APPENDIX A

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

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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.

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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

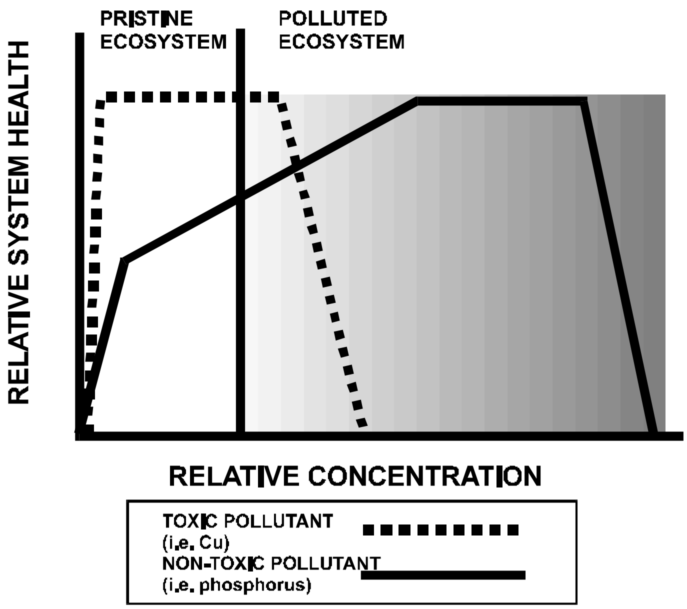

Figure 1. Generalized responses of an ecosystem to toxic and non-toxic pollutants

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).

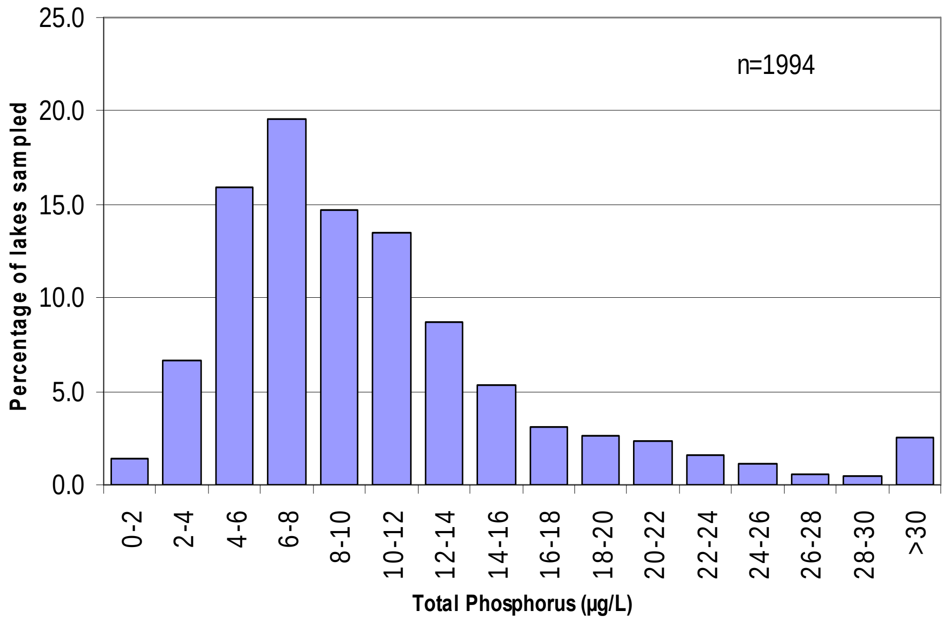

Figure 2. Distribution of total phosphorus concentrations in sampled Ontario lakes (source: MOE Inland Lakes database, March 2004)

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.

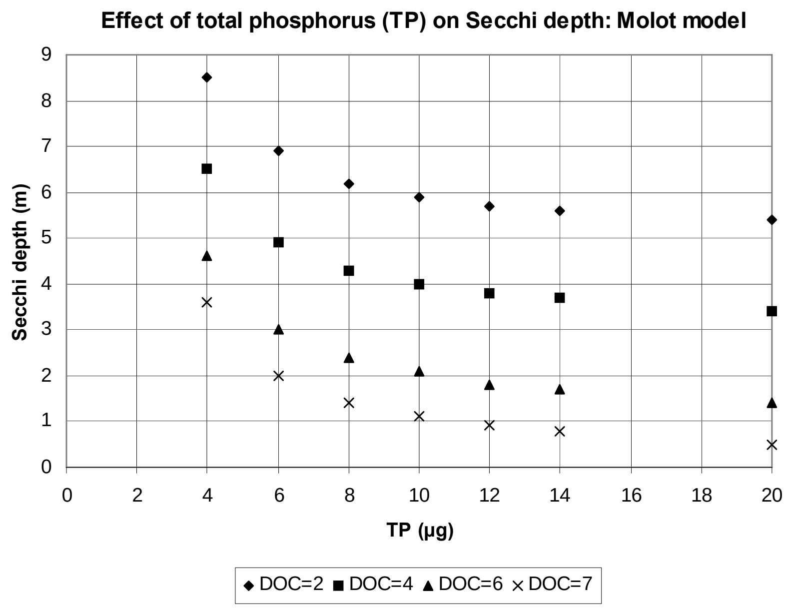

Figure 3. Relationship of predicted water clarity to total phosphorus and dissolved organic carbon (DOC) concentrations in Precambrian Shield lakes in south-central Ontario.

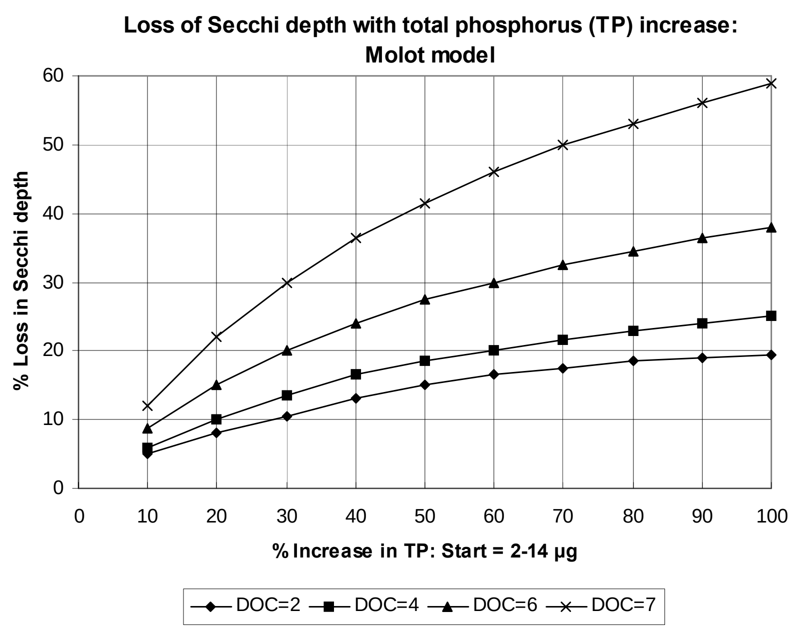

Figure 4. Predicted response of Secchi depth to 10 to 100 per cent increases in total phosphorus concentration from initial values of 2 to 14 µg/L at dissolved organic carbon (DOC) levels of 2, 4, 6 and 7 mg/L.

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

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