 µg/L, maintain its mesotrophic classification, and development would not be unnecessarily constrained to 10 µg/L
- The existing diversity of trophic status in Ontario would be maintained in perpetuity

2.3 Phosphorus and dissolved oxygen

The lake trout, *Salvelinus namaycush*, is found in about 2,200 lakes in Ontario, most of which are on or near the Precambrian Shield. These lakes are noted for their relatively pristine water quality: they generally have high clarity, low levels of dissolved solids, organic carbon and phosphorus, high concentrations of dissolved oxygen, cool temperatures in bottom waters year round and relatively stable water levels. Self-sustaining populations of lake trout are found in these lakes because they provide the specific, narrow environmental conditions required by this species.

Ontario's lakes were re-colonized by lake trout 10,000 years ago after the glaciers of the last Wisconsin Ice Age retreated. Populations have been largely isolated from one another since that time and adaptation to local conditions has led to genetically distinct, locally adapted stocks. The preservation of genetic diversity of the species requires conservation of individual populations through the protection of the habitat and water quality in the lakes in which they occur.

Lake trout are long-lived and late maturing, with females first spawning at six to ten years of age. This late maturation, combined with modest egg production and low recruitment rates, makes lake trout vulnerable to external factors that increase mortality. These factors include over-fishing and degradation or loss of spawning and summer habitat.

Loss of late summer habitat is influenced by phosphorus loading. In the southern part of their range, lake trout live in the hypolimnion during the summer. The hypolimnion is isolated from the atmospheric and photosynthetic supply of oxygen from the time when the lakes become thermally stratified during spring overturn until recirculation or turnover takes place in the fall. To sustain lake trout over the summer, the hypolimnion must contain enough dissolved oxygen. When nutrient enrichment takes place as a result of shoreline development, the algae production-decomposition cycle depletes the oxygen in the deep waters of the hypolimnion.

Low concentrations of dissolved oxygen in bottom waters impair the lake trout's respiration, and therefore its metabolism, which compromises its ability to swim, feed, grow and avoid predators. Studies have shown that juvenile lake trout need at least 7 milligrams (mg) of dissolved oxygen per litre (L) of water. Measured as a mean, volume-weighted, hypolimnetic dissolved oxygen concentration (MVWHDO), this level is also sufficient to make sure that natural recruitment takes place. The Ministry of Natural Resources has thus developed a criterion of 7 mg of dissolved oxygen/L (measured as MVWHDO) for the protection of lake trout habitat (references in Appendix B). The provincial water quality objective for dissolved oxygen allows for the establishment of more stringent, site-specific criteria for the protection of sensitive biological communities.[14]

---

[14] Ontario Ministry of Environment and Energy. 1994. Water management: Policies, guidelines, Provincial

The Province recommends that generally there will be no new municipal land use planning approvals for new or more intense residential, commercial or industrial development within 300 metres of lake trout lakes where the MVWHDO concentration has been measured to be at or below 7 mg/L. This recommendation also applies to lakes where water quality modelling has determined that the development of existing vacant lots, with development approvals, would reduce the MVWHDO to 7 mg/L or less. Preservation of an average of at least 7 mg of dissolved oxygen/L in the hypolimnion of Ontario's lake trout lakes will help to sustain the province's lake trout resources. For more information on sampling oxygen and calculating the MVWHDO concentration, please see the Technical Bulletin in Appendix C.

Water Quality Objectives of the Ministry of Environment and Energy. Queen’s Printer for Ontario.

3.0 BASICS OF ASSESSING LAKESHORE CAPACITY

3.1 When lakeshore capacity assessment should be considered

Lakeshore capacity assessment is a scientifically-established and recommended tool for municipalities to use on a routine basis as part of their ongoing land-use planning process. Triggers to carry out lakeshore capacity assessment may include the following:

- When developing or updating official plans
- If significant improvements to road access to a lake are being considered, or have occurred, increasing the use of residences from seasonal to extended seasonal or permanent
- If development (i.e., new planning approvals) are being considered within 300 metres of a lake or a permanently flowing stream within its watershed[15]
- If significant or unusually large amounts of development are proposed for a lake beyond the 300 metre boundary
- If water quality problems (such as elevated levels of phosphorus, loss of water clarity, or algal blooms) are noted
- If lake trout populations are present
- If changes in fisheries have been noted, especially diminishing populations of coldwater species such as lake trout
- If cottagers or year-round residents raise concerns about the effects of development on water quality

3.2 What lakeshore capacity assessment will tell you

The Lakeshore Capacity Model will estimate a lake's development capacity and compare its current level of development to this estimate. If the lake hasn't attained its development capacity, the model will also estimate the additional amount of development it can tolerate. This will allow a municipality to decide how many residential and cottage lots, or other uses, should be permitted on the lake. **Municipalities with lake trout lakes should note that dissolved oxygen may be a more stringent criterion than phosphorus for limiting development on these lakes to protect fish habitat.**

[15] The use of the 300-metre distance is described in Section 4.3 of the handbook. The area within 300 metres of a lake or permanently flowing stream is considered to be the area of influence for phosphorus loading, (*i.e.,* the area within which phosphorus from septic systems may move to the lake or stream).

3.3 What is needed to carry out a lakeshore capacity assessment?

Expertise needed

Resource managers, planners and environmental engineers carrying out lakeshore capacity assessment on inland lakes will require some level of familiarity with environmental resource management, the overall land-use development process, and the Lakeshore Capacity Model. Some municipalities may have staff with this expertise; others won't. Local conservation authorities may have experts on staff that could be of assistance.

Most resource managers, planners and environmental engineers with a basic understanding of aquatic science can be trained to use the Lakeshore Capacity Model in less than a week. Alternately, there are consultants familiar with lakeshore capacity assessment and the model that could provide municipalities with their expertise.

Information needed

This section provides an overview of the information needed to run the Lakeshore Capacity Model. The minimum information required to run the LCM is:

- Lake name
- Lake latitude and longitude, defined as the point where the outflow leaves the lake (degrees, minutes, seconds)
- Lake area (hectares)
- Local catchment or watershed area[16], excluding both the lake area and the area of any upstream lakes and their watershed(s) (hectares)
- Current shoreline development status of all lots (*i.e.,* the number of cottages and resort units and the nature of their usage: permanent/seasonal/extended seasonal); this information should also include vacant lots of record
- Land-use data for the watershed (*i.e.,* the percent of the watershed that is composed of wetlands, agricultural or urban land use)
- Categorization of the hypolimnion as anoxic or oxic at the end-of-summer (see Technical Bulletin in Appendix C for more information on sampling deepwater oxygen in lakes)
- Observed or measured total phosphorus concentrations to evaluate the model's performance

If you wish to model oxygen conditions and/or to evaluate lake trout habitat and the effect of development on lake trout habitat, further information is required:

- Detailed morphometric/bathymetric data (areas within each contour interval in hectares)
- Water temperature profiles from August and September to determine the depth of the hypolimnion at the end of summer stratification (metres)
- Dissolved oxygen profiles to evaluate the model's performance

[16] Catchment area and watershed area are treated as synonyms herein, and exclude the lake surface area. Catchment or watershed area is defined as the area of land that drains water, sediment and dissolved materials to a common receiving body or outlet. The local catchment or watershed area excludes the catchment areas of upstream lakes.

- Maximum fetch (maximum distance across the lake through the deepest location in kilometres)

Additional information that will improve the accuracy of the model's predictions includes:

- Detailed site specific information to assess whether there is potential for the long-term attenuation of phosphorus in watershed soils (see Section 5.2 for additional information)

Information sources

The Government of Ontario's Lakeshore Capacity Model uses input data from sources such as topographic maps, geological maps, fishing maps (*e.g.,* bathymetric maps, aquatic habitat inventory and lake files available from MNR for all significant cottage lakes in the province), MOE's lake files, and additional information that has been built into the model.

Shoreline development is the critical managed parameter. Information can be obtained from the assessment rolls of municipalities, lake residents' associations or direct counts. At a cost, the Municipal Property Assessment Corporation can provide assessment data that identify waterfront lots and second-tier development. In areas of the province where they exist, conservation authorities can also be a source of information on water quality in lakes and tributaries.

The following table provides some additional information regarding the possible sources of input data for the Lakeshore Capacity Model:

Table 2: Information on sources of input data for the Lakeshore Capacity Model

Information Required	Source	General Quality of Source
Lake name	MNR, MOE, Municipality, Geographical Information Systems (GIS), Gazetteer of Ontario	Good
Lake latitude and longitude	GIS, Web-based mapping programs (e.g., Google Earth)	Good
Lake area	MNR, MOE, GIS	Good
Local catchment or watershed area	MNR, MOE, GIS	Good
Current shoreline development status	Municipal tax roll information	Good
	Municipal Property Assessment Corporation (MPAC)	Good, GIS expertise is required
	Municipal Affairs and Housing	Good, where information is available
	Cottagers' Associations	Quality and availability varies
	Web-based mapping programs	Good, but resolution may vary regionally; usage estimates are not available using this source
Land-use data for the watershed	GIS	Quality varies; percent wetland area values are often underestimated

	Information that has been verified on the ground by measurement	Good, but requires technical expertise
Categorization of the hypolimnion as oxic or anoxic	MNR, MOE, Municipality	Good if recommended sampling protocols are followed (Appendix C)
Observed or measured total phosphorus concentrations	MNR, MOE, Municipalities, Cottagers' Associations	Good if recommended sampling and analytical protocols are followed (Appendix C). Analysis should be completed by a reputable lab with suitable detection limits for low-level phosphorus concentrations (see Section 6.5)

3.4 Implementing lakeshore capacity assessment

The Implementation of effective lakeshore capacity assessment will require a coordinated and cooperative approach by the various agencies involved to develop and implement the planning and regulatory tools that are needed. It is expected that implementation will be phased in, in a manner that reflects differing levels of municipal organization and the ability of municipalities to develop or acquire the expertise needed to do the assessment.

Adoption of appropriate policies in official plans and zoning bylaws

It is recommended that municipalities and planning boards update the policies in their official plans to implement lakeshore capacity assessment. Reforms made to the Planning Act in 2007 require municipalities to update their official plan not less frequently than every five years after the plan comes into effect, followed by an update of the accompanying zoning by-law within three years after the new official plan is in effect. These may include policies and standards that identify:

- Water quality objectives required to protect water quality and fish habitat
- Where lakeshore capacity assessments need to be completed and/or lake capacity limits need to be established prior to additional development approvals
- Where lakeshore capacity assessments have been completed and/or lake capacity limits have been established and:
    - Which lakes, if any, have reached their development capacity
    - Which lakes haven't reached their development capacity and what additional application requirements, approval considerations and/or development conditions may be required to protect their water quality and coldwater fish habitats

Where the catchment area of a lake is shared with another planning authority, official plans should establish a mechanism for allocating development capacity in cooperation with the neighbouring jurisdiction(s) to make sure that the water quality objectives of the lake are met.

Establishment of appropriate review mechanisms for new development

All planning authorities that have been delegated or assigned responsibility for the approval of new development through mechanisms such as official plans, official plan amendments, zoning bylaws, severances and subdivision plans should ensure as part of their review that:

- New planning approvals will meet all the policies of the official plan, including water quality objectives
- Where no policies on water quality exist in an official plan, the limits specified in this handbook and the provincial water quality objectives be used as a basis for defining water quality limits
- Where appropriate, a Lakeshore Capacity Model is used and development capacity limits are established
- Development doesn't exceed the capacity of the lake
- Appropriate design and construction conditions are incorporated as conditions of approval to minimize the effect of development on water quality and fish habitat
- All planning decisions shall be consistent with the Provincial Policy Statement (2005)

Modeling, setting capacity limits and allocating development capacity

In reviewing new developments, municipal planning authorities are encouraged to:

- Use the Lakeshore Capacity Model to establish development capacity limits, where necessary
- Set development capacity limits for lakes within their jurisdiction
- Allocate lakeshore development capacity among landowners and developers within the catchment area of a lake
- Cooperate in the allocation of development capacity where the catchment area of a lake is shared with an adjacent planning authority or authorities

Municipalities and planning boards are viewed as the most appropriate level of government to carry out these responsibilities. They're in the best position to identify and set development limits at the local level in the context of other social, economic and environmental considerations. This may require municipalities to train staff, hire consultants or work with conservation authorities to use the Lakeshore Capacity Model, set development capacities and translate them into development potential. Costs for such activities can often be recouped from the applicants as part of the development review process.

Upper-tier municipalities with planning and engineering staff are viewed as having the responsibility and capacity to carry out this role. The Ontario government encourages these jurisdictions to assume responsibility for the entire process of lakeshore capacity planning with some ongoing technical assistance and training from the province.

Planning authorities who make decisions on plans of subdivision, plans of condominium, severance applications or other Planning Act proposals, are expected to make decisions on the suitability of severance applications based on planning direction received from the municipalities or planning boards in which they are located, as well as technical information received from the Province.

Provincial role

The Ontario government, through MOE and MNR, will provide technical support to municipal planning authorities by:

a) Providing educational/outreach materials on the application of the Lakeshore Capacity Model

b) Providing municipalities with existing information on lake trout habitat and lakes at or near development capacity

c) Providing technical advice or support to municipalities on lakeshore capacity assessment, when asked

d) Providing technical advice to municipalities on site-specific applications of the Lakeshore Capacity Model on a limited, short-term basis until the municipalities have fully assumed these responsibilities

In areas with no municipal organization, the Province will continue to apply the Lakeshore Capacity Model and establish lakeshore capacity limits.

Watershed planning

Ecosystem-based watershed planning is used to assess long-term changes and cumulative effects, and overcomes the limitations of administratively-defined planning boundaries. The Ontario government recognizes the watershed as the ecologically meaningful scale for planning. This is a policy of the Provincial Policy Statement (2005) and is consistent with the principles of source water protection.

The PPS (2005) also states that a coordinated, integrated and comprehensive approach should be used when dealing with planning matters which cross municipal boundaries. The watershed is an appropriate arena for this inter-municipal coordination — especially as applied to inland lakes and river systems. Conservation authorities are watershed-based and already provide inter-municipal coordination in various parts of the province.

4.0 APPLYING THE LAKESHORE CAPACITY MODEL

4.1 Elements of the model

The Ontario government's Lakeshore Capacity Model quantifies the linkages between the natural contributions of phosphorus to a lake, the contributions of phosphorus to a lake from shoreline development, the water balance of a watershed, the size and shape of a lake and the resultant phosphorus concentration. A schematic of the model is given in **Figure 3.**

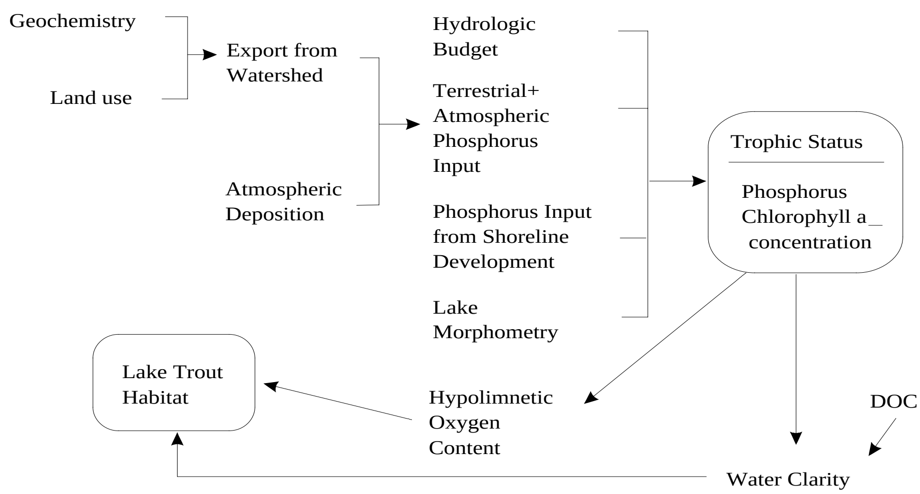


Figure 3. Ontario government's Lakeshore Capacity Model

The model allows the user to calculate how the water quality of a lake will be affected by the addition or removal of shoreline developments (such as permanent homes, seasonal cottages, resorts, campsites) and point source discharges (such as sewage treatment plants). It can calculate the natural, undeveloped condition of a lake, the amount of development (in terms of number of dwellings) the lake could sustain without changing its total phosphorus concentration past a given point, and the difference between existing conditions and that tolerance point. The model also allows the user to theoretically modify the land-use and development parameters of upstream lakes to estimate the effect of potential development on downstream lakes in the watershed.

4.2 How the model was developed

The Dillon-Rigler model, published in 1975[17], was the first model to specifically address the relationship between the eutrophication of Ontario's Precambrian Shield lakes and the density of development along their shorelines. Its rapid acceptance by the international scientific community led to the development of the Ontario government's Lakeshore Capacity Study (1976-1980) in the belief that substantial predictive relationships might be developed for other responses of lakes to shoreline development. The Lakeshore Capacity Study was coordinated by the Ministry of Municipal Affairs and Housing and published in 1986[18]. It produced predictive models for land-use (MMAH), fisheries exploitation and wildlife (MNR), microbiology and water quality (MOE), as well as a capacity model that integrated all of these components (MMAH). Although several of these models were very useful, MOE's water quality model was the only one that management agencies adopted for routine use.

MOE's Lakeshore Capacity Model is based on the total phosphorus concentration or trophic status of a lake. It provides an accurate and quantitative linkage between the level of shoreline development and the level of phosphorus in a lake. This output can subsequently be used to predict the impacts of development on water clarity and deepwater oxygen content.

Over time, resource managers in MOE's regional offices, other government agencies in Canada and the United States, and the scientific and consulting communities have adopted the Lakeshore Capacity Model as an assessment tool. Although the model was accepted as a useful planning approach, the Ontario government never formalized its implementation. As a consequence, resource managers developed their own modifications to the model to address local concerns and interpretations. By the early 1990s, it became apparent that these informal implementation arrangements were no longer suitable; significant variations of the model were in use across the province, leading to a fragmented approach to water quality protection and confusion among stakeholders.

With the MOE's corporate adoption of watershed planning in 1993, a process leading to the formalization of lakeshore capacity assessment in policy commenced. This handbook is a result of this process. It was developed to give clear and consistent guidance to municipal planning authorities (as well as developers and lake residents),and to provide effective succession training to ministry staff, municipal staff and consultants.

---

[17] Dillon. P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *J. Fish. Bd. Can.* 32: 1519-1531.

[18] Ontario Ministry of Municipal Affairs and Housing (Research and Special Projects Branch). 1983-1986. Lakeshore Capacity Study. Queen's Printer for Ontario:

- Committee Report
- Land use (Downing, J.C. 1986. Ministry of Municipal Affairs and Housing)
- Fisheries (McCombie, A.M. 1983. Ministry of Natural Resources)
- Microbiology (Burger, C.A. 1983. Ministry of the Environment)
- Trophic Status (Dillon, P.J., Nicholls, K.H., Scheider, W.A, Yan, N.D. and Jeffries, D.S. 1986. Ministry of the Environment)
- Wildlife (Euler, D.L. 1983. Ministry of Natural Resources)
- Integration (Teleki, G. 1986. Ministry of Municipal Affairs and Housing)

4.3 Assumptions built into the model

The Lakeshore Capacity Model includes several assumptions and coefficients. These numeric data represent the unknown and variable conditions in a lake or watershed. In the past, resource managers often adapted these variables to fit local conditions or to achieve certain management goals.

The mathematical assumptions in the Lakeshore Capacity Model have been refined over the past 25 years. Those presented herein reflect the current position of the MOE, and are based on the recent peer-reviewed scientific evidence. They also reflect MOE's commitment to a precautionary approach, as outlined in the Ministry's *Statement of Environmental Values*. This approach supports the use of conservative assumptions to protect the environment when there is uncertainty in the science. Resource materials related to the assumptions are listed in Appendix B, *Lakeshore capacity assessment resources*.

Definition of shoreline development

The original Lakeshore Capacity Study (1986) defined shoreline development as the total number of units to be situated within 300 metres of the lake or any inflowing stream of the lake. Herein, the definition of development is broadened to include any activity which, through the creation of additional lots or units or through changes in land and water use, has the potential to adversely affect water quality and aquatic habitat. Development includes the addition of permanent residences, seasonal or extended seasonal use cottages, resorts, trailer parks, campgrounds and camps, and the conversion of forests to agricultural or urban land. It also recommended that consideration be given to any proposed large-scale alterations in land use (e.g., clearcutting of forest, dredging or filling of lowland areas) which may affect the TP input from the terrestrial watershed.

A watershed represents the total land area that contributes drainage to a lake. In some cases, significant portions of the watershed may be situated numerous kilometres from the lake they drain into. For management purposes, the 300 metre distance from the shoreline of the lake or any inflowing stream of the lake will continue to be used as the primary influence area. This 300 metre zone is immediately adjacent to the lake and is therefore considered sensitive in terms of lake water quality protection. On a case-by-case basis, large-scale developments (e.g., subdivisions) or any other significant land use activities which may affect the TP input from the terrestrial watershed beyond 300 metres may also be considered.

Phosphorus loadings to septic systems

Since the Lakeshore Capacity Model was first developed in the 1970s, the water usage rates for recreational lakes have increased due, in part, to the increased use of washing machines and dishwashers. These changes have been partially offset by decreases in the phosphorus content of detergents. The model now assumes that 0.66 kilograms of phosphorus is contributed per capita per year to septic systems (Paterson et al. 2006, Appendix B). This loading is considered to be the most appropriate coefficient in cases where detailed site-specific measurements haven't been made.

In general, reduced phosphorus loading rates should only be used for calculating lakeshore capacity where:

- The sewage effluent is received and treated in a municipally or provincially operated system designed to produce lower per unit phosphorus loading levels; if this system discharges into the lake being modeled, its total phosphorus load should be accounted for as a point source when modeling;

- The sewage effluent is transported, treated and discharged outside the catchment area of the lake in accordance with regulatory requirements.

Other sources of phosphorus from shoreline development

The Lakeshore Capacity Model focuses on phosphorus from septic systems as the major, human contributor to lake loadings. In recent years, as lake developments have become more urban with extensive cleared areas, gardens and turf grass, overland runoff has also been recognized as an additional contributor of phosphorus.

The model assumes an overland run-off loading to lakes of 0.04 kilograms of phosphorus per lot per year. This is calculated by multiplying the export coefficient for phosphorus from pasture land (9.8 $mg/m^2/yr$; Dillon et al. 1986, Appendix B) by the mean size of lots in the District of Muskoka and the County of Haliburton (3798 m^2, n>1000; Paterson et al. 2006, Appendix B). Additional sources of phosphorus such as sewage treatment plants, golf courses, intensive agriculture or timber harvesting, and lake sediments may also contribute significant nutrient loads to lakes. In cases where these loads have been quantified through direct measurement, they may be input into the Lakeshore Capacity Model as additional loads.

Retention of phosphorus from septic systems

The degree to which septic system phosphorus may be retained in watershed soils has been the subject of considerable scientific debate over the past two decades. While the Ontario Ministry of the Environment has recognized that the degree of retention may vary with soil type and grain size[19], it has consistently held the position that all of the P deposited in septic systems will eventually migrate to lake ecosystems. This reflects the predominance of thin, organic or sandy soils and tills on the Precambrian Shield, the fractured nature of the bedrock, and the predominance of aging septic systems that were designed for hydraulic purposes (*i.e.,* to ensure fast infiltration) rather than for nutrient retention. Furthermore, at the time of model development, there was no scientific evidence that phosphorus could be retained in watershed soils over the long-term.

Subsequent studies, however, have shown that the movement of phosphorus from septic tank-tile bed systems may be retained to some degree in certain soil types[20,21]. In response to this new science, the Ministry has developed criteria (Section 5.2) that can be used to assess the likelihood of P retention at a site over the long-term (i.e., decades). These criteria were developed after organizing technical workshops on the topic, liaising with technical experts, reviewing relevant peer-review studies from Ontario and elsewhere, and following the completion of technical reports by Dr. W.D. Robertson (Department of Earth Sciences, University of Waterloo) examining the fate of P in septic system plumes at sites on the Precambrian Shield.

A review of the peer-reviewed literature and the Robertson reports indicates that eight septic system plumes located within the Precambrian Shield in Ontario have been the subject of

---

[19] Dillon, P.J., K.H. Nicholls, W.A. Scheider, N.D. Yan, and D.S. Jeffries. 1986. Lakeshore Capacity Study – Trophic Status. Ont. Min. Muncip. Affairs Tech. Report. Table 29.

[20] Robertson W.D., S.L. Schiff and C.J. Ptacek, 1998. Review of phosphate mobility and persistence in 10 septic system plumes. Groundwater. 36: 1000-1010.

[21] Robertson, W.D. 2003. Enhances attenuation of septic system phosphate in noncalcareous sediments. Groundwater. 41: 48-56.

detailed field studies[22]. Of these, significant (> 90%), long-term (decadal-scale) retention of P has been demonstrated at half of the sites (Muskoka, Harp, Lake Joseph and Nobel). However, the Harp site was not investigated in detail because of monitoring difficulties (Zanini et al. 1998)[23], and the Nobel plume is described by Robertson (2003) as distinct from the other sites because its septic system receives only “blackwater”. Thus, only two of the aforementioned sites (one quarter of the sites on the Precambrian Shield in Ontario with detailed monitoring networks) provide field evidence of significant, long-term retention of P.

It is worth noting that the two sites showing long-term P retention (Muskoka, Lake Joseph) have native soils in excess of six meters. In contrast, all of the monitoring sites that have native soils of less than three meters show elevated concentrations of phosphate in groundwater (Delawana, Sturgeon Bay), have uncertainty in how they were monitored (Harp), or have uncertainty regarding the location of the P plume (Killarney). Poor attenuation at these sites, and the apparent loss of the plume core zone at the Killarney site, has been attributed to a variety of factors including the presence of thin soils, reducing conditions that develop in saturated soils, or chemical interference from water treatment apparatus. The above findings remind us that we must be cautious on the issue of P retention, and that failure to do so may place sensitive lakes at an unacceptable level of risk.

Thus, the recommended approach for applying phosphorus retention factors reflects the type of information that is available on the factors that influence the movement of phosphorus in soils. There are two basic approaches:

Use of phosphorus retention factors

1. In areas of the province where soils are thin or absent, and bedrock is exposed or fractured, site-specific information may show that very little phosphorus is retained, and modelers should use a 100 per cent loading coefficient within 300 m of the shoreline or inflowing tributary.
2. At sites where deeper native soils are present, planning authorities or development proponents may consider undertaking detailed site-specific studies to assess phosphorus distribution, migration velocity and long-term retention. This information should be made available to the local planning authority for review and consideration (see Section 5.2). In such cases, MOE will provide interpretation and guidance on the requirements of site-specific studies. Following approval, the resulting retention factor may be used in the model to reduce the input of P loading from septic systems.

Site engineering and vegetated buffers as nutrient sinks

In urban areas, techniques such as stormwater detention ponds, constructed wetlands and infiltration areas can be used to reduce the concentration of nutrients in overland runoff. For lakeshore properties, techniques such as shoreline naturalization and vegetated buffer strips have been accepted in many jurisdictions as sound management practices. However, there is

[22] References in footnotes [19] and [20], and: Robertson, W.D. Robertson. 2005. 2004 Survey of phosphorus concentrations in five central Ontario septic system plumes. Technical Report prepared for the Ontario Ministry of the Environment, Dorset Environmental Science Centre. 24 pp.; and Robertson, W.D. 2006. Phosphorus distribution in a septic system plume on thin soil terrain in Ontario cottage country. Technical Report prepared for the Ontario Ministry of the Environment, Dorset Environmental Science Centre. 16 pp.

[23] Zanini, L., Roberston, W.D., Ptacek, C.J., Schiff, S.L., and Mayer, T. 1998. Phosphorus characterization in sediments impacted by septic effluent at four sites in central Canada. Journal of Contaminant Hydrology. 33: 405-429.

not enough information to reliably predict the level of nutrient control that may be achieved through such techniques, or their long-term effectiveness at reducing phosphorus loading. Accordingly, the Lakeshore Capacity Model makes no allowances for mitigation of overland runoff through site engineering and vegetated buffers. It is recommended, however, that further studies be done to quantify the effectiveness and longevity of such techniques.

Rivers, wetlands and phosphorus transport

The Lakeshore Capacity Model assumes that all the phosphorus leaving one lake will be transported downstream to the next lake. Questions have been raised about the potential for phosphorus retention in wetlands and river channels. Evidence to date doesn't support the idea of phosphorus retention in either wetlands or river channels on a long-term basis. In both rivers and riverine wetlands, phosphorus retention is seasonal, with retention in the summer and export during high flow periods in the spring and fall. Accordingly, the current model doesn't include the possibility of phosphorus retention along river systems between lakes. This assumption may be revisited in the future as more information is gathered.

Usage rate of shoreline properties

One of the critical unknown variables in the Lakeshore Capacity Model is the usage rate of shoreline properties: how many days a year a property is occupied and by how many people. Usage rates vary dramatically with factors such as distance to major population centres and rate of conversion of seasonal residences to permanent use. Some indication of current usage rates may be obtained from surveys, tax records, lake residents' associations, topographic maps or aerial photos, although uncertainties are associated with all these information sources. Estimating future usage rates is more difficult. Estimating usage rates for uses other than year-round residences and seasonal cottages (such as resorts) is also challenging. The current MOE position is that the provincial standard usage rates should remain in effect (**Table 3**).

Table 3. Standard usage rates for lakeshore residences

Type of shoreline residence	Usage rate (capita years per year)
Seasonal	0.69
Extended seasonal	1.27
Permanent	2.56

Usage rates can be modified based on local survey data. MOE also recommends that lake managers develop and update registries of development for each lake. In cases where usage rates are unknown and where there is no winter road access, MOE recommends using the seasonal rate of 0.69 capita years per year as a default. The extended seasonal rate of 1.27 capita years per year should be used for other non-permanent developments that have reliable year-round access.

MOE also recommends that specific phosphorus loading and/or usage rates be used for youth camps, resorts, permanent trailer parks, and campgrounds/tent trailers/RV parks:

Phosphorus loading / usage rates

Youth camps

Each camper = 125 g per year

Resorts ***(serviced, housekeeping cabins or meal plan)***

Each resort unit = 1.18 capita years per year; **OR**

Each guest = 308 g per year; **OR**

If staff are considered, the resort contribution can be estimated using the extended seasonal usage figure of 1.27 capita years per year per unit

Trailer parks

Each site or hook up = 0.69 capita years per year

Campgrounds / Tent trailers / RV parks

With septic system to service pump outs, comfort and wash stations:
Each campsite = 0.37 capita years per year

With vaulted (*i.e.,* pumped out) outhouses and grey water treatment only:
Each campsite = 0.175 capita years per year

To allocate remaining development (existing vacant lots plus new severances) where usage patterns are known, managers should use a hybrid usage factor: the existing ratio of seasonal / extended seasonal / permanent residences, and their respective standard usage factors.

Watershed-based planning issues

Lakeshore capacity assessment is consistent with watershed planning in that it considers phosphorus loading on a watershed basis. All lakes in a watershed have to be taken into account and modeled to make accurate predictions. Failure to model all lakes in a watershed may result in: 1) an overestimate of the concentration of phosphorus in the target lake because, with no accounting for retention by upstream lakes, the phosphorus export from the entire watershed will be added to the target lake; or 2) an underestimate of the P concentration in the target lake because the phosphorus load from nutrient-rich lakes upstream is not considered. In practice, lakes that are less than 25 hectares in size aren't considered unless they have significant shoreline development. Wetlands aren't modeled as separate water bodies.

Watershed-based planning can be applied in three different ways, depending upon the situation:

Application of watershed-based planning

1. **First time modeling, no lakes known to be at capacity**
   All upstream sources of phosphorus must be accounted for in a lake's budget. Development capacity must allow for human sources of phosphorus from upstream. In this case, the watershed includes all lakes greater than 25 hectares in size, and smaller lakes with significant development, up to the headwaters of that catchment.

2. **Risk-based decision making**
   When a lake is getting close to capacity, managers should review the implications of further upstream development, taking into consideration the amount of sampling that has been done:
   - How much development capacity is left upstream?
   - What type of development is planned for the future?
   - How much will full development upstream drive a target lake past its water quality objective?
   - What resource is at risk if an objective is exceeded (*e.g.,* clarity, dissolved oxygen)?

3. **When a lake reaches capacity**
   In this situation, MOE recommends using a less restrictive definition of a watershed as a balance between environmental protection and economic development. In this case, the watershed includes the lake that has reached capacity and extends upstream to the point where cumulative in-lake retention of phosphorus exceeds 80 per cent.

Lakeshore capacity assessment should be based on phosphorus loadings for the entire watershed so that phosphorus offset trading, remediation and mitigation can be incorporated if they become established practices in the future.

Comparisons between modeled estimates and measured water quality values

There will always be some discrepancy between modeled estimates and measured water quality values. This can occur because current development may not yet be expressed as changes in trophic status due to the lag time that exists between construction and phosphorus loading. Discrepancies may also result from use of inappropriate coefficients, inaccurate water quality data, or an insufficient sampling period (**Table 4**).

Table 4. Possible reasons for a poor prediction of measured TP concentrations using the model

Common reasons for over-prediction of measured TP	Common reasons for under-prediction of measured TP
• A lag time in the movement of phosphorus from septic systems to lakes - the impact has not yet been realized in the lake • Site conditions favour the long-term retention of phosphorus in watershed soils, and anthropogenic contributions of phosphorus are overestimated • There are significant groundwater inputs to the lake, diluting phosphorus concentrations in the lake • The lake is modeled as being anoxic, when it is oxic during the end-of-summer period • Inaccurate input coefficients are used (e.g., runoff values, usage values, lake area) • The lake falls outside the calibration and test range of the modes (e.g., lakes with very small surface areas) • Measured phosphorus data are of poor quality	• There is a significant internal load of phosphorus to the lake that the model does not account for • The portion of the catchment that is estimated as wetland area (i.e., % wetlands) is underestimated • The amount of cleared land is underestimated • The lake is modeled as being oxic, when it is anoxic during the end-of-summer period • Inaccurate input coefficients are used (e.g., runoff values, usage values, lake area) • The lake falls outside the calibration and test range of the model (e.g., shallow lakes where there is a significant internal load of phosphorus to the water column) • Measured phosphorus data are of poor quality

MOE recommends that total phosphorus be used as the parameter for comparison of model results with measured values. The sampling period must be long enough to enable the long-term mean to be estimated to within 20 per cent with 95 per cent confidence. In most cases, this means that at least two years of spring overturn measurements or one year with at least five measurements of volume-weighted phosphorus concentrations should be used (*see* Section 6.2, Table 5). Measurements should be summarized using an arithmetic mean for comparison purposes.

If the modeled estimates and measured values are within 20 per cent of each other, then they aren't considered to be significantly different. If the modeled estimates and measured values differ by more than 20 per cent, then lake managers should inspect the measured record for quality and the data used in the model for accuracy, consider alternative coefficients that may be more accurate, and consult other water quality measurements (*i.e.,* Secchi depth and oxygen-temperature profile records).

Following a review of the model coefficients and monitoring data, predicted and measured values may still differ by more than 20 per cent. A test of the Lakeshore Capacity Model across many watersheds in Ontario suggests that, in general, the following lake types may not model well, because they fall beyond the calibration and test range of the model:

- *Shallow lakes (lakes with mean depth < 5 metres)*: The lakeshore capacity model was calibrated on Precambrian Shield lakes that thermally stratify during the ice-free season. The model assumes a constant to estimate the rate of loss of phosphorus to lake sediments (i.e., the settling velocity, or mass transfer coefficient). This constant is modified depending on whether or not a lake's hypolimnion is oxic or anoxic in late summer. For shallow lakes, the default values may overestimate the loss of phosphorus to sediments, as it does not account for P re-suspension during wind events.

- *Tea-stained lakes (dissolved organic carbon concentrations > 10 mg/L*): The model has not been calibrated for lakes that are highly coloured due to humic and fulvic acids. These lakes are common in northern Ontario, and may have relatively high background phosphorus concentrations.
- *Lakes with small surface areas (< 25 ha)*: For very small lakes, minor differences in surface area can have a large impact on the model output. For example, the difference in surface area between a 25 and 20 ha lakes is small in absolute terms, but represents a 20% difference in relative size. This change in the model input may result in a significant increase in predicted P.

What if the model fails?

The Ministry recommends that the Lakeshore Capacity model be used to manage the effects of shoreline development and land-use change on P concentrations in Precambrian Shield lakes. As outlined in Appendix A, this approach allows resource managers and planning authorities to assess changes relative to lake-specific PWQOs for phosphorus, to assess future risks from the cumulative effects of development, and to protect the trophic diversity of lakes across the province. However, in some cases the model may not predict phosphorus concentrations within acceptable limits, putting into question its applicability. In these cases, it is recommended that the interim PWQO for phosphorus be followed as a guideline (Section 2.2).

In both cases, a total phosphorus concentration of 20 µg/L will be used as the upper limit to protect against nuisance algal blooms. In situations where a lake is naturally above 20 µg/L (e.g., highly coloured, tea-stained lakes), Regional MOE staff may use discretion to allow a limited amount of new development (e.g., < 10 lots), provided the lake is not sensitive, and downstream lakes are not designated at-capacity.

Changes to model assumptions

Over the past 30 years, some of the original assumptions and coefficients of the Lakeshore Capacity Model have been modified based on new scientific evidence. With the shift to municipalities for many responsibilities in land-use planning and in recognition of the need for a stable planning environment, questions have been raised about how best to continue with the process of updating assumptions. MOE recommends establishing a working group with representation from MOE, MNR, MMAH, municipalities and the private sector to periodically review major scientific advances and to discuss challenges to the model. Based on this information, the workgroup would consider if changes to the model are warranted.

4.4 Overview of the Lakeshore Capacity Model

The Lakeshore Capacity Model will assess the lakeshore capacity of a specific lake. The model was developed and calibrated for Precambrian Shield lakes in south-central Ontario, but has been tested and used in lakes across the entire Precambrian Shield. At the end of the assessment process, the user will have had the opportunity to determine the amount of development — whether seasonal, permanent, resort or point source that each lake in a watershed could accommodate while adhering to its water quality targets.

Using the Lakeshore Capacity Model to assess the development capacity of a lake

1. Modeling begins at the top of the watershed and continues downstream until the target lake is reached. The model is used to track phosphorus sources and the transport of phosphorus from one lake to the next downstream lake.
2. The model calculates the total phosphorus (TP) concentration of a lake by calculating what the TP concentration would have been without shoreline development (the predevelopment concentration) and adding this amount to the current estimated TP contribution from shoreline development.
3. The model can also be used to calculate the response of water quality to increases in shoreline development as well as the amount of additional development the target lake could tolerate while still adhering to its desired water quality targets. The model will also illustrate how changes in the upper watershed would influence the quality of water in downstream lakes.
4. The user can compare the model results with the provincial water quality objectives for total phosphorus. The user can then determine the amount of development that could occur while still enabling these objectives to be met.
5. The model translates water quality objectives (as µg/L phosphorus) into total allowable phosphorus load. The total allowable phosphorus load can either be expressed in kilograms or as the number of allowable cottages, permanent residences or resort units.

The Lakeshore Capacity Model is an assessment tool that is intended to be used by resource managers to predict the response of water quality to shoreline development. The municipal bodies surrounding the lake or the watershed are responsible for implementing the model predictions and allocating lakeshore capacity after the assessment has been completed.

5.0 LAND USE PLANNING APPLICATIONS AND BEST MANAGEMENT PRACTICES

5.1 Why use best management practices?

Best management practices (BMPs) are practices that can help to reduce the migration of phosphorus from septic system effluents to water bodies, thereby reducing the effects of shoreline development on lake water quality. Coupled with lakeshore capacity assessment, BMPs will help municipalities maintain good lake water quality. On their own, BMPs can help to reduce the adverse effects of shoreline development on inland lakes.

Best management practices can take many forms. One category involves practices that can be implemented during the planning and construction phase of shoreline development and especially during the design and construction of septic systems. Other practices relate to the ongoing maintenance of a septic system and other operating practices of the cottage or homeowner. An overview of BMPs that lessen phosphorus migration is provided below. Sources of more detailed information on BMPs are listed in Appendix B.

As noted in Section 4.3, BMPs such as shoreline naturalization and vegetated buffer strips have been accepted in many jurisdictions as sound management practices for lakeshore properties. However, there is insufficient information on these techniques to reliably predict the level of nutrient control that may be achieved or their long-term effectiveness at reducing phosphorus loading. This is why the Lakeshore Capacity Model makes no allowances for mitigation of overland runoff through site engineering and vegetated buffers.

Involving residents and cottagers' associations in the voluntary adoption and promotion of BMPs is a useful way to introduce the notion of lake stewardship (caring for lakes). Where they exist, conservation authorities often have programs or communications materials that promote the use of BMPs.

5.2 Development and planning considerations

This Handbook is a beneficial planning tool for approval authorities (municipalities, planning boards and MMAH) to use when reviewing planning applications adjacent to water bodies. A qualified consultant will likely undertake the modeling and provide interpretations and recommendations. This will assist decision makers when reviewing planning applications involving shoreline development.

Shoreline setbacks "in general"

The *Ontario Building* Code (OBC) sets a province-wide uniform standard requiring that there be a minimum of 15 metres clearance between a Class 4 or 5 Sewage System and any lakes, pond, spring, river or stream (as well as other water sources such as wells or reservoirs). This requirement is intended to mitigate pathogens that are harmful to humans from entering water bodies. There are no requirements in the building code that apply specifically to phosphorus.

To address possible impacts of development on fish habitat, municipalities may enact zoning bylaws setting out setbacks or other zoning provisions. These could, for example, set out setbacks greater than 15 metres or zone the shoreline to restrict locating of buildings or structures. Such bylaws would be established through the planning process under the Planning

Act.

Throughout the Precambrian Shield soil cover is typically thin and fractured bedrock is common. For lakes in this environment, irrespective of whether or not they are at capacity for shoreline development, MOE and MNR recommends a minimum of 30 metre setback or a 30 metre non-development zone from water bodies. If natural heritage features are identified on or adjacent to a lot then additional appropriate setbacks or restrictive development zones might be required. Cottagers and lake residents are encouraged to provide as great a setback as possible to minimize the impact of development on lakes.

Vegetation and site preparation

Phosphorus is an essential element required to support plant growth. What is not broadly accepted scientifically, however, is the amount of phosphorus that is removed permanently by a vegetative buffer that may exist at the shoreline of the proposed lot. Because of this uncertainty, further studies should be completed to quantify the effectiveness and longevity of such techniques. Thus, as a default in Lakeshore Capacity modeling, the Handbook does not consider a retention rate for phosphorus for vegetative buffers. However, the model is flexible and a coefficient of this nature could be added in the future if new science supports its use; a vegetated buffer is still considered to be a Best Management Practice. For example, MNR recommends that generally 30 metres of natural vegetation be maintained or rehabilitated adjacent to fish habitat for its protection (Natural Heritage Reference Manual, 2nd Edition).

Where natural vegetation exists at the juncture of land and water, it should be maintained. Where this doesn't occur naturally, or has been removed, a vegetative buffer (riparian zone) of shrubs and ground cover can be planted along a shoreline bank. Preserving aquatic vegetation and retaining shoreline woodlots will also help to reduce phosphorus loadings. To capture and infiltrate runoff, infiltration trenches with filter fabric and crushed stone may be placed along the drip line of the cottage or house instead of traditional gutters and downspouts.

Septic system design

Cottagers and lake residents may take measures they consider will lessen the impact of their on-site sewage treatment on the environment as long as these measures do not impact negatively on any of the approved and OBC-required features of the sewage system. For example, acidic sites on non-calcareous sands (sands with low % calcium carbonate), may provide better phosphorus retention than sites on calcareous sands. Another example is the use of a siphon or pump to reduce phosphorus loading by providing an even distribution of septic tank effluents to the tile bed. Until a technology is proven effective over the long term, however, the phosphorus removal rate cannot be factored into the lakeshore capacity modeling.

What is a lake at capacity?

Lakes can be modeled to determine what their carrying capacities are with respect to phosphorus loading from shoreline development. Modeling takes into account vacant lots of record, incorporates assumptions that are inherent in the calculation of 'background' or 'undeveloped' conditions, and can be predictive with respect to any remaining capacity of the lake. See section 2.0 for a discussion on the link between phosphorus, dissolved oxygen, water quality, and lakeshore capacity. (See also Appendix A and references in Appendix B).

As set out in Section 2.2, the revised Provincial Water Quality Objectives (PWQO) for lakes on the Precambrian Shield allows a 50 per cent increase in phosphorus concentration from a modeled baseline of water quality in the absence of human influence. Based on this test, a lake would be 'at capacity' with respect to phosphorus if the modeling process determined that the existing development, including vacant lots of record, exceeded the modeled 'background' or ‘undeveloped’ concentration of (total) phosphorus, plus 50%.

In some cases, a lake may be considered to be ‘at capacity’ based on modeling results, but be ‘below capacity’ based on measured phosphorus concentrations, or *vice versa*. Because of natural variability in phosphorus concentrations over time, and inaccuracies in some model coefficients when applied to lakes across the Precambrian Shield, there is some error associated with the model predictions. Thus, we recommend that in cases where the predicted value is within 10% of the revised PWQO for total phosphorus (i.e., between background + 40% and background + 60%), that some flexibility be allowed when making management decisions. For example, further consideration should be given to a lake’s sensitivity[24] to anthropogenic development and to other potential threats to water quality. If a lake has a history of nuisance algal blooms, or has undergone noticeable aesthetic changes in recent years (e.g., changes to water clarity), these observations should be considered as part of the overall management strategy for a lake.

The PWQO for dissolved oxygen allows for the establishment of more stringent criteria for the protection of specific, biologically-sensitive communities. A small percentage of all lakes provide suitable lake trout habitat. Low concentrations of dissolved oxygen in deeper water impair lake trout respiration, and therefore its metabolism, which compromises its ability to swim, feed, grow, and avoid predators. Studies have shown that juvenile lake trout need at least 7 milligrams (mg) of dissolved oxygen per Litre (L) of water to thrive and reproduce. The Ministry of Natural Resources consequently adopted a criterion of 7 mg/L dissolved oxygen measured as mean volume-weighted hypolimnetic concentration at the end-of-summer, to protect lake trout habitat. This is considered to be a scientifically established standard (for purposes of the PPS, 2005). For more information on this criterion, and how it is measured, please see references in Appendix B.

To protect natural heritage features, including fish habitat, policy 2.1.6. of the PPS (2005) includes direction that development and site alteration shall not be permitted on adjacent lands to the natural heritage features and areas unless the ecological function of the adjacent lands has been evaluated and it has been demonstrated that there will be no negative impacts on the natural features or on their ecological functions. Further to this, policy 2.1.5. of the PPS (2005) provides that development and site alteration shall not be permitted in fish habitat except in accordance with provincial and federal requirements. Provincial and federal requirements are defined in the PPS (2005) as legislation and policies administered by the federal and provincial governments for the purpose of protection of fish and fish habitat, and related, scientifically-established standards such as water quality criteria for protecting lake trout populations.

Requirements and restrictions for development on lakes at capacity

The following applies to lakes that have been modeled to be at-capacity for phosphorus (i.e., phosphorus concentrations exceed ‘background’ or ‘undeveloped’ concentrations + 50%), or have modeled or measured dissolved oxygen concentrations that are less than MNR’s criterion for lake trout lakes (i.e., less than 7 mg/L dissolved oxygen, measured as mean volume-weighted hypolimnetic dissolved oxygen concentration at end-of-summer). Where these circumstances exist, new lot creation and other planning approvals should only be allowed:

- to separate existing habitable dwellings, each of which is on a lot that is capable of

[24] Sensitivity can be broadly defined as the degree of change in phosphorus (P), relative to background conditions, that a lake experiences with shoreline development. The relative sensitivities of lakes within a watershed can be tested by adding a set P load to all lakes, standardized to lake area, and comparing the resultant changes in predicted P concentrations.

supporting a Class 4 sewage system, provided that the land use would not change and there would be no net increase in phosphorus loading to the lake;

- where all new tile fields would be located such that they would drain into a drainage basin which is not at capacity; or
- where all new tile fields would be set back at least 300 metres from the shoreline of lakes, or such that drainage from the tile fields would flow at least 300 metres to the lake[25]; and,

The following additional site-specific criteria can be applied where new development is proposed on at-capacity lakes and where certain municipal planning tools and agreements are in place such as a Development Permit System under the Planning Act, and/or site plan control under the Planning Act, and site alteration and tree-cutting by-laws under the Municipal Act:

- where a site-specific soils investigation prepared by a qualified professional[26] has been completed showing the following site conditions:
    - o the site where the septic tile-bed is to be located, and the region below and 15 metres down-gradient of this site, toward the lakeshore or a permanently-flowing tributary, across the full width of the tile bed, consist of deep (more than three metres), native and undisturbed, non-calcareous (<1% $CaCO_3$ equivalent by weight) overburden with acid-extractable concentrations of iron and aluminum of >1% equivalent by weight (following Robertson 2005, 2006, Appendix B). Soil depth shall be assessed with test pits and/or boreholes at several sites. Samples for soils chemistry should be taken at a depth adjacent to, or below, the proposed tile bed; and
    - o an unsaturated zone of at least 1 ½ metres depth exists between the tile bed and the shallowest depth (maximum) extent of the water table. The position of the water table shall be assessed with test pits during the periods of maximum soils saturation (e.g., in the spring, following snowmelt, or late fall)

Given that some relevant measures are not applicable law under the Ontario Building Code, agreements pursuant to the Planning Act that are registered on title will be needed to ensure the following for each lot created:

- design of the septic system shall include pump-dosing or equivalent technology to uniformly distribute septic effluent over the tile bed;

[25] Sewage effluent travels from the infiltration bed to the receiving water body in both the unsaturated and saturated zone of the sub-surface. Most commonly, the effluent pathway within the unsaturated zone is considered to be directly downward. After reaching the water table, effluent is transported with local groundwater along the groundwater gradient, which is generally in the direction of the shortest linear distance to the receiving water body. The effluent pathway may vary from the above definition under the following circumstances: 1) the effluent flow path may vary from vertical in the vadose zone if site conditions promote horizontal flow. These conditions may include topographic influences or hydraulic variations in subsurface stratigraphy. The potential for horizontal flow should be evaluated on a site specific basis; and 2) the effluent flow path in the saturated zone may vary from the shortest distance to the receiving water body. This may occur because of topographic or bedrock structural features (e.g., orientation of dominant fracture patterns). In such cases, the inference of a groundwater flow direction that is not directly to the receiving water body must be supported by hydrogeological data. This may require the identification of the groundwater gradient through measured potentiometric surface elevations at several piezometers and, or characterization of structural geology.

[26] Qualified professional is defined here as a licensed member of the Association of Professional Geoscientists of Ontario or the Professional Engineers of Ontario who is qualified to practice geoscience.

- no add-on system components such as water-softening apparatus, to ensure the proper functioning of the septic tank-tile bed system over the long-term;
- provision of a 30-metres minimum undisturbed shoreline buffer and soils mantle, with the exception of a pervious pathway;
- preparation of a stormwater management report and a construction mitigation plan (including phosphorus attenuation measures such as directing runoff and overland drainage from driveways, parking areas, other hard surfaces to soak away pits, infiltration facilities);
- location of the tile bed, in accordance with the recommendations of the site-specific soils investigation;
- long-term monitoring – for research purposes – of the sewage disposal system and reports to the planning approval authority and the Ministry of Environment. Monitoring would commence from the time of installation of the sewage treatment systems and proceed for at least 10 years. This monitoring will, at a minimum, include:
  - sampling locations immediately below the tile bed, down-gradient of the tile bed, and at least one site up-gradient of the tile bed;
  - collection of groundwater samples by a certified professional. All samples should be field filtered (0.45 µm) prior to atmospheric exposure. Samples for PO_4^{3-} (or TP) and Fe should be acidified in the field ($pH < 2$) with HCl or H_2SO_4, and analysed within two weeks of collection; and
  - chemical analyses should also include pH, chloride, total or dissolved phosphorus, nitrate, ammonium and iron;
  - sampling to occur annually (mid-summer) for the first five years, and once (mid-summer) every five years thereafter.

5.3 BMPs for maintenance and operation

Inspection and Regulation

Septic systems are regulated by provisions in the Building Code. Systems are required to perform based on the standard or requirements in place when the system was approved for use. If a system is not performing to the standard required of it and an inspector believes the system presents a health hazard, remedial steps may be required of the owner to bring the septic system into compliance.

Septic system operation and maintenance

Septic systems contained on one lot with a designed sewage flow of not more than 10,000 litres per day are regulated through the Building Code Act (1992) and the Building Code, which are administered by the Ministry of Municipal Affairs and Housing. The Building Code contains technical requirements that must be met when constructing a new septic system, or when extending, repairing or altering an existing system. The Code also mandates that owners of septic systems operate and maintain their systems in accordance with requirements to which they were designed. Under the act, enforcement bodies have the authority to determine whether existing systems are unsafe, to issue orders where unsafe conditions are found and, in extreme conditions, to remediate dangerous situations at the owner's expense.

All household sewage waste should be discharged into its septic tank. Wastewater (grey water) from laundry and saunas shouldn't be discharged directly into the drain field as the detergent and soap scum will quickly clog soil pores and cause the septic system to fail.

Starters shouldn't be added to septic systems as enough bacteria are available in the wastes that are flushed into the septic tank. Septic systems should be pumped out every three to five years to remove solids and scum. While the tank is being pumped out, the cover should be removed to make sure that all solids are pumped out. Pumping through the inspection port may clog the outlet baffle with scum and grease.

Water conservation

Excessive water use is the most common cause of septic failure. Residents should be encouraged to reduce as much as possible the amount of water they use for bathing, laundry and flushing the toilet.

Shoreline vegetation

Surface waters can be contaminated by soil particles that have been washed or blown into the water. In addition to reducing water clarity, these particles may also carry phosphorus into the water. Residents can minimize soil erosion by retaining a vigorously growing filter zone (or buffer) of native grasses, trees and shrubs beside the lake and along any streams that empty into the lake. Residents can also reduce erosion by maintaining native vegetation throughout their properties to minimize areas of exposed soil. The use of native vegetation as a ground cover instead of a lawn is especially beneficial as it doesn't require the application of pesticides and phosphorus-rich fertilizers that can add to water quality problems. Minimizing the amount of impermeable surfaces such as concrete or asphalt will reduce stormwater runoff and its erosive effects.

5.4 Phosphorus abatement technologies

In recent years, interest has grown in the potential to reduce phosphorus loadings to inland lakes by using technologies such as different filter media for septic systems. Currently, approval of conventional septic systems is carried out under the Ontario Building Code. This statute sets out septic system requirements including distance from water and size.

The Lakeshore Capacity Model takes into account the phosphorus load from conventional sewage treatment systems. The model allows for the phosphorus load to be varied if phosphorus abatement or phosphorus removal technologies are used. Currently, the Ontario government hasn't acknowledged any technologies as being suitable to be installed with, or instead of, small-scale subsurface sewage treatment systems for individual dwellings, cottages or other small buildings.

6.0 MONITORING LAKE WATER QUALITY

6.1 Why monitoring is important

As noted in Section 3.4, although the Lakeshore Capacity Model makes reliable predictions when properly applied, it should be validated by water quality monitoring. Monitoring water quality in a lake over time will allow municipalities to follow trends, determine whether the lake systems are behaving as predicted and detect any unforeseen problems as they emerge.

The following sections provide an overview of monitoring. More detailed information on what and how to monitor is available from MOE.[27] Historical information on a lake's water quality may also exist at MOE (*e.g.,* through the Lake Partner Program, see Section 6.3) or at the local conservation authority. For more about acquiring such information, see Appendix B, *Lakeshore capacity assessment resources*.

6.2 What should be monitored?

The most useful estimate of trophic status, considering ease of collection and temporal variability, is total phosphorus (TP). For the purpose of using the Lakeshore Capacity Model, the optimal method of assessing the trophic status of a lake is to collect several years of TP data at spring overturn. Alternately, a lake can be characterized by using whole-lake, volume-weighted, ice-free means of TP (**Table 5**). Epilimnetic TP data (*i.e.,* samples taken from the warm, wind-circulated upper layer of a thermally stratified lake) aren't as suitable for use in the Lakeshore Capacity Model.

In lakes that support populations of lake trout, dissolved oxygen is a critical measure. Levels of dissolved oxygen are usually at their minimum just before fall turnover and monitoring usually focuses on this time period. To better understand seasonal changes, spring profiles can also be taken to determine the degree of mixing. Several years of data, taken at multiple depths, are needed to make sure that atypical profiles aren't being used to represent long-term average conditions.

[27] Ontario Ministry of Environment and Energy. 1992. Measuring the trophic status of lakes: sampling protocols. Queen's Printer for Ontario.

Table 5. Optimal sampling strategies for the most commonly used trophic status indicators[28]

Indicator	Derivation	Sample method	Samples per year		Number of years		Time
			95% confident of being within				
			10% mean	20% mean	10% mean	20% mean	
$TP_{(so)*}$	usually single sample	5m composite	1‡	1‡	10	2	during spring turnover prior to thermal stratification
$TP_{(if)*}$	average of all samples collected for ice-free period	composites when lake is mixed volume weighted during stratification	9-13 (bi-weekly)	4-5 (monthly)	5	1	between ice out and freeze up
$TP_{(epi)*}$	average of all samples collected during stratification	epilimnetic composite	19	5	7	2	during thermal stratification
Chl $a_{(ss)*}$	average of all samples collected during stratification (*e.g.* through self help programs)	euphotic zone composites	less than for Chl $a_{(if)}$; should use Chl $a_{(if)}$ if spring/fall blooms expected				during thermal stratification
Chl $a_{(if)*}$	average of all samples collected for ice-free period	euphotic zone composites	10	5	>5	2-5	between ice out and freeze up
Oxygen	usually profile data	oxygen meter with some Winkler test samples to confirm	sample frequency based on final use of data				key period just prior to fall de-stratification
Secchi	individual observations	Secchi disc	11-17 (weekly)	3-4 (monthly)	2-5	1	ice-free period

* **so** = spring overturn; **if** = ice free; **epi** = epilimnetic; **ss** = summer stratified

‡ usually only enough time for one visit

[28] Ontario Ministry of Environment and Energy. 1992. Measuring the trophic status of lakes: sampling protocols. Queen's Printer for Ontario.

6.3 Lake Partner Program

The Ministry of the Environment's Lake Partner Program works in partnership with the Federation of Ontario Cottagers' Associations, the Lake of the Woods District Property Owners Association and many other organizations to foster lake stewardship by increasing the public's awareness of the links between phosphorus and water clarity in Ontario lakes.

The program uses volunteers to collect total phosphorus (TP) and water clarity data for lakes throughout Ontario and cooperates with many science partners (including other MOE departments and municipalities) to provide accurate TP monitoring for specific lakes of interest. The program has been quite successful: in 2004, water quality information was collected from more than 1,000 locations scattered throughout the major cottage areas of the province (**Figure 4**).

Lakes on the Precambrian Shield are sampled once each spring for TP, while water clarity is measured monthly with a Secchi disc during the ice-free period (May through October). Off-shield lakes are sampled monthly for both TP and water clarity during the ice-free period.

The TP samples are analysed by MOE to an average precision of approximately 0.7 µg/L, which is sensitive enough to detect between-year differences in spring turnover concentrations for individual lakes. The numbers are also precise enough to test the performance of the Lakeshore Capacity Model or for use as input to hypolimnetic oxygen models.

The Lake Partner Program is based out of the Ministry's Dorset Environmental Science Centre. Annual reports for the program are made available to volunteers, science partners and the public in hard copy or electronically via the ministry's website (http://www.ene.gov.on.ca/en/water/lakepartner/index.php). Inquiries about the Lake Partner Program can be made by calling 1-800-470-8322 or by emailing lakepartner@ontario.ca.

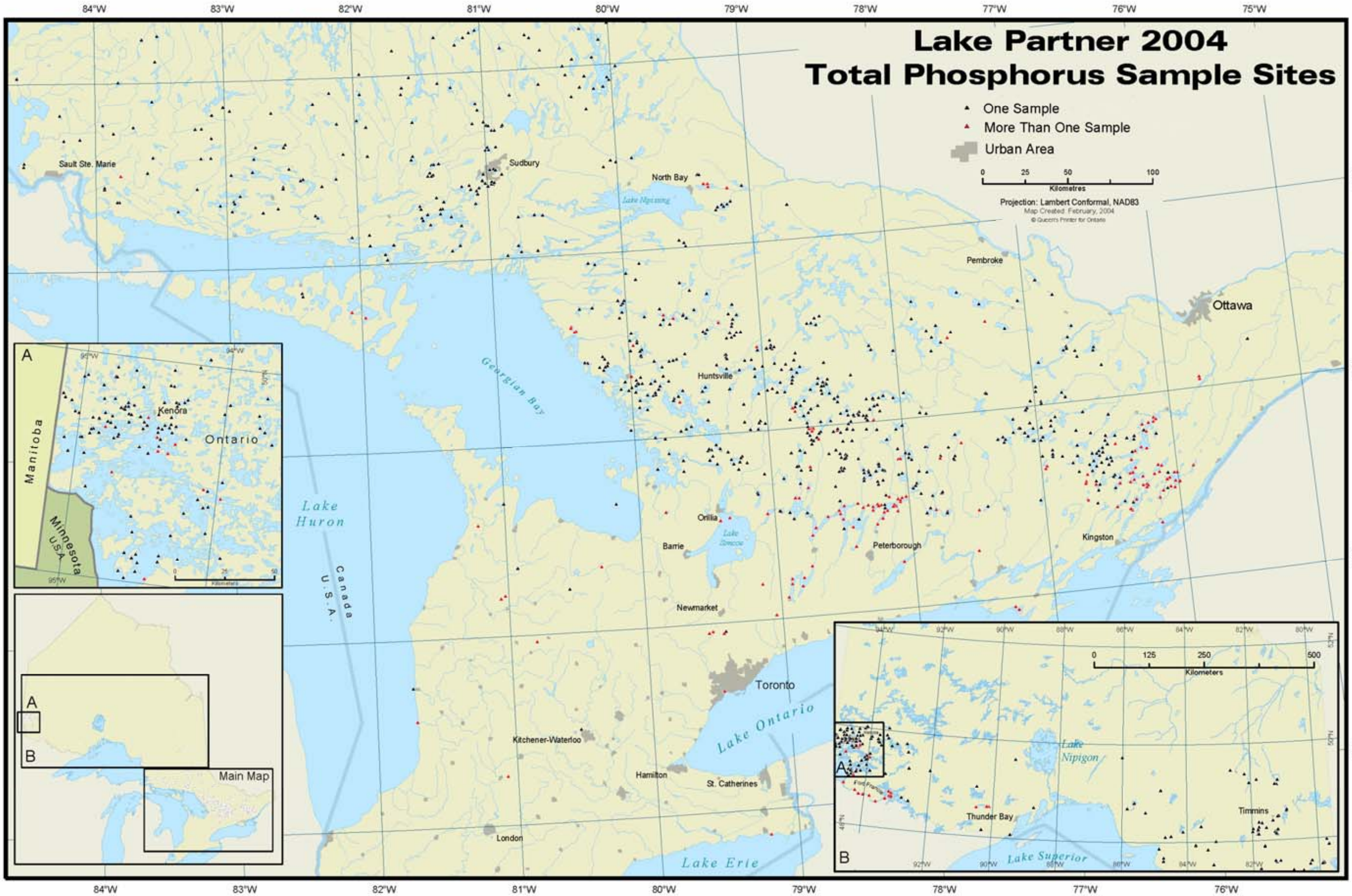


Figure 4. Lake Partner Program: Sample locations in 2004

6.5 How chemical analysis should be done

Phosphorus occurs naturally in many forms. Both organic and inorganic phosphorus are present as dissolved, colloidal and particulate fractions in lake water samples. The analysis of total phosphorus (TP) in a lake water sample is the best test to yield precise results for phosphorus.

Total phosphorus can be accurately measured even at low microgram per litre (µg/L) levels if certain precautions are taken. To obtain acceptable phosphorus results, it is best to use the classic colourimetric method: reduced phospho-antimonyl-molybdate (heteropolyblue) complexing reaction with subsequent colourimetric measurement. This reaction is specific to the orthophosphate form and is stable and relatively interference-free (when arsenate and silicate concentrations are both less than 10 µg/L). Phosphorus analysis by inductively-coupled plasma emission isn't recommended because the level of detection is generally 50 µg/L or greater. This isn't sensitive enough for modeling the trophic status of Precambrian Shield lakes.

The colourimetric method is amenable to automation, making large numbers of analyses possible. It is straightforward and quick, giving reliable results if done by a trained analyst. Sample pre-treatment is further simplified through the use of an autoclave and acid digestion with persulfate oxidation. This digestion converts all phosphorus fractions (total phosphorus) to orthophosphate.

The optimal method of TP analysis for the purpose of the Lakeshore Capacity Model also includes the collection of duplicate lake water samples directly into the autoanalyzer tubes to minimize container effects.

The laboratory at MOE's Dorset Environmental Science Centre specializes in low-level phosphorus analysis and can be contacted for information on this procedure. The ministry's Laboratory Services Branch can also be contacted to provide information on methods to determine both total and soluble phosphorus at higher concentrations for a nominal fee (about $35 currently). Contacts for the ministry are listed in Appendix B. There are also several commercial labs in the province that can carry out TP analysis using the colourimetric method.

7.0 CONCLUSION

Lakeshore capacity assessment is a tool to help municipalities and other agencies with responsibility for land-use planning to develop inland lakes in a sustainable manner. Used in concert with other federal, provincial and municipal water-related laws, regulations and bylaws, lakeshore capacity assessment will help to ensure that the province's inland lakes on the Precambrian Shield will continue to have good water quality and healthy fish communities for generations to come.

This *Lakeshore Capacity Assessment Handbook* was developed, along with the Lakeshore Capacity Model, to help municipalities to meet their obligations under the Planning Act and the Provincial Policy Statement (2005). Cooperation among agencies, municipal planning authorities, residents' and cottagers' associations, developers and the public will help to achieve sustainable development of Ontario's inland lakes.

APPENDIX A

RATIONALE FOR A REVISED PHOSPHORUS CRITERION FOR PRECAMBRIAN SHIELD LAKES IN ONTARIO

May 2010

Ministry of the Environment
Environmental Sciences & Standards Division
Standards Development Branch
40 St. Clair Avenue West
Toronto, Ontario M4V 1M2

Table of contents

Figures

Tables

ABSTRACT

Ontario should revise the existing provincial water quality objective (PWQO) for total phosphorus in surface waters. The existing, two-tiered, numeric guideline overprotects some lakes, fails to adequately protect others, produces unwarranted asymmetries in shoreline development potential and does not protect against a cumulative loss of diversity in the resource as a whole. A new, interim PWQO is proposed for lakes on the Precambrian Shield. This revised PWQO allows a 50 per cent increase in phosphorus concentration from a modeled baseline of water quality in the absence of human influence. The proposed objective prevents cumulative losses of water clarity, is detectable with a modest sampling effort, maintains the existing diversity in lake water quality and incorporates the regionally specific objectives of other jurisdictions into a single numeric criterion. The same principles should be considered in a future review of the PWQO for phosphorus in off-Shield lakes and rivers.

Document inquiries to:

Tim Fletcher, Team Leader
Standards Development Branch
Ecological Standards
Phone: (416) 327-5002
Fax: (416) 327-6421
E-mail: tim.fletcher@ontario.ca

With contributions from:

Ron Hall	Formerly MOE
Peter Dillon	Formerly MOE
Ken Nicholls	Formerly MOE
Ian Smith	Standards Development Branch, MOE
Adam Socha	Formerly of Standards Development Branch, MOE
Conrad de Barros	Operations Division, Eastern Region, MOE
Shiv Sud	Formerly of the Environmental Partnerships Branch, MOE

For critical review we wish to thank:

Dr. Joe Kerekes	Canadian Wildlife Service, Environment Canada, Dartmouth, NS
Dr. Rick Nordin	British Columbia Ministry of the Environment, Victoria, BC
Greg Searle	Wisconsin Department of Natural Resources, Madison, WI, USA

Additional contributors:

Neil Hutchinson	Gartner Lee, Markham, ON (formerly MOE)
Doug Spry	Environment Canada, Hull, QC (formerly MOE)

1.0 EXISTING PWQO FOR TOTAL PHOSPHORUS

The existing provincial water quality objective (PWQO) for total phosphorus was developed by MOE in 1979. It draws on the trophic status classification scheme of Dillon and Rigler (1975) to protect against aesthetic deterioration and nuisance concentrations of algae in lakes and excessive plant growth in rivers and streams. The rationale (MOE 1979) acknowledges that elemental phosphorus can be toxic but that, since it is rare in nature, its toxicity is rarely of concern. Instead, the purpose of this water quality objective is to protect the aquatic ecosystem from non-toxic forms of phosphorus:

> "…***phosphorus must be controlled, however, to prevent any undesirable changes in the aquatic ecosystem due to increased algal growth***..." (MOE 1979)

The 1979 PWQO for phosphorus reflects the uncertainty regarding the effects of phosphorus and acknowledges the differences in the management of toxic and non-toxic pollutants. The PWQO does not explicitly distinguish between lakes in different regions of Ontario (*i.e.,* Precambrian Shield versus southern Ontario) but, instead, categorizes lakes of low and moderate productivity into two corresponding levels of water quality. It is still in use today and reads:

> "***Current scientific evidence is insufficient to develop a firm objective at this time. Accordingly, the following phosphorus concentrations should be considered as general guidelines which should be supplemented by site-specific studies:***
>
> [For lakes:]
>
> ***To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L.***
>
> ***A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 µg/L or less. This should apply to all lakes naturally below this value.***
>
> [For rivers and streams:]
>
> ***Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 µg/L.***"

2.0 THE NEED FOR PHOSPHORUS MANAGEMENT

The Government of Ontario's goal for surface water management is:

> "...***to ensure that the surface waters of the province are of a quality which is satisfactory for aquatic life and recreation***..." (MOEE 1994)

In Ontario, phosphorus is managed to protect the clarity of its recreational waters from unacceptable increases in turbidity caused by algal growth in the water column and to prevent the formation of nuisance blooms of algae on the water's surface. Although water clarity is also reduced by its content of dissolved organic carbon (DOC), which stains the water brown, DOC in Precambrian Shield waters is controlled by natural factors and is not readily amenable to management. Phosphorus concentrations will have little influence on the clarity of lakes with high DOC levels but may still have to be considered for the protection of other attributes.

The process of decomposition of organic matter consumes oxygen from a lake and so, at some point, the stimulation of excess algal growth by increasing phosphorus concentrations may decrease the amount of dissolved oxygen that is available to aquatic life. In addition, phosphorus may be released from the bottom sediments of lakes during periods of anoxia (oxygen deprivation), which further enriches the lake water. Although Ontario has a separate PWQO for dissolved oxygen, the relationship between phosphorus and oxygen is implicit in any lake management activities and should, at least, be considered in formulating the PWQO.

In summary, the PWQO for total phosphorus is intended to:

- Protect the aesthetics of recreational waters by preventing losses in water clarity
- Prevent nuisance blooms of surface algae
- Maintain the existing diversity in water clarity in Precambrian Shield lakes
- Provide indirect protection against oxygen depletion

2.1 Need for revision

The total phosphorus PWQO serves as the cornerstone for making lake management decisions and achieving the necessary balance between health of the aquatic system and development in a watershed. The PWQO must, therefore, be based on the most current, scientifically sound information. The existing rationale states that the PWQO was developed and used despite incomplete knowledge of relationships between phosphorus concentrations in water and the corresponding plant and algal growth in lakes and rivers (MOE 1979). It was therefore later revised to an interim PWQO (MOEE 1994). Evaluation of the scientific advances since that time is necessary to ensure that the interim PWQO reflects current scientific understanding and to determine whether a revision in its status is warranted.

The rationale for revisiting the PWQO for phosphorus does not lie exclusively in better information on its effects as a pollutant. Instead, improved understanding of watershed processes, biodiversity and the assessment of cumulative effects over the past 20 years have lead to the corporate adoption of these considerations into the water management process (MOEE 1994). This has revealed several shortcomings with the existing, two-tiered guideline of 10 µg/L for "a high level of protection against aesthetic deterioration" and 20 µg/L "to avoid nuisance concentrations of algae." Although these numeric objectives are designed to maintain water clarity and aesthetic values and have performed well for more than 20 years, they fail to protect against the cumulative effects of development and do not protect the existing diversity in water quality across the province and the associated biodiversity.

In 1996, Ontario decided to review its PWQO for total phosphorus. The bulk of Ontario's 226,000 lakes (Cox 1978) lie on the Precambrian Shield and the scientific basis for a new PWQO had previously been developed for these lakes (Hutchinson et al. 1991). Accordingly, the three-year review process targeted Precambrian Shield lakes first, with off-Shield lakes, the Great Lakes, and streams and rivers to be reviewed later.

3.0 TOTAL PHOSPHORUS AND THE PWQO DEVELOPMENT PROCESS

Ontario's PWQO development process is intended to deal specifically with toxic substances. It uses published studies on the effects of pollutants to estimate a safe concentration for indefinite exposure (MOEE 1992). The only data which are mandatory for PWQO development are data on toxicity, bioaccumulation and mutagenicity (the capability of mutation). Information on aesthetic impairment, such as taste and odour, may also be considered but is not mandatory. The protocol for the Government of Ontario's water quality objective development process (MOEE 1992) requires a minimum dataset and specifies both the number and quality of studies which are required for development of a PWQO. If either the mandatory elements are not fulfilled or the minimum dataset does not exist, then an interim PWQO is developed with the intent to upgrade it to a full PWQO when the data become available.

The interim status of the existing PWQO for total phosphorus should not, however, be interpreted solely as a reflection of incomplete knowledge at the time of its formulation. Development of a PWQO for total phosphorus is distinctly different from the development of a PWQO for toxic substances. Phosphorus' lack of toxicity and the insufficient knowledge of its effects should not provide the rationale for its interim status. It is therefore inappropriate to adhere strictly to the established procedures (MOEE 1992). Instead, those reviewing the status of the phosphorus criterion should consider the following:

- The detrimental effects of phosphorus are indirect and not a result of toxicity
- Some effects of phosphorus are aesthetic and so its management requires an element of subjectivity
- Our knowledge of the effects of small increases in phosphorus on the aquatic ecosystem are incomplete
- Factors such as dissolved organic carbon and the biotic community may modify the detrimental effects of phosphorus on the environment.

3.1 Toxicity and PWQO development

Although pollutants such as copper or zinc are required nutrients at trace levels, they become toxic at concentrations slightly above ambient levels. As a result, the health of aquatic organisms, and hence the ecosystem, is maintained at low ambient concentrations but declines rapidly with even slight increases in concentration (**Figure 1**).

Phosphorus is a major nutrient. The first responses of an aquatic system to phosphorus additions — increased productivity and biomass — are beneficial and concentrations can increase substantially with no direct adverse effects. Beyond a certain point, however, further additions stimulate indirect detrimental effects which ultimately decrease system health. It is therefore a more difficult proposition to derive safe levels for phosphorus than it is for toxic pollutants.

3.2 Other considerations addressed in PWQO development

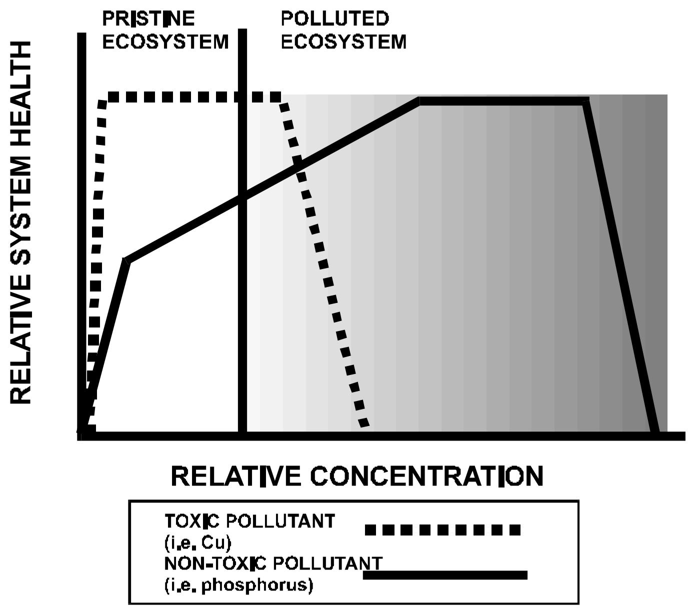


Figure 1. Generalized responses of an ecosystem to toxic and non-toxic pollutants

The first responses of a lake to enrichment — decreased water clarity and increased algal biomass — are aesthetic and of concern only to humans. Assessment of aesthetic effects is highly subjective, however, and perceived changes in water clarity are based largely on what one is used to (Smeltzer and Heiskary 1990). The development of a phosphorus objective must therefore acknowledge an element of subjectivity in dealing with human concerns and consider that aesthetic effects begin where a change in water clarity is first noticeable to the human eye or where the average water clarity first exceeds natural variation.

The biotic effects of incremental phosphorus enrichment remain poorly understood. Some — such as the formation of nuisance blooms of blue-green algae and their associated toxicity — are well known but, with few exceptions, are not a consideration at the phosphorus concentrations observed in Precambrian Shield lakes. Effects of small changes in phosphorus concentration may well be beneficial to the productivity of the aquatic system, but the effects on diversity and system function have not been studied.

In contrast, the effects of phosphorus enrichment on the oxygenated hypolimnetic habitat of many cold water species (*e.g.,* the lake trout, *Salvelinus namaycush*) are known and can be addressed objectively (MacLean et al. 1990). Dissolved oxygen concentrations are explicitly protected by the Ontario PWQO for dissolved oxygen (MOEE 1994) or by specific guidelines for fish habitat which are administered by agencies such as the Ministry of Natural Resources. They are not intended as a direct consideration in phosphorus objective development. Nevertheless, recent advances in oxygen-phosphorus models (*i.e.*, Molot et al. 1992) allow for a direct estimation of the effect of phosphorus concentrations on dissolved oxygen in lakes. Any protection of dissolved oxygen which is achieved, even indirectly, by the phosphorus objective is beneficial.

Management of phosphorus as a method of controlling algal biomass, water clarity and dissolved oxygen is the central presumption behind setting safe limits. Total phosphorus concentrations set the upper limits on algal yields in lake water. The relationship between algal yield and water clarity is well established and these indicators are all predictably related (Dillon and Rigler 1975, Volleinweider and Kerekes 1980, Canfield and Bachmann 1981). Although natural levels of dissolved organic carbon may alter these relationships, the effects are predictable, have been quantified (Dillon et al. 1986) and have been considered in this rationale document.

Nevertheless, in recent years, some challenges have emerged as to the adequacy of phosphorus-loading models for managing trophic status (Mazumder and Lean 1994) and some controversies have developed regarding the importance of nutrient loading (bottom up) versus biotic interactions (top down) in controlling algal growth in lakes (DeMelo et al. 1992, Carpenter and Kitchell 1992). These criticisms, however, address only the unexplained variance in the phosphorus/chlorophyll/water clarity relationship and have not produced convincing arguments against, or alternatives to, its use. Biotic models are best viewed as complementary explanations of the same phenomena (Carpenter and Kitchell 1992) and not as alternatives to that relationship. Management of biotic factors to control water clarity is hampered by incomplete understanding, large and unpredictable variance in the natural system and the mandate of the Ministry of the Environment to manage sources of nutrients and their concentrations in the water. As such, “the prudent lake manager...might be best advised to focus first on nutrient abatement and then on biomanipulation” (DeMelo et al. 1992). The PWQO for total phosphorus therefore provides the basis to maintain desirable levels of phosphorus in Ontario’s surface waters through the control of nutrient loading only.

The sources of phosphorus to the aquatic environment also influence the derivation of a PWQO. With the exception of sewage treatment plant discharges, non-point sources of phosphorus are the most important contribution to nutrient enrichment of Precambrian Shield surface waters. These include changes in land use, septic systems from residential and cottage development, agriculture, timber harvest and urbanization. In many cases, these sources are diffuse and develop over extended periods of time. There may also be delays of up to decades between the addition of phosphorus sources to a watershed (*i.e.*, septic systems), its movement from the source to surface water (Robertson 1995) and its expression as a change in trophic status. Shoreline residential development in particular represents a significant contribution to the eutrophication of Ontario’s Precambrian Shield lakes (Dillon et al. 1986).

As a result, phosphorus management in Ontario requires the extensive use of nutrient-loading models. These provide instantaneous estimates of the long-term, steady-state response of surface waters to non-point sources of phosphorus. They operate on the fundamental principles of areal loading of phosphorus to a lake’s surface (Volleinweider 1976, Volleinweider and Kerekes 1980) and can consequently be adapted to a variety of sources.

There are, therefore, elements of uncertainty which are unique to the development of a PWQO for naturally occurring, non-toxic, non point-source pollutants such as phosphorus. Some may be resolved as models are further refined or as scientific understanding is further developed. Subjective elements of uncertainty, such as aesthetics, typically cannot be addressed in the conventional PWQO development process (currently only the aesthetics of taste and odour are considered). In addition, management of the pollutants that may take decades to manifest their effect on the aquatic system necessitates the use of models to predict such future effects.

4.0 NEW CONSIDERATIONS FOR PWQO DEVELOPMENT

4.1. Managing to preserve diversity in trophic status

The existing numeric objectives for total phosphorus ignore fundamental differences between lake types and their nutrient status in the absence of human influences. Ontario's Precambrian Shield lakes now span a range of phosphorus concentrations from oligotrophic to mesotrophic, however, the distribution favours an abundance of higher quality, oligotrophic lakes (**Figure 2**). Within this range, however, there is still a large diversity of water clarity, controlled by both total phosphorus concentrations and dissolved organic carbon (Dillon et al. 1986).

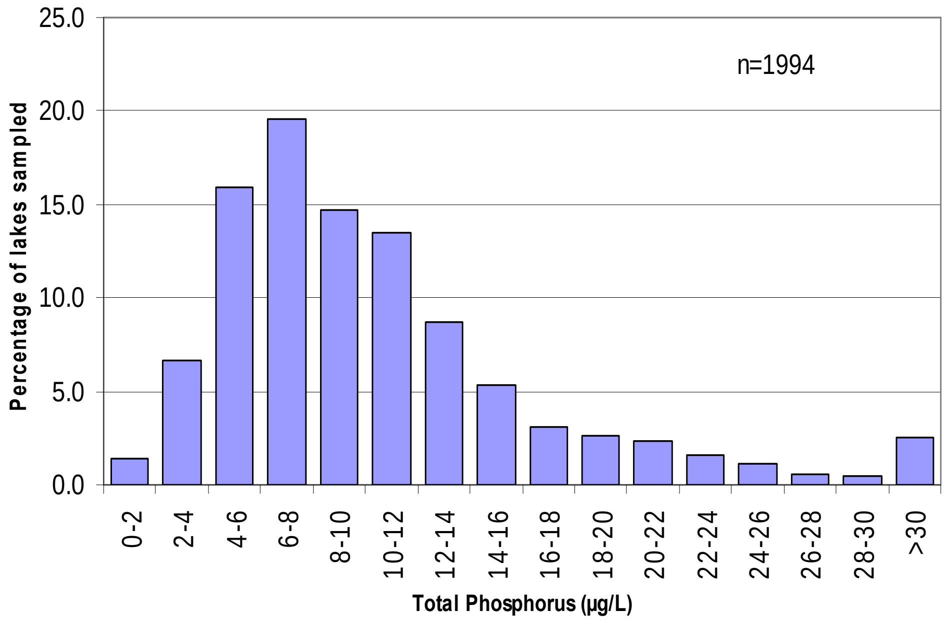


Figure 2. Distribution of total phosphorus concentrations in sampled Ontario lakes (source: MOE Inland Lakes database, March 2004)

The logical outcome of the current two-tiered PWQO is that, over time, all recreational waters will converge on each of the two water quality objectives. This will produce a cluster of lakes slightly below 10 µg/L and another slightly below 20 µg/L — this means that the provincial diversity in lake water quality will decrease along with the diversity of the associated aquatic communities.

The second shortcoming is that, over time, some lakes would sustain unacceptable changes in water quality while others would be unaffected, producing both ecological and economic asymmetries as their shorelines are developed. A lake with a natural phosphorus concentration of 4 µg/L is a fundamentally different from a lake at 9 µg/L. Both lakes, however, would be allowed to increase to 10 µg/L under the existing PWQO. One lake would experience no perceptible change (9 to 10 µg/L) and be overprotected, but the other (4 to 10 µg/L) would be under-protected and would change dramatically. In both cases, human perceptions of aesthetics would be ignored in the objective. Allocation of phosphorus loadings between these two lakes would be unfair as well; the high phosphorus lake could sustain a greater change than the low phosphorus lake, but would be restrained to a much lower load.

A final concern is that the existing PWQO does not explicitly consider the effect of phosphorus on hypolimnetic oxygen or aquatic biota. It does, however, make reference to site-specific studies in the assessment process.

In summary, the existing numeric objectives are too stringent for some lakes and do not protect others adequately. Allocation of phosphorus loadings is unnecessarily restricted in some lakes and overly generous in others. Neither biotic nor aesthetic attributes are adequately protected. Over time, Ontario's diversity in lake trophic status will decrease.

4.2 Environmental baselines and measured water quality

An emerging concern in environmental assessment is the need for a standard baseline for comparison against environmental change. The existing PWQO is interpreted through measurements of present and past water quality. Detecting change is thus difficult for non-point additions which may occur over large areas and extended time periods. Phosphorus measurements made in the period between development of a non-point source and its expression as a change in trophic status will therefore underestimate the effect and may wrongfully lead to the conclusion that the lake has not responded to the phosphorus loading.

The incremental nature of watershed development results in a slow and gradual increase in trophic status. The high degree of seasonal and annual variance in lake phosphorus levels (Clark and Hutchinson 1992) means that changes may not be detectable without an intensive monitoring program that requires the collection of many samples and uses a precise and replicable analytical method.

Finally, a slow increase in trophic status over a generation may not be noticed by human observers. Environmental change which occurs during one generation becomes the status quo for the next. Over a long period, therefore, any assessment baseline which is based on measurements of total phosphorus will increase.

In summary, any phosphorus objective which relies exclusively on measured water quality will suffer from:

- Detection problems due to natural variance and analytical problems
- The lag time between addition of phosphorus to a watershed and its expression in a lake
- Failure to detect incremental changes in water quality
- Human perceptual conditioning which reduces the apparent change in water quality over time

As a result, a rising assessment baseline and incremental decreases in water quality will slowly degrade the quality of lake water past any objective. Effects will accumulate by virtue of delay in their expression, repetition over time and space, extension of the boundary of the effects by the transport of phosphorus downstream or by triggering indirect changes in the system such as the release of phosphorus from sediments during anoxic periods. Non-point source phosphorus loading is thus an excellent example of a pollutant which produces cumulative effects on the aquatic environment. The emergence and validation of mass balance phosphorus models for lakes, however, offers an opportunity to correct some of the disadvantages of water quality measurements and conventional assessment techniques.

5.0 PHOSPHORUS CRITERIA IN OTHER JURISDICTIONS

A brief survey of jurisdictions across Canada and the U.S. states bordering the Great Lakes shows different approaches to establishing criteria for surface water quality and to managing contributions of phosphorus to surface waters.

5.1 Canada

In February, 2004, the National Guidelines and Standards Office of Environment Canada published the *Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems*. The Framework offers a tiered approach in which phosphorus concentrations should not exceed pre-determined trigger ranges, and phosphorus concentrations should not increase more than 50% over a system-specific baseline (reference) condition. The trigger ranges are based on the range of phosphorus concentrations in water that define the reference trophic status for a site. If the upper limit is exceeded, or is likely to be exceeded, further assessment is required, and a management decision may be required.

5.1.1 Quebec

The Province of Quebec uses the 20 and 30 µg/L phosphorus values that are also in use in Ontario (but not the 10 µg/L value), however there is no indication of implementation approaches yet. Quebec has begun to review the approaches of other jurisdictions with the goal of updating its own during the next three years and has expressed particular interest in the approach being considered in Ontario (D. Nadeau, Ministère du Loisir, de la Chasse et de la Pèche, Direction régionale de l'Abitibi-Temiscamingue, Noranda, QC pers. comm.)

5.1.2 British Columbia

British Columbia uses criteria for surface water quality which vary as a function of the type of aquatic system and its intended use (**Table 1**).

Table 1. Phosphorus objectives for the Province of British Columbia

Water use	Characteristics	
	Phosphorus (µg/L)*	Chlorophyll *a* (mg/m^2)**
Drinking water (lakes)	10 max	none proposed
Aquatic life (streams)	none proposed	100 max
Aquatic life (lakes only—with salmonids as the predominant fish species)	5 to 15 inclusive	none proposed
Recreation: streams only	none proposed	50 max
Recreation: lakes only	10 max	none proposed

* Total phosphorus in lakes is either the spring overturn concentration, if the residence time of the epilimnetic water is greater than six months, or the mean epilimnetic growing-season concentration, if the residence time of the epilimnetic water is less than six months

** Chlorophyll *a* criteria in streams apply to naturally growing periphytic algae

5.1.3 Manitoba

The Province of Manitoba has two phosphorus criteria for surface water: one for flowing waters of 50 µg/L and one for lakes of 25 µg/L. Manitoba will be reviewing these criteria in the next two years.

5.1.4 Alberta

The Province of Alberta generally uses 50 µg/L as an objective for phosphorus in surface water.

5.2 United States

The U.S. Environmental Protection Agency (USEPA) has decided not to develop a national standard for phosphorus in surface water. Instead, the USEPA provides guidance to states to develop their own methods to assess trophic status and to develop criteria for surface water quality.

Criteria are intended to guide resource assessment, establish management priorities, evaluate projects and assist with long-range planning. The USEPA is emphasizing non-traditional indicators of enrichment, such as regional biological criteria and land-use changes, as well as the more conventional indicators, such as total phosphorus and water clarity. Biological indicators are showing particular promise. Methods of nutrient classification will emphasize differences between regions of the U.S. based on the size, and the nutrient and watershed status of water bodies and will advise on consistent means of gathering, storing and evaluating data, all with the intent of moving beyond classification to improve the resource (George Gibson, USEPA, Annapolis, MD. pers. comm. Nov. 14, 1996).

5.2.1 Minnesota

Table 2. State of Minnesota: Most sensitive lake uses by ecoregion and corresponding phosphorus criterion (Heiskary and Wilson 1988)

Ecoregion	Most Sensitive Use	P Criterion
Northern lakes and forests	Drinking water supply	< 15 µg/L
	Cold water fishery	< 15 µg/L
	Primary contact recreation and aesthetics	< 30 µg/L
North central hardwood forests	Drinking water supply	< 30 µg/L
	Primary contact recreation and aesthetics	< 40 µg/L
Northern glaciated plains	Recreation and aesthetics • full support • partial support	 < 40 µg/L < 90 µg/L
Western corn belt plains	Drinking water supply	< 40 µg/L
	Primary contact recreation and aesthetics • full support • partial support	 < 40 µg/L < 90 µg/L

The State of Minnesota uses an ecoregion approach in which eutrophication standards vary with the region (*i.e.*, the natural water quality) (**Table 2**). Criteria were developed to meet specific uses, such as fishery protection and swimming, and are based on reference lakes and public perceptions of water quality. They are not formal standards (which are legally binding in the U.S.) but are used for setting goals and priorities. As a starting point, if the concentration of phosphorus in a lake is better than the criterion for that ecoregion, then efforts will be made to protect it. If the concentration of phosphorus is greater than the criterion, then site-specific assessments may be done to ensure that the criterion is appropriate before corrective actions are taken.

Phosphorus criteria are related to summer chlorophyll *a* concentrations and acceptable chlorophyll concentrations are quite variable. In the areas of the northern lakes and forests, 10 µg/L would be considered to be a mild bloom, whereas 70 to 90 µg/L would be the norm in more southerly agricultural areas. Minnesota has also produced some guidelines which relate phosphorus concentrations to the probability of severe summer blooms and is starting work on phosphorus criteria for rivers and streams (Heiskary 1997).

5.2.2 Wisconsin

The State of Wisconsin is in the final stages of developing phosphorus standards based on the ecoregion approach. It has used 14 years of monitoring data to establish three phosphorus regions for the state, each of which is characterized by statistically distinct water quality. It has relied on the best professional judgment of water quality experts to establish the background water quality of various types of water bodies in each region. The phosphorus objectives were chosen as the average of the lowest 25 per cent of measured phosphorus concentrations for each lake type in each region, rounded down to the nearest multiple of five (**Table 3**). Separate standards were developed for impoundments and natural lakes. Exceeding the standard is interpreted as a trigger for further evaluation (Searle 1997).

Table 3. State of Wisconsin: Ambient water quality criteria for phosphorus

Natural lakes

Region	Drainage/ mixed (µg/L)	Drainage/ stratified (µg/L)	Seep/ mixed (µg/L)	Seep/ stratified (µg/L)
North	15	10	10	10
Central	5	5	5	5
South	25	15	15	10

Impoundments

Region	Mixed (µg/L)	Stratified (µg/L)
North	20	10
Central	5	10
South	25	10

5.2.3 Maine

The State of Maine has developed a non-degradation approach to phosphorus management. The existing phosphorus concentration of a lake and its sensitivity to loadings are used to establish a lake-specific allowable phosphorus increase. Lakes are classified into categories ranging from outstanding water quality to poor/restorable, and to low, medium and high levels of protection based on considerations such as usage and unique qualities. Acceptable increases are very stringent, ranging from 0.5 µg/L of total phosphorus for outstanding quality/high protection to 2 µg/L for good quality/low protection lakes. A watershed model is then used to allocate development to achieve the water quality goal. Very generous use is made of mitigation techniques such as buffer strips, storm water detention ponds and septic system setbacks in an attempt to control phosphorus export from new development in the watershed. Specific mitigation techniques will vary with the degree of protection required and each technique has a quantitative export coefficient to estimate the effect of the development on water quality (Dennis et al. 1992).

5.2.4 Vermont

The State of Vermont has focused on site-specific management of enriched lakes (*e.g.,* Lake Champlain) in the past. It has recently completed an intensive study of Lake Champlain and developed separate phosphorus objectives for 13 basins of the lake. These range from 10 to 25 µg/L, compared to current levels of 9 to 58 µg/L which exceed the objective in eight of the 13 basins. Vermont is now considering developing standards for all lakes in the state (Smeltzer 1997 and pers. comm.).

5.2.5 Other states

Some jurisdictions, such as Michigan and Pennsylvania, have not developed surface water criteria, but rely solely upon effluent concentrations, discharge loadings or best management practices.

5.2.6 Great Lakes

The Great Lakes Water Quality Agreement (1987) states that:

> ***"The concentration should be limited to the extent necessary to prevent nuisance growths of algae, weeds and slimes that are or may become injurious to any beneficial water use."***

Fourteen impairments to beneficial uses are listed in the agreement. The agreement also contains lake-specific target loads and restrictions on sewage treatment plant discharges: 1 mg/L total phosphorus in the basins of lakes Superior, Michigan and Huron and 0.5 mg/L for plants in the basins of lakes Erie and Ontario. Several narrative statements regulate phosphorus loadings from industrial discharges to the maximum extent possible.

5.3 Summary

All jurisdictions have attempted to deal with regional variance in natural or background water quality in various ways and to accommodate different criteria for different uses. One cannot judge the success of each approach but, in all cases, the intent is reasonable and achievable. Jurisdictions in which water quality is similar to Ontario's have developed similar objectives but, in many cases, use a series of regional or use-specific objectives.

The State of Maine, unlike other jurisdictions, has tied very specific implementation details to its phosphorus objectives. Maine's objectives, like Ontario's proposed objective, appear to address shoreline development as the most important water quality stressor. It has combined very restrictive allowable increases in phosphorus concentrations to very permissive assumptions regarding the efficacy of techniques for mitigating phosphorus export. Ontario, in contrast, is proposing to allow for a generous proportional increase, combined with restrictive assumptions regarding mitigation — this approach is described in the following section (Section 6.0).

6.0 PROPOSAL FOR A REVISED PWQO FOR PRECAMBRIAN SHIELD LAKES

Recent advances in phosphorus modeling, the understanding of watershed dynamics and the assessment of cumulative effects have been used to develop a new PWQO for Ontario's Precambrian Shield lakes. The proposal encompasses two innovations:

1. The use of models to establish a baseline for changes in trophic status
2. A proportional increase from that baseline due to phosphorus loadings from human activities

This approach would allow each Precambrian Shield to have its own numeric water quality target. The challenge now lies in expanding this understanding beyond shoreline development in Precambrian Shield lakes (for which it was originally developed) to apply it to all the waters of the province, including off-Shield lakes, the Great Lakes, and rivers and streams.

6.1 Modeled assessment baseline

The basis of the revised PWQO is increased reliance on water quality modeling in the objective setting process. Recent advances in trophic status models allow us to calculate the predevelopment phosphorus concentrations of inland lakes (Hutchinson et al. 1991). This is done by modeling the total phosphorus budget for the lake, comparing the predicted concentration to a reliable water quality measurement and subtracting that portion of the budget which is attributable to human activities. Further work is necessary for water bodies lying off the Precambrian Shield, but the basic premise is applicable to any water body where a phosphorus budget can be calculated.

The main advantage of the modeling approach is the establishment of a constant assessment baseline. A modeled predevelopment baseline is based on an undeveloped watershed so it will not change over time. This serves as the starting point for all future assessments. Every generation of water quality managers will therefore have the same starting point for decision-making, instead of a steadily increasing baseline of phosphorus measurements.

The ministry therefore proposes a PWQO for total phosphorus which is based on a modeled predevelopment phosphorus concentration. This will provide water quality managers with a:

- Constant assessment baseline
- Buffer against incremental loss of water quality
- Buffer against variable water quality measurements

The predevelopment phosphorus concentration should not be interpreted as a PWQO. Pristine phosphorus levels have not existed in Ontario for more than a century and their attainment is not cost effective in a heavily developed society. The modeled predevelopment concentration only serves as the starting point for the PWQO and as a reference point for future changes.

A model-based objective would have two additional advantages. First, the modeled response of the watershed to future changes is instantaneous. It applies new development directly against capacity, without the intervening decades it takes for phosphorus to move into a lake and be expressed as a measured change in water quality. Second, Ontario's trophic status model is based on entire watersheds, so it allows explicit consideration of downstream phosphorus transport in the assessment.

6.2 Proportional increase

The second component of the objective is a proportional increase from the modeled predevelopment condition. The proportional increase accommodates regional variation in natural or background water quality through the use of a lake-specific numeric objective for each Precambrian Shield lake. It is, in fact, a broader — yet simpler — application of the regionally specific, multi-tiered objectives proposed in other jurisdictions as a means of accommodating regional variation in background water quality (*e.g.,* Minnesota and Wisconsin).

Ontario is proposing an allowable increase of 50 per cent above the predevelopment level. Under this proposal, a lake which was modeled to a predevelopment phosphorus concentration of 4 µg/L would be allowed to increase to 6 µg/L. Predevelopment concentrations of 6, 10 or 12 µg/L would increase to 9, 15 and 18 µg/L, respectively. A cap at 20 µg/L would still be maintained to protect against nuisance algal blooms.

There are numerous advantages to this approach:

- Each water body would have its own water quality objective that would be described with one number (*i.e.*, predevelopment plus 50 per cent).
- Development capacity would be proportional to a lake's original trophic status.
- As a result, each lake would maintain its original trophic status classification. A 4 µg/L lake could be developed to 6 µg/L and would maintain its classification as oligotrophic. A 10 µg/L lake could be developed to 15 µg/L, maintain its mesotrophic classification and development would not be unnecessarily constrained to 10 µg/L.
- The existing diversity of trophic status in Ontario would be maintained forever, instead of a future set of lakes at 10 µg/L and another at 20 µg/L.

6.3 Rationale for a 50 per cent increase

6.3.1 Water clarity

Water clarity in Ontario's Precambrian Shield lakes is controlled by both dissolved organic carbon (DOC) and phosphorus (Dillon et al. 1986). Any phosphorus objective should therefore consider DOC as well as phosphorus in its derivation. Molot and Dillon (pers. comm.) used 14 years of data (1976-1990) from lakes in south central Ontario to produce the following relationship, summarized in **Figure 3**.

$$\mathbf{SD = 6.723 - (0.964 \times DOC) + (9.267 \div TP_{ep})}$$

where: SD = Secchi depth (water transparency)

DOC = dissolved organic carbon

TP_{ep} = total phosphorus concentration in the epilimnetic waters of the lake

Figure 3 shows that the rate of loss of water clarity with phosphorus increase is greatest between 4 and 10 µg/L, suggesting that the existing PWQO of 10 µg/L allows the greatest effects in the most sensitive, high-quality lakes.

Figure 4 shows the response of water clarity to various proportional increases in total phosphorus concentration predicted for various DOC levels using the same equation. Responses have been grouped to include all lakes with initial phosphorus concentrations between 2 and 14 µg/L, so a 50 per cent increase represents final values of 3 to 21 µg/L. There is no clear threshold of changed water clarity — a point where further increases in phosphorus would induce a markedly severe change. Instead, there is a gradual loss of water clarity as phosphorus concentrations are increased from 10 to 100 per cent. The allowable percentage increase cannot, therefore, be determined on the basis of water clarity alone.

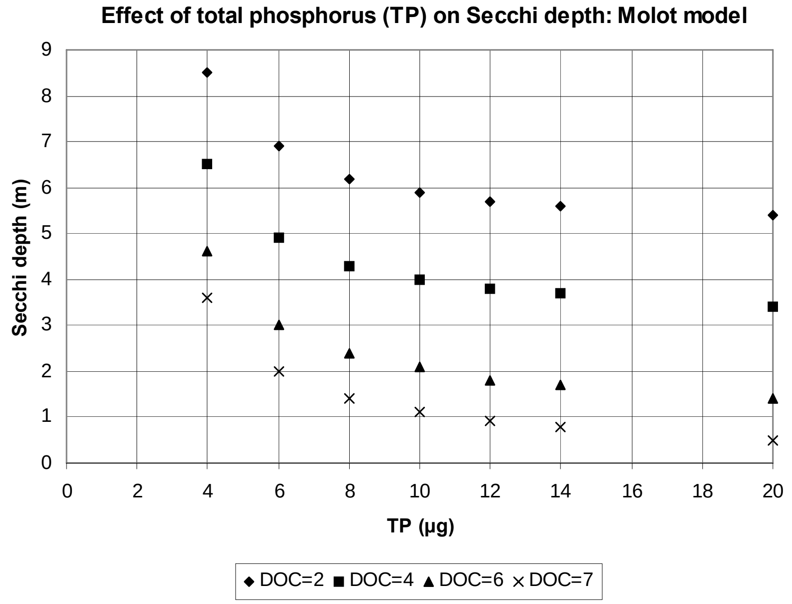


Figure 3. Relationship of predicted water clarity to total phosphorus and dissolved organic carbon (DOC) concentrations in Precambrian Shield lakes in south-central Ontario.

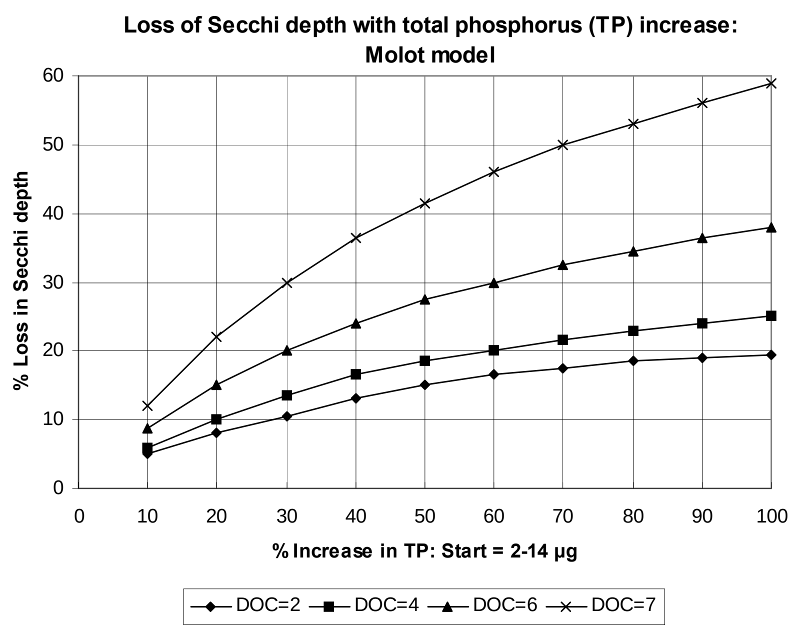


Figure 4. Predicted response of Secchi depth to 10 to 100 per cent increases in total phosphorus concentration from initial values of 2 to 14 µg/L at dissolved organic carbon (DOC) levels of 2, 4, 6 and 7 mg/L.

6.3.2 Detection of change in phosphorus and water clarity

The average coefficient of variation in Secchi depth for a series of southern Ontario Precambrian Shield lakes was 17 per cent to 21 per cent during a 14-year period of record (Clark and Hutchinson 1992). A change of 25 per cent in water clarity would therefore represent a significant, detectable departure from natural variation. Based on the data from Figure 4, a 50 per cent increase in phosphorus concentration produces, on average, a 25 per cent loss in Secchi depth across the range of initial phosphorus (2 to 14 µg/L) and DOC (2 to 7) concentrations (**Table 4**). In addition, a 50 per cent increase protects the clearest and most desirable water clarity and allows a greater proportional change only in those lakes with high DOC where this parameter (rather than the phosphorus/chlorophyll relationship) is the limiting factor (Table 4).

Table 4. Average loss in Secchi depth with a 50 per cent increase in total phosphorus concentration as a function of dissolved organic carbon (DOC) concentration*

DOC	% Loss in water clarity
2	14
4	18
6	27
7	41
Average	25.3

***The 50 per cent increase in TP is taken from a starting range of 2 to 14 µg/L to produce final values of 3 to 21 µg/L.**

Hutchinson et al. (1991) reported a natural coefficient of variation in total phosphorus concentrations in south central Ontario lakes of about 20 per cent. Detection of a 20 per cent change in total phosphorus requires only two years of spring overturn measurements or one year of four to five measurements in the ice-free season (Clark and Hutchinson 1992). A phosphorus objective 50 per cent greater than the predevelopment conditions would therefore be detectable with even the most rudimentary sampling program and would limit changes in water clarity to an average of 25 per cent, a level just beyond the range in natural Secchi depth variation.

6.3.3 Protection of dissolved oxygen

Although dissolved oxygen concentration is not intended to be a direct consideration in phosphorus objective development, any indirect protection of this parameter that results from the maintenance of the phosphorus objective is beneficial. Implementation procedures for Ontario's PWQOs allow more stringent applications to protect beneficial uses in specific locations (MOEE 1994). In the case of phosphorus, more stringent applications are used most often to assist the Ministry of Natural Resources (MNR) with the protection of fish habitat in lakes inhabited by lake trout. Protection of lake trout is not, however, an explicit requirement of the PWQO for total phosphorus. Instead, habitat may be considered through the effect of phosphorus on dissolved oxygen content.

Dissolved oxygen concentrations are explicitly protected by Ontario's existing PWQO for dissolved oxygen of 6 mg/L at 10ºC for most biological species present in the cold water layer (hypolimnion) of thermally stratified lakes (MOEE 1994). For oxygen-sensitive species such as lake trout, a more specific water quality objective may be required (MOEE 1994). MNR has adopted a dissolved oxygen criterion of 7 mg/L for the protection of lake trout.

Oxygen-phosphorus models (*i.e.*, Molot et al. 1992) have been incorporated into Ontario's phosphorus model for the direct estimation of the effect of phosphorus on dissolved oxygen. These models can be used to identify those situations in which more stringent protection is required and for the explicit consideration of the lake trout habitat in routine management applications. They predict the effect of phosphorus on the hypolimnetic oxygen profile at the critical end-of-summer period, when lakes are warmest and oxygen depletion is near its maximum.

The revised PWQO for total phosphorus does appear to provide some indirect protection of hypolimnetic oxygen. The effect of a 50 per cent increase in phosphorus on dissolved oxygen was modeled using four stratified lake types, spanning a range from highly sensitive (shallow and small) to least sensitive (deep and large). Responses were expressed as volume-weighted average hypolimnetic oxygen concentration and as the volume of hypolimnion exceeding the PWQO of 6 mg/L. On average, limiting the increase in phosphorus to background plus 50 percent protects dissolved oxygen in any lake which is larger than 67 hectares, at least 28 metres deep, and has less than 12 µg/L of predevelopment phosphorus. Some portion of the hypolimnion remained at 6 mg/L of dissolved oxygen or better in all such lakes modeled. Lakes with predevelopment concentrations of 7 µg/L or less were particularly well protected, but the 50 per cent increase did not protect lakes with natural total phosphorus concentrations of 12 µg/L or more because of their higher initial phosphorus levels.

7.0 FUTURE PWQO DEVELOPMENT ACTIVITIES

This proposal for an interim PWQO for phosphorus applies only to inland lakes on the Precambrian Shield. A full revision of the PWQO for phosphorus in all surface waters should address the following:

- Evaluation of new science relating phosphorus effects to changes in ecosystem responses including dissolved oxygen levels
- Evaluation of the proposed PWQO for off-Shield lakes, especially in southern Ontario
- Evaluation of the proposed PWQO with regard to dystrophic lakes, particularly those in northern Ontario (these lakes are highly coloured due to humic and fulvic acids and typically have relatively high background phosphorus concentrations which may not provoke typical eutrophication responses)
- Evaluation of the approach used for Precambrian Shield lakes for its applicability to rivers and streams
- Review of the objectives for the Great Lakes and modifications, if required
- Evaluation of the role of introduced (exotic) species such as zebra mussels and the spiny water flea on ecosystem changes relating to phosphorus effects

8.0 REFERENCES

Canfield, D.E. Jr. And R.W. Bachmann. 1981. Prediction of total phosphorus concentrations, chlorophyll *a* and Secchi depths in natural and artificial lakes. Can. J. Fish. Aquat. Sci. 38: 414-423.

Carpenter, S.R. and J.F. Kitchell. 1992. Trophic cascade and biomanipulation: interface of research and management — a reply to the comment by DeMelo et al. Limnol. Oceanogr. 37: 208-213.

Clark, B. and N.J. Hutchinson. 1992. Measuring the trophic status of lakes: sampling protocols. Ontario Ministry of the Environment. September 1992. PIBS 2202. ISBN 0-7778-0387-9. 36 p.

Cox, E.T. 1978. Counts and measurements of Ontario lakes 1978. Fisheries Branch, Ontario Ministry of Natural Resources. 114 p.

DeMelo, R., R. France and D.J. McQueen. 1992. Biomanipulation: hit or myth? Limnol. Oceanogr. 37: 192-207.

Dennis, J., J. Noel, D. Miller and C. Eliot. 1992. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. Maine Department of Environmental Conservation. Revised September 1992. 111 p.

Dillon, P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Bd. Can. 32: 1519-1531.

Dillon, P.J., K.H. Nicholls, W.A. Scheider, N.D. Yan and D.S. Jeffries. 1986. Lakeshore Capacity Study: Trophic Status. Final Report. Ontario Ministry of Municipal Affairs. May 1986. ISBN 0-7743-8077-2. 89 p.

Heiskary, S.A. and C.B. Wilson. 1988. Minnesota Lake Water Quality Assessment Report. Minnesota Pollution Control Agency, St. Paul. 63 p.

Heiskary, S.A. 1997. The Minnesota ecoregion and attainable trophic state approach. pp. 8-15 in: Smeltzer, E. U.S. Environmental Protection Agency Lake Nutrient Criteria Guidance Manual Appendix — Case Studies. Draft 7/31/97.

Hutchinson, N.J., Neary, B.P. and P.J. Dillon. 1991. Validation and use of Ontario's trophic status model for establishing lake development guidelines. Lake Reserv. Manage. 7: 13-23.

International Joint Commission. 1987. Revised Great Lakes Water Quality Agreement of 1978. 130 p.

MacLean, N.G., J.M. Gunn, F.J. Hicks, P.E. Ihssen, M. Malhiot, T.E. Mosindy and W. Wilson. 1990. Environmental and genetic factors affecting the physiology and ecology of lake trout. Lake Trout Synthesis — Physiology and Ecology Working Group. Ontario Ministry of Natural Resources. Toronto. 84 p.

Mazumder, A. and D.R.S. Lean. 1994. Consumer-dependent responses of lake ecosystems to nutrient loading. J. Plankton Research 16: 1567-1580.

MOE. Ontario Ministry of the Environment. 1979. Rationale for the establishment of Ontario's Provincial Water Quality Objectives. Queen's Printer for Ontario. 236 p.

MOEE. Ontario Ministry of Environment and Energy. 1992. Ontario's Water Quality Objective Development Process. Queen's Printer for Ontario. 42 p + app.

MOEE. Ontario Ministry of Environment and Energy. 1994. Water Management: Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of Environment and Energy. Queen's Printer for Ontario. July 1994. 32 p. PIBS 3303E. ISBN 0-7778-3494-4.

Molot, L.A., P.J. Dillon, B.J. Clark and B.P. Neary. 1992. Predicting end-of-summer oxygen profiles in stratified lakes. Can. J. Fish. Aquat. Sci. 49: 2363-2372.

Robertson, W.D. 1995. Development of steady-state phosphate concentrations in septic system plumes. J. Contam. Hydrology. 19: 289-305.

Searle, G. 1997. Wisconsin Lake Phosphorus Criteria. pp. 25-29 in: Smeltzer, E. U.S. Environmental Protection Agency Lake Nutrient Criteria Guidance Manual Appendix — Case Studies. Draft 7/31/97.

Smeltzer, E. and S.A. Heiskary. 1990. Analysis and applications of lake user survey data. Lake and Reserv. Manage. 6: 109-118.

Smeltzer, E. 1997. Total phosphorus criteria for Lake Champlain (Vermont, New York and Quebec) pp. 29-35 in: Smeltzer, E. U.S. Environmental Protection Agency Lake Nutrient Criteria Guidance Manual Appendix — Case Studies. Draft 7/31/97.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 44: 53-83.

Vollenweider, R.A. and J. Kerekes. 1980. Synthesis Report. Co-operative Programme on Monitoring of Inland Waters (Eutrophication Control). Rep. Technical Bureau, Water Management Sector Group, Organization for Economic Co-operation and Development (OECD), Paris. 290 p.

APPENDIX B

LAKESHORE CAPACITY ASSESSMENT RESOURCES

May 2010

Ministry of the Environment
Environmental Sciences & Standards Division
Environmental Monitoring & Reporting Branch
125 Resources Road
Toronto, Ontario M9P 3V6

Table of contents

Watershed management

Watershed Academy Web (www.epa.gov/watertrain):

- Free distance learning modules on key watershed management topics from the Office of Water at the United States Environmental Protection Agency.

North American Lake Management Society (www.nalms.org):

- The society's mission is to forge partnerships among citizens, scientists and professionals to foster the management and protection of lakes and reservoirs.

The Source Water Protection Primer

- Available from Pollution Probe (www.pollutionprobe.org)

Best management practices

The Shore Primer: A cottager's guide to a healthy waterfront

- Available from Cottage Life magazine (www.cottagelife.com) and Fisheries and Oceans Canada.

Living by Water Project (www.livingbywater.ca):

- National partnership initiative offering programs, projects and resources on shoreline living.

University of Minnesota:

- Minnesota Shoreland Management Resource Guide (www.shorelandmanagement.org)
- The Onsite Sewage Treatment Program (http://septic.coafes.umn.edu/)

A Guide to Operating and Maintaining Your Septic System

- Available from the Ontario Ministry of Municipal Affairs & Housing (www.obc.mah.gov.on.ca)

Lakeshore Capacity Model: Coefficients, assumptions and validation

Dillon, P.J., and L.A. Molot. 1996. Long-term phosphorus budgets and an examination of a steady-state mass balance model for central Ontario lakes. *Water Research*. 30: 2273-2280.

Dillon, P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *J. Fish. Res. Bd. Can.* 32: 1519-1531.

Dillon, P.J., R.A. Reid and H.E. Evans. 1993. The relative magnitude of phosphorus sources for small, oligotrophic lakes in Ontario, Canada. *Verh. Internat. Verein. Limnol.* 25: 355-358.

Dillon, P.J., W.A. Scheider, R.A. Reid and D.S. Jeffries. 1994. Lakeshore Capacity Study: Part 1 — Test of effects of shoreline development on the trophic status of lakes. *Lake and Reserv. Manage.* 8:121-129.

Dillon, P.J., K.H. Nicholls, W.A. Scheider, N.D. Yan, D.S. Jeffries. 1986. Lakeshore Capacity Study: Trophic status. Ontario Ministry of Municipal Affairs and Housing.

Hutchinson, N.J., B.P. Neary and P.J. Dillon. 1991. Validation and use of Ontario's trophic status model for establishing lake development guidelines. *Lake and Reserv. Manage.* 7(1):13-23.

Paterson, A.M., P.J. Dillon, N.J. Hutchinson, M.N. Futter, B.J. Clark, R.B. Mills, R.A. Reid, and W.A. Scheider. 2006. A review of components, coefficients, and technical assumptions on Ontario's Lakeshore Capacity Model. *Lake and Reserv. Manage.* 22(1): 7-18.

Robertson, W.D. 2005. 2004 survey of phosphorus concentrations in five central Ontario septic system plumes. Technical Report prepared for Ontario Ministry of the Environment.

Robertson, W.D. 2006. Phosphorus distribution in a septic system plume on thin soil terrain in Ontario cottage country. Technical Report prepared for Ontario Ministry of the Environment.

Lake monitoring

Information on the Lake Partner Program for monitoring water quality in Ontario lakes is available from:

Ontario Ministry of the Environment
Dorset Environmental Science Centre
Lake Partner Program
P.O. Box 39
Bellwood Acres Road
Dorset, ON P0A 1E0

Tel: 1-800-470-8322
Fax: (705)766-2254

E-mail: lakepartner@ontario.ca
Web: www.ene.gov.on.ca/en/water/lakepartner/index.php

Methods for phosphorus analysis

The MOE's Dorset Environmental Science Centre can provide information on methods for low-level phosphorus testing:

Don Evans
Ontario Ministry of the Environment
Dorset Environmental Science Centre
P.O. Box 39
Bellwood Acres Rd.
Dorset, ON P0A 1E0

Tel: (705)766-0632
Fax: (705)766-2254
E-mail: don.evans@ontario.ca

The MOE's Laboratory Services Branch can provide methods to determine both total and soluble phosphorus for a nominal fee (about $35-$50):

Laboratory Services Branch
Quality & Reference Services
Ontario Ministry of the Environment
125 Resources Road
Toronto, ON M9P 3V6

Tel: (416)235-6311
Fax: (416)235-6312

Dissolved oxygen criterion

EBR Decision Notice: Proposal for a dissolved oxygen criterion for the protection of lake trout habitat (www.ene.gov.on.ca/envregistry/026605ep.htm):

- The proposed uniform, standard, dissolved oxygen criterion to determine development capacity on inland lake trout lakes on the Precambrian Shield for use by MNR field staff and municipalities.

Effects of hypoxia on scope-of-activity of lake trout: defining a new dissolved oxygen criterion for protection of lake trout habitat

- Available at (www.mnr.gov.on.ca/256674.pdf)

APPENDIX C

DORSET ENVIRONMENTAL SCIENCE CENTRE TECHNICAL BULLETINS

May 2010

Ministry of the Environment
Environmental Sciences & Standards Division
Standards Development Branch
40 St. Clair Avenue West
Toronto, Ontario M4V 1M2

Table of contents

MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL SCIENCES AND STANDARDS DIVISION
DORSET ENVIRONMENTAL SCIENCE CENTRE

Technical Bulletin No. DESC-4
May 1996
Reprinted June 1999

STRATEGIES AND PARAMETERS FOR TROPHIC STATUS AND WATER QUALITY ASSESSMENT

TROPHIC STATUS The concentration of nutrients (phosphorus and nitrogen) in a lake directly influences algal growth, water clarity, and other in-lake processes such as hypolimnetic oxygen depletion and growth of near-shore periphyton and rooted aquatic plants. The evaluation of trophic status is, therefore, often a prerequisite to the management of a water body. Evaluation of trophic status is especially important if nutrient loading to the water body is expected to change or if there are recent signs of increased eutrophication.

Trophic status is commonly measured (or monitored) using at least one of three parameters. These are transparency (Secchi depth), chlorophyll a, and total phosphorous (TP) concentration. Dissolved oxygen which is also considered an indicator of trophic status is addressed in another report.

Transparency is a sensitive indicator of long-term changes in trophic status. It has been shown that Secchi disc measurements are less subject to within-year variability than either chlorophyll a or phosphorous measurements and as such can provide a better monitoring tool for early detection of eutrophication. Transparency observations, however, may be influenced by factors other than those related to trophic status (e.g., dissolved organic carbon (DOC)) and should, therefore, be interpreted together with TP and/or chlorophyll a data, especially for between-lake comparisons.

Chlorophyll a often is collected as an indicator of trophic status primarily because a change in algal biomass is the most evident result of a change in the trophic status of the lake. Chlorophyll a, however, tends to show a great deal of seasonal and inter-annual variation, especially in more eutrophic systems. As these seasonal patterns cannot be represented by a single or even several observations, it is often necessary to collect numerous samples throughout the year to determine meaningful 'ice free average' concentrations. It is, on average, necessary to collect more than 10 samples per season to derive averages which are within 20% of the seasonal mean (95% confidence) and 30 to 50 samples to be within 10% of the seasonal mean. Based on data from Dorset lakes, establishing a long-term mean will require one to four years of data collection to be within 20% of the long-term mean and three to 16 years to be within 10%. Generally, the more eutrophic the system the more years of data that will be required. In addition, chlorophyll a samples tend to be perishable and very susceptible to a number of 'handling' problems between the time of sampling and analysis of the sample. While there may be merit in quoting individual chlorophyll a concentrations to quantify the extent of an algal bloom or to indicate how high or low concentrations are in general, it is both costly and labour-intensive to use chlorophyll as a tool to reflect trophic status.

Total phosphorus, the basis for most trophic status models, including the MOEE Lakeshore Capacity Model, is the most reliable indicator of trophic status. Average TP concentrations in a lake can be estimated by measuring a single spring turnover concentration and long-term average numbers can be determined with the collection of only several years of turnover data. Two years of data records will provide results within 20% of the long-term mean (95% confidence), but approximately seven years are required to be within 10% of the long-term mean (provided the lake is not undergoing significant changes in nutrient level). Some researchers report 'ice free average TP concentrations' which require the collection of up to ten samples each year and the use of volume-weighted distinct 'layer' samples while the lake is stratified. These observations will yield reliable long-term averages in fewer years than spring turnover samples, but this advantage generally does not justify the extra effort required to collect the data. The recommended method for determining the trophic status of a lake is therefore based on the collection of spring overturn TP data over several years. These are usually collected as composites of the top 5 m of water at the deepest location in the lake. Samples are best collected after the lake has had an opportunity to mix for several days (temp >4°). Thermal stratification may occur rapidly after turnover, but chemical stratification does not occur as quickly so that surface TP concentrations are usually similar to spring overturn concentrations for several weeks after thermal stratification occurs. Generally, spring TP concentrations can be collected any time when surface water temperatures are between 5 and 10°. Caution is required with respect to the type of sample containers used. Details of this concern and outlines of other sampling protocols can be obtained by contacting the Dorset Research Centre.

Field programs that require staff to visit a lake several times each year (at least monthly) would also benefit by collecting Secchi disc observations at each visit. This would allow the addition of 'ice free average' transparency data to the database which would allow the observation of long-term trends in trophic status.

WATER QUALITY ASSESSMENT It is desirable to collect water quality data to describe chemical or physical characteristics of a lake for reasons other than trophic status. Concerns over acidification, for example, require the collection of pH, alkalinity, sulphate, and other related parameters. When comparative studies are undertaken, it is useful to group lakes on the basis of concentrations of major ions or to distinguish the dystrophic (brown water) lakes in the data set by observing DOC or colour. Each research related use for the database may require the collection of additional parameters and it may become difficult to choose tests that both fulfil the current project needs and provide background information for future research.

Parameters collected by the Ministry of the Environment and Energy (MOEE) which can be used as a guideline for describing the general water quality of a water body include: pH, alkalinity, total Kjeldahl nitrogen, nitrate, ammonia, iron, conductivity, colour, dissolved inorganic and organic carbon, calcium, sulphate, and total phosphorus. Secondary parameters collected less often include: aluminum, fluoride, manganese, chloride, potassium, magnesium, silica, and sodium.

Similar to the sampling strategies outlined for the determination of trophic status, these parameters can be measured with minimal effort at spring turnover with 5 m composite samples. The data obtained from a single visit when the lake is 'mixed' will be more valuable than several years of data that may include several visits per season if those sample dates are at times when distinct samples do not represent the whole lake. Small lakes will require measurements at only one mid-lake station while large lakes or lakes with localized influences may require the establishment of several sampling locations. More extensive collections of information from distinct layers during stratification or at other times of the year will only be necessary if specific, complex interpretations are required.

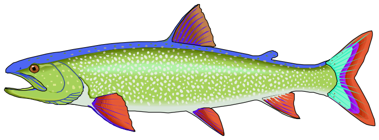
The number of years of water quality data that are required is parameter specific. The use of a single number for complex analysis or for input to models should consider between year or seasonal variability on a parameter by parameter basis. It is, however, common to accept the water quality description of a water body based on the results of the most recent visit without concern for the year to year variance associated with the individual parameters.

Sample container and submission protocols vary with each parameter and should be verified through contact with MOEE labs or by contacting MOEE field staff at the Dorset Research Centre.

For further information, contact:
B. Clark
Phone: 705 766-2150
Fax: 705 766-2254
Email: clarkbe@ene.gov.on.ca

MINISTRY OF THE ENVIRONMENT

ENVIRONMENTAL SCIENCES AND STANDARDS DIVISION
DORSET ENVIRONMENTAL SCIENCE CENTRE



Technical Bulletin No. DESC-5
May 1996
Reprinted June 1999

HYPOLIMNETIC OXYGEN: DATA COLLECTION STRATEGIES FOR USE IN PREDICTIVE MODELS

DATA COLLECTION STRATEGIES FOR PREDICTIVE MODELS

Hypolimnetic oxygen concentrations are a key element of habitat quality for many cold-water species. These include fish such as lake trout and whitefish as well as many invertebrates including Copepods and Mysis that are important food for fish. Oxygen concentration profiles are typically measured at the deepest location in the lake, usually on a monthly basis throughout the open water season. These types of data are difficult to interpret because concentrations change both spatially and temporally in a specific year and also tend to show considerable inter-annual variation.

One method of addressing a great deal of this variation is to examine only end-of-summer or end-of-stratification oxygen profiles. This eliminates the need to evaluate seasonal changes in the profile and concentrates on the “worst case” profiles at the time of year when oxygen concentrations in the hypolimnion are at the open-water minimum. When attempting to characterize lakes in this manner, it is preferable to use average profiles which are derived from several years of data to offset the effects of inter-annual variation. This approach will allow the description of average conditions in a lake’s hypolimnion at the end of summer (early in September) and compare between-lake differences under similar conditions.

In 1992, a model* which predicts steady state, end-of-summer oxygen profiles for small oligotrophic lakes was developed as an additional component of the ministry’s Lakeshore Capacity Model (LCM). The oxygen model uses lake morphometry and epilimnetic phosphorus concentration to predict end-of-summer oxygen concentrations of each stratum in the hypolimnion. An example is shown in Fig. 1. The model requires total phosphorus (TP) as one of its parameters, and can therefore be used to predict the effects of shoreline development on hypolimnetic oxygen.

Recent efforts to validate the model indicate that it will predict end-of-summer profiles for lakes with a broader range of size and trophic status than those that were used to formulate the model.

Morphometry plays a major role in determining hypolimnetic oxygen concentrations. With the model, oxygen profiles can be predicted using as a minimal, a lake morphometric map and a modelled TP value (if no measured TP data exist). It is preferable to use long-term mean spring overturn TP.

To use the model for predicting the effects of changes in trophic status, it is preferable to average several years of oxygen profiles from the time period spanning two weeks either side of the first week in September. The model is then used to predict how changes in TP concentrations would effect the measured (not modelled) long-term average profile. This approach maintains the unique shape and magnitude of the lake's end-of-summer oxygen profile. Operation of the model is straightforward and it can be obtained as a spread sheet from the Dorset Research Centre.

From a data collection standpoint, this approach to oxygen monitoring suggests that field crews concentrate on the collection of end-of-summer profiles specifically between August 15 and September 15. Temperature profiles should also be collected to determine hypolimnetic boundaries. Data bases, for example, could benefit more from the collection of oxygen profiles from several different lakes circa early September than from a series of monthly observations from the same lake over the course of a summer. In other words, in this case, a survey approach would be more useful than a monitoring program.

DETERMINING HYPOLIMNETIC VOLUME-WEIGHTED OXYGEN CONCENTRATION There are several methods used to quantify cold-water fish species habitat based on oxygen concentrations. For lake trout, optimal habitat has been described as having greater than 6 mg L^{-1} oxygen at less than 10°C. Usable habitat has expanded boundaries at greater than 4 mg L^{-1} oxygen and less than 15°C. These guidelines can be used to generate habitat "volumes". However, these may be difficult to interpret since similar "volumes" between lakes may represent different proportions of total lake volumes.

The proposed use of end-of-summer, volume-weighted hypolimnetic oxygen concentrations to define lake trout habitat would eliminate many of these problems. Lakes with large volumes of oxygenated water would not have their average greatly affected by small volumes of depleted water near the bottom. Lakes with small and enriched hypolimnia would be affected to a greater degree by increased depletion in bottom waters. It is suggested for lake trout that these values remain above 7 mg L^{-1} oxygen.

Calculating volume-weighted hypolimnetic oxygen requires morphometric data and at least one end-of-summer oxygen profile (Aug 15 - Sept 15). Ideally, oxygen profiles from several years would be used to reflect long-term average conditions. Area and depth information from morphometric maps should first be converted to ha and m if originally in acres and feet. This will yield contour areas in ha for uneven numbers of m but these can be converted to 1 or 2 m contour areas by one of two methods:

1. Metres and ha are plotted and the individual areas for each stratum are simply read from the axis of the graph.

2. Individual pairs of adjacent points in ha and m are used to interpolate areas for the intervals that fall within the depth range spanned by the pair of points. This can be done through simple linear interpolation or by doing a linear regression on two pairs of points. However, it is important to note that entire sets of hypolimnetic depth/area data cannot be regressed as a single group of numbers because the relationship is almost always curvilinear. Individual contour areas are then converted to volumes by the formula:

$$V = \frac{m}{3} \left(A_t + A_b + \sqrt{A_t * A_b}\right)$$

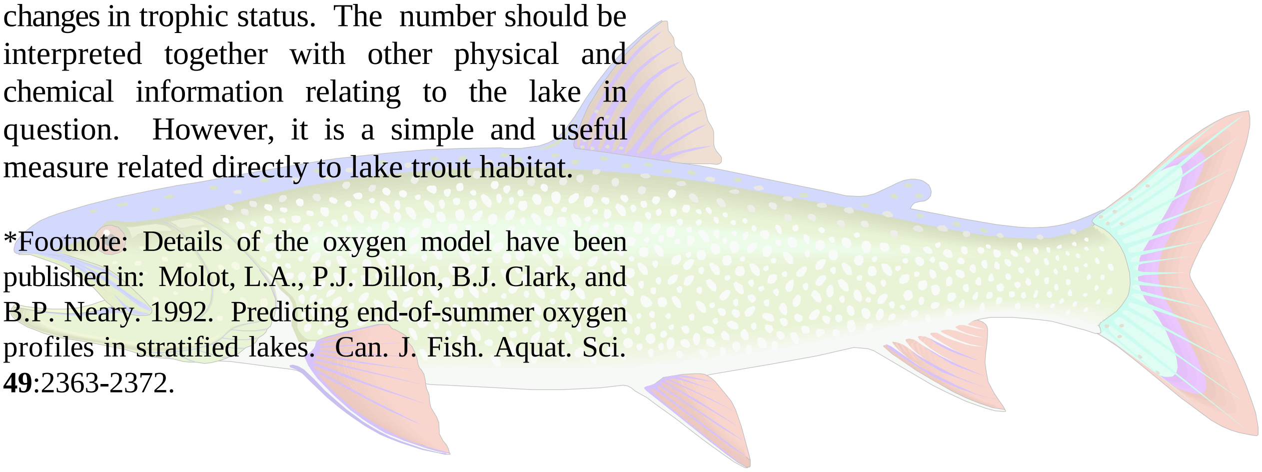
where **V** is volume in $m^3 \times 10^4$
A_t is the area in ha of the top of the stratum
A_b is the area in ha of the bottom of the stratum
and **m** is the depth of the stratum in m

The volume of each stratum of the hypolimnion is then expressed as a fraction of the total hypolimnetic volume and multiplied by the oxygen concentration observed for that stratum. These individual concentrations are summed to yield volume-weighted average oxygen as shown in the example below.

Stratum	Volume ($10^3 m^3$)	**A**-Volume as fraction of total Volume	**B**-Dissolved oxygen (mg L^{-1})	**A * B**
14-16m	1500	0.49	10.0	4.9
16-18m	1000	0.33	8.0	2.6
18-20m	400	0.13	6.0	0.78
20-22m	150	0.05	1.0	0.05

Total of A*B is volume weighted oxygen concentration 8.33

It should be noted that volume-weighted oxygen concen-tration calculations yield a single number which may respond differently from lake to lake to changes in trophic status. The number should be interpreted together with other physical and chemical information relating to the lake in question. However, it is a simple and useful measure related directly to lake trout habitat.



*Footnote: Details of the oxygen model have been published in: Molot, L.A., P.J. Dillon, B.J. Clark, and B.P. Neary. 1992. Predicting end-of-summer oxygen profiles in stratified lakes. Can. J. Fish. Aquat. Sci. **49**:2363-2372.

For further information, contact:
B. Clark
Phone: 705 766-2150
Fax: 705 766-2254
Email: clarkbe@ene.gov.on.ca

MINISTRY OF THE ENVIRONMENT

ENVIRONMENTAL SCIENCES AND STANDARDS DIVISION
DORSET ENVIRONMENTAL SCIENCE CENTRE

Technical Bulletin No. DESC-10
October 1996
Reprinted June 1999

THE TROUBLE WITH CHLOROPHYLL: CAUTIONS REGARDING THE COLLECTION AND USE OF CHLOROPHYLL DATA

Resource managers and researchers from many agencies commonly use chlorophyll as a trophic status indicator. Although variation in chlorophyll concentration tends to be the most evident consequence of changes in trophic status, there are problems involved with using this test as a basis for either setting trophic status objectives or detecting long-term change. These problems can be summarized as follows:

- the collection and submission of chlorophyll samples require precautions that are complex compared to other trophic status parameters

- changes in analytical methods may disrupt long-term chlorophyll data sets.

- significant seasonal and inter-annual variation in chlorophyll requires the collection of large numbers of samples over many years.

- many different chlorophyll pigments are commonly measured, ie: Chl a, b, c, chl a corrected etc., concentrations of these pigments may not correspond to actual phytoplankton cell densities.

DATA COLLECTION Chlorophyll samples must be collected into opaque bottles and immediately fixed with magnesium carbonate ($MgCO_3$ ensures that the sample remains 'basic' to avoid conversion of primary pigments to phaeopigments under acidic conditions). They must then be kept cool and filtered as soon as possible. The filtrate must be frozen and transported to the lab without being allowed to thaw. This makes the remote collection of samples difficult or impossible such that, from the onset, chlorophyll data can present uncertainties if the samples have not been collected under strictly controlled conditions.

Chlorophyll samples are often collected as euphotic zone composites and reported as ice-free means. The euphotic zone, usually approximated as twice the Secchi disc visibility, is sometimes well mixed since much of this layer is composed of epilimnion. However algal cells will often stratify dramatically below the epilimnion and this can occur even in mixed layers (Fig.1). This means that chlorophyll concentrations based on euphotic zone composite samples may vary based simply on the physical collection methods ie: how the water is combined in proportion from given depths. This is very relevant in situations where the depth of the euphotic zone relative to the thermocline changes over time.

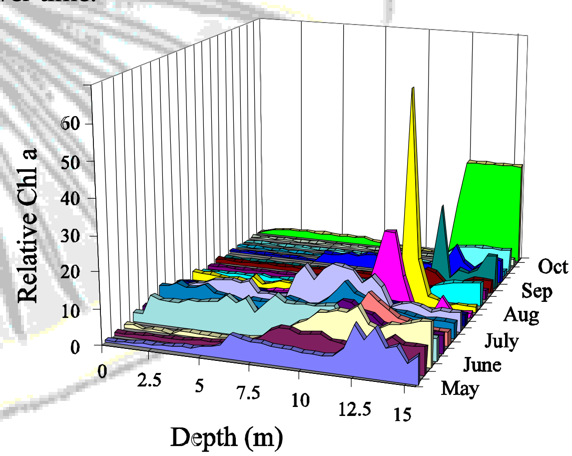


Figure 1: Vertical distribution of Chl a in Plastic Lake.

CHANGES IN ANALYTICAL METHODS The reported concentrations of chl a have been subject to methods changes at the MOEE laboratories. The long-term data base has been most notably broken due to changes in the methods that occurred in 1985. At that time, a switch to nylon filters increased extraction efficiencies of the acetone. This resulted in an increase in post '85 values. Although it may be possible to 'align' the data before 1985 to match current values, there is no single correction factor that can be applied to these data. Data base managers who have chlorophyll values spanning 1985 should refer to the documentation referring to the methods changes which was published by the Lab Services Branch in 1985.

SEASONAL AND INTER-ANNUAL VARIATION The largest problem with the interpretation of chlorophyll data is associated with seasonal and inter- annual variation. Chlorophyll concentrations vary significantly on a seasonal basis within lakes and often show different seasonal patterns between lakes (Fig.2). In addition there is a great amount of long-term, or between-year variation in the ice-free means for individual lakes. (Fig.3) This makes it necessary to collect numerous samples each year to derive ice-free
means that are close to the actual value, and many years of this type of data are required to estimate the long-term mean (TABLE 1). Thus it is difficult to

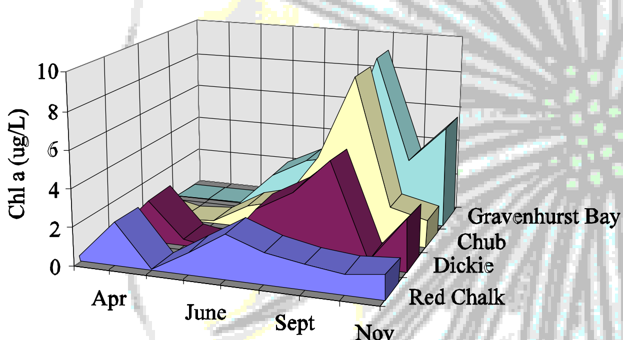


Figure 2: Seasonal changes in chl a for Gravenhurst Bay, Chub, Dickie and Red Chalk lakes in 1993.

assess whether observed changes in chlorophyll are actually reflecting long-term change or whether they are simply noise based on the collection of too few samples each year or too few years of data being used to detect the change. Development objectives for

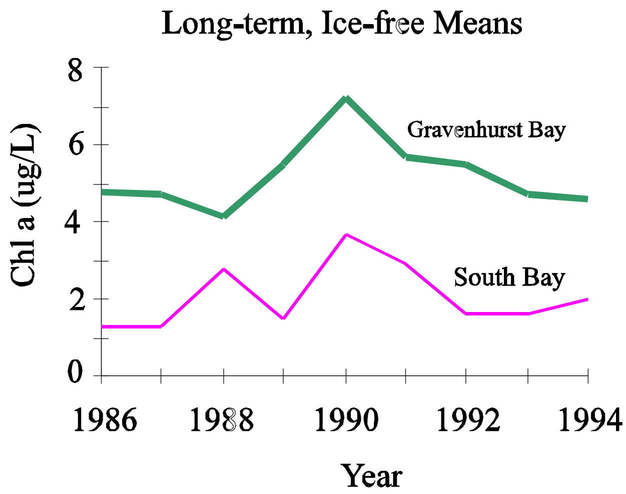


Figure 3: Long-term variation in ice-free Chl a for Gravenhurst Bay and South Bay (Lake Muskoka).

individual lakes that are based on chlorophyll will therefore be difficult to assess since it will be imposible to tell the difference between the actual surpassing of objectives and simple variation based on the collection of too few samples. These problems tend to increase in severity with increasing trophic status such that the situations that require the most attention, ie: more enriched systems, also tend to require the most samples to describe accurately.

Table 1: Number of chlorophyll samples required each year and the number of years of data required to be within specified percents of the actual mean. Number of years of data is based on seasonal means that are approx.within 20%.

	# samples/year			# years		
% of mean	10	20	50	10	20	50
Blue chalk	55	14	2	3	1	1
Harp	59	15	2	7	2	1
Dickie	126	32	5	16	4	1

CELL DENSITY VS PIGMENT CONCENTRATION Finally, the whole picture is further complicated by the fact that chlorophyll concentrations are not always tied to phytoplankton cell densities. The actual concentration of chlorophyll in algal cells is determined by incident radiation, species composition, nutrient supply and certain aspects of algal physiology. These determinants have a seasonal component such that the correspondence between chlorophyll a and algal cell densities is not constant. These relationships can further be specific to different chlorophyll pigments. In most cases chlorophyll a or a version of chlorophyll a corrected for phaeopigments is used to represent the phytoplankton community. Sometimes chl b or chl c are quoted but often the relationship between the concentrations of specific pigments and the concentrations of algal cell in the lake do not correspond because the cells in greatest abundance do not contain pigments that are being measured. Also, algal communities are changing seasonally back and forth between those that contain the investigator's pigment of choice and those that do not.

CONCLUSIONS AND RECOMMENDATIONS

When all of these problems are considered it makes it difficult to recommend chlorophyll as a trophic status indicator in situations where small amounts of data are collected. Most of the problems outlined above are amplified by the collection of too little data. This is not to say that chlorophyll data should not be collected. A great deal of usefull data exists that show the effects of phosphorus load reductions, zebra mussels, etc. on chlorophyll concentrations. These are generally based on large data sets that are not plagued by seasonal or inter-annual variation.

Since virtually none of the same problems outlined for the collection of chlorophyll data apply to the collection of total phosphorus data it is probably better to use total phosphorus as an indicator of trophic potential in situations where minimal data sets are being collected.

Lastly, the cost of monitoring the trophic status of a lake based on spring turnover TP would be a fraction of that involved with using chlorophyll. Spring turnover total phosphorus based trophic status estimates would require only one visit to each lake per year. Since ice-free mean chlorophyll estimates require at least 6 or 7 visits per year and considering that the chlorophyll test is approx 4 times as expensive as a TP test, the relative difference in test costs alone would be in the neighbourhood of 25 times. When staff and transportation costs are considered the numbers become significantly different. Cost aside, the results would be much more reliable when based on total phosphorus such that it would be recommended in almost every case to base trophic status estimates on total phosphorus. If information about the phytoplankton community must be collected, managers should consider collecting seasonal composite phytoplankton enumeration samples. Generally, weekly, bi-weekly or monthly phytoplankton samples are collected and fixed with Lugols fixative. These may be combined at the ennumeration Lab in Rexdale and counted to provide seasonal, mean, phytoplankton cell densities. These numbers will relate better to trophic status than will chlorophyll estimates (Fig.4) and the costs will still be approximately half.

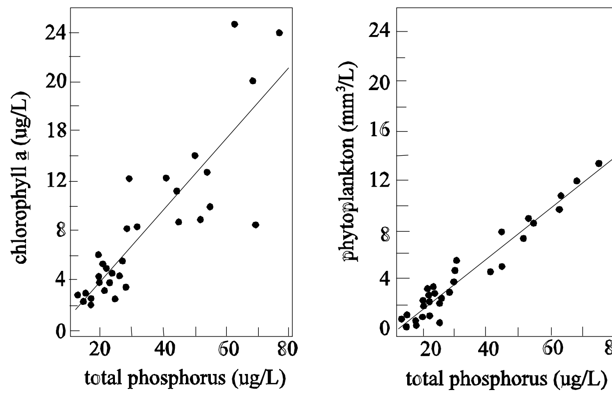


Figure 4: Relationship between total phosphorus and chlorophyll a (left) and phytoplankton cell volume (right).

Details about estimating the trophic status of a lake based on total phosphorus are available in STB Tech. Bull. DESC-4.

For further information, contact:

B. Clark
Phone: 705 766-2150
Fax: 705 766-2254
Email: clarkbe@ene.gov.on.ca

MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL SCIENCES AND STANDARDS DIVISION
DORSET ENVIRONMENTAL SCIENCE CENTRE
Technical Bulletin No. DESC-25
May 1998
Reprinted June 1999

LONG-TERM MONITORING OF TROPHIC STATUS: THE VALUE OF TOTAL PHOSPHORUS CONCENTRATION AT SPRING OVERTURN

There are many reasons to measure the nutrient status of a water body. It may be done as part of an initiative to control nutrient inputs in an effort to reduce nuisance levels of aquatic plants or algae. In some cases, measurements are taken as part of a self-regulation program designed to monitor inputs to surface waters. In most cases, however, the nutrient status of a water body is measured to detect long-term changes in water quality (the nutrient status) of the water body.

The three most common measures of the nutrient status of a water body are TP (total phosphorus), chlorophyll a and Secchi depth. In Ontario, Secchi depth is often controlled by DOC rather than by chlorophyll and the chlorophyll measurements themselves are costly and must be pooled in large numbers to yield meaningful ice-free means (see *Techbull DESC_ 10*). For these reasons, TP is the recommended parameter to monitor long-term changes in trophic status. This is supported by the fact that TP is almost always the limiting nutrient for algal growth in Ontario lakes. In addition, TP surveys are easy and comparatively inexpensive to conduct.

Once the decision has been made to monitor long-term changes in TP, decisions must be made with respect to the type of sampling regime that will be followed. Since seasonal variation in TP would rarely be of interest, it is, in most cases, desirable to obtain some number that describes an annual average condition such that the individual annual means can be monitored through time.

There are many different ways to combine TP samples to derive some measure of an annual mean. Monthly samples can be pooled to derive an "ice-free mean" but care must be taken when combining these numbers to produce "means" that can be validly compared to the numbers derived by similar studies elsewhere. For example, individual surface water samples when taken as 5 metre composites or euphotic zone composites when pooled will give an ice free epilimnetic or euphotic zone (annual) mean. This number will be different from numbers generated by other programs that volume weight the stratified season samples taken from all layers of the lake to accurately produce a "whole-lake" ice free annual mean. For these reasons it is often safer to collect TP samples at spring overturn to detect long-term trends. Certainly, it is better to have a single, reliable spring-overturn number than it is to average several samples that have been collected in a helter skelter fashion at other times of the year. The DESC database clearly shows that long-term average TP concentrations derived for a given lake using spring turnover samples are very closely corelated to those derived using ice-free means by volume weighting. (Fig 1).

$$\mathbf{TP}_{if} = 0.96\mathbf{TP}_{so} + 0.31 \qquad r^2 = 0.93$$

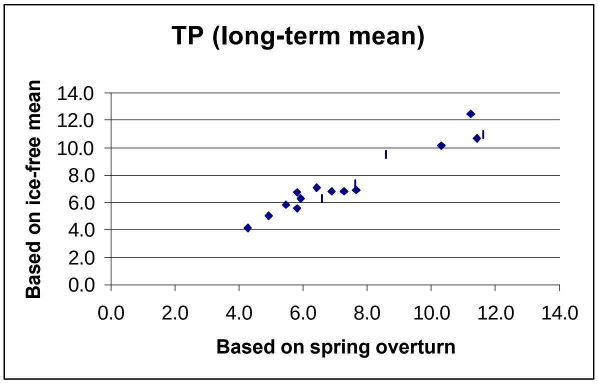


Fig. 1. The relationship between long term mean TP derived using spring turnover and ice-free mean data for the lakes in the Dorset database.

Note: Volume weighting is used to collect data for all parameters for use in mass balance calculations at the DESC and probably would not be conducted if the only goal was to monitor changes through time in whole lake TP concentrations.

Previous calculations based on DESC data have shown that a reliable long-term mean can be derived with 2-4 years of spring turnover data. The ice-free, volume-weighted means will provide a reliable long-term mean sooner ie, within 1-3 years but the extra effort and cost is usually not justified. In fact, for many lakes, the long-term trend is described as well or better by spring turnover TP than by ice-free volume weighted means (Fig 2).

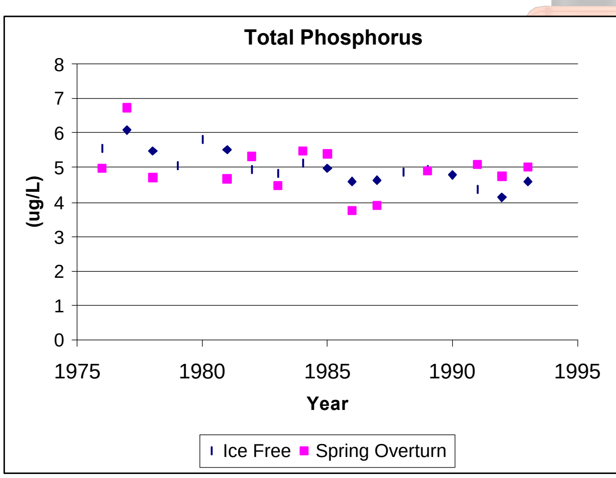


Fig.2. Annual TP expressed as spring overturn concentrations and as ice free means (mean of monthly volume weighted concentrations) for Blue Chalk Lake.

Spring turnover TP concentrations should be taken as some form of surface water composite (ie, 5m composite bottle sample) from the deepest location in the lake(Fig.3.). Ideally the sample should be taken a week or so after ice out to allow the lake to completely mix. Samples should be taken, however, before water temperatures reach ~10ºC. It is not acceptable, to include values in the database that are collected outside this window. It should also be noted that a single

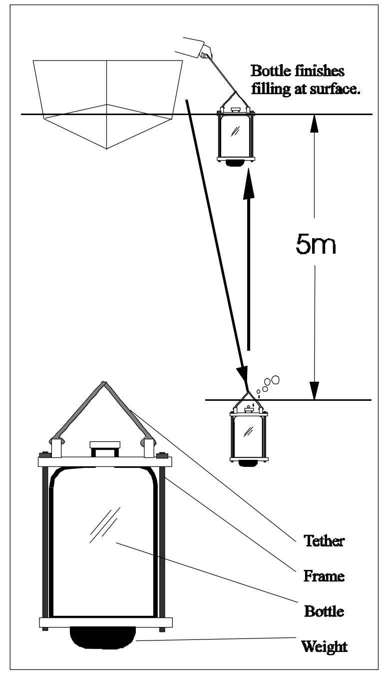


Fig.3. The 5m composite sampling method.

spring TP sample will not be adequate to describe the conditions that occur in complex systems such as;

- in very large lakes
- where large inflows dominate the nutrient concentrations in the lake
- in eutrophic lakes where there are large nutrient fluxes or a high degree of spacial variation
- in lakes where anthropogenic loads are high such as in lakes that adjoin urban centres.

For more information, contact
Bev Clark, DESC, 705-766-2150
email: clarkbe@ene.gov.on.ca