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Ref.:	LCC_Threshold_TP2014	(21 pages)
To:	Multiple recipients	
From:	S. M. Mandaville Post-Grad Dip., Professional Lake Manage. Chairman and Scientific Director	
Date:	March 14, 2014	
Subject:	Phosphorus:- Details on LCC (Lake Carrying Capacity)/Threshold values of lakes, and comparison with artificially high values chosen by the HRM	

We are an independent scientific research group with some leading scientists across Canada and the USA among our membership. Written informally. I provide web scans where necessary as backup to Government citations. Pardon any typos/grammar.

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Overview

Our Threshold/LCC TP values are based on the federal CCME (2004) policy. HRM appears to be basing their standards on the `recent field data' and not on the pre--cultural hindcast data, although the latter is recommended in numerous scientific literature inclusive of the CCME (Canadian Council of Ministers of the Environment). Further, paleolimnological literature suggests instead a compromise of selecting the diatom inference (DI) values of the pre-industrial era. In the HRM/Nova Scotia domain, it would be approximately pre-1850. These inference values can be also be used to set the acceptable TP values as well. Our modelled pre-cultural TP, the DI (Diatom Inference) TP, suggestions on proper LCC's, as well as the HRM's threshold values are in the tables on pages 10 to 13 incl.

Below, I don't address all the two thousand lakes/ponds (2,000) that we have researched within four (4) Nova Scotia counties but for practicality, I include only representative lakes within HRM.

Introduction

Important Note: At first glance, our recommended Threshold/LCC TP values may appear overly stringent. But, there are case histories in Canada and the USA where considerable effort is being expended to restore lakes to 1.5 times the pre-cultural values. Pragmatic action by `conscientious regulators' is preferable with stakeholder support.

Lead scientists from Ontario carried out the first ever paleolimnology of select lakes across Nova Scotia. The NSERC (Natural Sciences and Engineering Research Council of Canada) awarded a major 5-year grant to them. Several government agencies as well as our scientific group (the SWCSMH) collaborated (access the URL, http://post.queensu.ca/~pearl/maritimes/partners.html for the list of partners).

One of the outcomes was the superb MSc thesis (2009) of Ms. Thiyake Rajaratnam of Queen's University, Ontario. Thiyake's thesis developed a paleolimnological approach to assess changes in diatom assemblages (class Bacillariophyceae) from present-day lake sediments in comparison to those deposited before significant human impact (*ca*. pre-1850) from 51 Halifax (Nova Scotia, Canada) region lakes in conjunction with regional diatom-based transfer functions for pH and total phosphorus (TP).

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I am including our team's modelled pre-cultural hindcast (+0.173 kg/ha.yr in precipitation) TP values for a selection of lakes which include most of the 80 stations that the HRM chose for sampling during 2006-2011. I am including the precipitation in TP in our modelling since it may not be directly related to local land development projects but may be long range transport. I do have values without the precipitation in our numerous modelling files.

We have completed certain research inclusive of predictive modelling of **TP** and **Ch*a*** of a massive two thousand (2,000) lakes/ponds within four (4) Nova Scotia counties which includes most of 1,100 lakes/ponds across the vast HRM. This submission is only on TP in order to focus on the primary limiting nutrient in our lakes (though TP may not the limiting nutrient in a few of the lakes per our research). We have not included the `biological inferences' of our studies of the phytoplankton and of the zoobenthos either. We are also conducting studies of chironomid mentum deformities, though the latter is progressing at a very slow pace. We do donate printed copies of some of the final results to select local university libraries when time and funds permit.

Exception: A few of the lakes are marked as highly coloured in the Table; hence our predictive modelling results may not be indicative of the true hindcast values in those few cases. Natural colour is a result of coloured humic acids which may result in higher background TP values even with no land development. Presently, certain research is ongoing at a leading Ontario university to more accurately predict the TP values of such lakes, and we have collaborated with them. We eagerly await the modelling methodology for such lakes.

In the following pages, I provide evidence (i.e., scans) of a selection of the leading peer reviewed literature and of select Government guidelines/standards.

There were numerous published papers in several peer reviewed journals relating to lake management dating as long back as the 1970's. Some examples of the peer reviewed journals are the international research 18-member countries of the OECD (Organization for Economic Co-Operation and Development), the Canadian Journal of Fisheries and Aquatic Sciences (CJFAS), the North American Lake Management Society (NALMS) journals, Handbooks of the NALMS, and the Province of Quebec standards.

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"**Eutrophication** is the response in water due to overenrichment by nutrients, primarily phosphorus and nitrogen, and can occur under natural or manmade (anthropogenic) conditions. Manmade (or cultural) eutrophication, in the absence of control measures, proceeds at an accelerated rate compared to the natural phenomenon and is one of the main forms of water pollution. The resultant increase in fertility of affected lakes, reservoirs, slow-flowing rivers and certain coastal waters causes symptoms such as algal blooms (with potential toxicity in extreme cases), heavy growth of rooted aquatic plants (macrophytes), algal mats, deoxygenation and, in some cases, unpleasant odour, which often affects most of the vital uses of the water such as water supply, recreation, fisheries (both commercial and recreational), or aesthetics. In addition, lakes become unattractive for bathing, boating and other water oriented recreations. Most often economically and socially important species, such as salmonids decline or disappear and are replaced by coarser fish of reduced economic/social value." (From multiple literature; see our web page, http://lakes.chebucto.org/eutro.html).

Potential sources of phosphorus:- Phosphorus has been reduced or eliminated in most laundry detergents but there are several other sources as follows:- fertilizers (farm, golf course, residential); animal, pet and bird feces; sewage treatment plant discharges (STP's do not remove all phosphorus, and the discharge is highly biologically available more so than other sources); overflows/bypasses from STPs and pumping stations; septic system failures; package treatment plants (over long periods); cross connections between sanitary and storm sewer laterals; certain industrial discharges; and high sedimentation. In some lakes, there could be internal loading, i.e., re-suspension, from bottom sediments as well.

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(1) See the CCME (Canadian Council of Ministers of the Environment)'s fact sheet (2004) for the phosphorus guidance framework. The 6-page document has been inserted in pages 15 to 20 incl., for all of your convenience.

This CCME guideline was indeed the result of extensive scientific consultations conducted across North America by Environment Canada's scientists over the early 2000's. But the `concept' has been known to many of us since approx. the early 1980's via peer reviewed literature.

Total phosphorus (TP) trigger ranges for Canadian lakes and rivers (CCME, 2004)

Trophic status	TP (µg/l)
Ultra-oligotrophic	< 4
Oligotrophic	4-10
Mesotrophic	10-20
Meso-eutrophic	20-35
Eutrophic	35-100
Hyper-eutrophic	>100

Per the CCME (2004), the framework offers a tiered approach where phosphorus concentrations should not (i) exceed predefined 'trigger ranges'; and (ii) increase more than 50% over the baseline (reference) levels. The trigger ranges are based on the range of phosphorus concentrations in water that define the reference trophic status for a site (i.e., hindcast values). If the upper limit of the range is exceeded, or is likely to be exceeded, further assessment is required. When assessment suggests the likelihood of undesired change in the system, a management decision must be made.

The pre-cultural hindcast (+0.173 kg/ha.yr precipitation) trophic status of our lakes is <u>ultra-oligotrophic to oligotrophic</u> per the aforementioned CCME (2004) guideline. As lakes get enriched, they become more eutrophic.

(2) Eutrophication of Waters: Research of the Organization for Economic Co-Operation and Development (OECD)

(see http://lakes.chebucto.org/TPMODELS/OECD/oecd.html; our URLs are case sensitive)

The OECD lakes ranged from "pond-size" lakes to the Great North American Lakes. The momentum initiated by the International Biological Programme in 1964 was maintained. The information available was broad enough to establish the general statistical behaviour of lakes with respect to nutrient load and trophic response. It should be noted, however, that subtropical (in USA) and Arctic lakes (including high Alpine) were poorly represented, and saline, closed basin lakes were not represented at all in the programme. The OECD study was restricted mainly to lakes of the temperate zone.

The final report is a synthesis of the main results of the OECD Cooperative Programme on Eutrophication under the Chairman of the Technical Bureau, Dr. Richard Vollenweider. It is the outcome of several years' concerted effort by 18 Member countries. The objectives were to establish, through international cooperation, a basis for eutrophication control of inland waters (lakes and reservoirs in particular), and to develop better guidelines for fixing nutrient load criteria compatible with water use objectives.

The results of the OECD study and approach have already been successfully applied in several instances in North America, Europe and elsewhere.

Statute of the report: The conclusions of this report have been successively agreed by the Water Management Policy Group, the Environment Committee and finally the Council. The technical part of this synthesis report has also been approved by the Water Management Policy Group.

Excerpt form the final report (Vollenweider and Kerekes, 1982):-

Natural limnological conditions vary considerably among countries and also among different regions, particularly the larger countries. Consequently, the water quality objectives would differ in each country, taking local conditions and expectations into account. In the absence of human activities, the nutrient load and the trophic response in waterbodies are determined by the natural fertility of soils on the drainage basin which in turn depends on the geology and the climate of the area in question. Ideally, the objective of lake management should be to maintain or restore waterbodies to their natural state determined by the basic natural nutrient load of the area in question (e.g. free from human activities). In practice, this is not always possible.

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(3) This popular NALMS handbook is used worldwide (*cf.* Holdren, C., Jones, W., and Taggart, J. 2001. Managing Lakes and Reservoirs. N. Am. Lake Manage. Soc. And Terrene Inst., in coop. with Off. Water Assess. Watershed Prot. Div. U.S. Environ. Prot. Agency, Madison, WI. Xiv, 382 pp.)

Excerpt inserted below; I am sorry that the scan did not come out too well but the info is clear there.-

Some typical restrictions include a certain percentage increase of phospho
rus concentration above pre-development concentrations. The Ministry of th
Environment in Ontario, Canada, proposes a factor of 1.5 increase above prehis
toric annual average phosphorus concentrations as target values for its more tha
100,000 lakes on the Canadian Shield (Hutchinson et al. 1991). The Swedish gov
ernment endorses a maximum of twice the background levels of phosphorus (an
nitrogen) as a national target (Swedish EPA, 1994). Compliance with these target
can be evaluated only by using phosphorus models in which current anthro
pogenic sources are first included and used to verify the model and then remove
to arrive at a pre-development phosphorus concentration.

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(4) The Province of Quebec has strict standards (March, 2006) (http://lakes.chebucto.org/TPMODELS/Quebec/phosphore-eco-regions_selection.pdf). Their guidelines are in French but hopefully some of you may understand them. I am inserting only the most relevant parts of it below:-

“Les critères de qualité de l’eau actuellement en vigueur au Québec pour le phosphore sont exprimés en phosphore total et sont les suivants :

- dans les ruisseaux et les rivières ne s’écoulant pas vers un lac : 30 µg/l;
- dans les cours d’eau s’écoulant vers un lac dont le contexte environnemental n’est pas problématique : 20 µg/l;
- dans les lacs dont la concentration naturelle est ou était inférieure à 10 µg/l : 50 % d’augmentation par rapport à la concentration naturelle, sans dépasser un maximum de 10 µg/l afin d’éviter l’eutrophisation des lacs oligotrophes;
- dans les lacs dont la concentration naturelle se trouve ou se trouvait entre 10 et 20 µg/l : 50 % d’augmentation par rapport à la concentration naturelle, sans dépasser un maximum de 20 µg/l afin d’éviter l’eutrophisation des lacs.

Ces deux derniers critères s’appliquent à la période sans glace et, pour les lacs abritant des habitats sensibles (ex. : lacs à touladis), ils doivent être validés par des modèles du comportement de l’oxygène dissous dans l’hypolimnion (MENV, 2001).

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(5) Leadership shown by the Kings County of Nova Scotia. Kindly note that the Kings County of Nova Scotia set a maximum objective **of yearly mean Ch*a* values in the low range of 2.5 µg/l for 18 lakes.** Ch*a* is the most commonly used indicator of algal production in freshwaters.

Incidentally, Dr. Joe Kerekes (Environment Canada) of the Organization for Economic Co-Operation and Development (OECD) repute was the prime adviser to the Kings County. I herewith insert a scan from their policy in our archives:-

Kings County adopted water quality objectives for 18 lakes in the county, through amendment of MPS and LUB. The maximum objective value of chlorophyll-a for most of these lakes is 2.5 µgm/L. Seven of the lakes' objectives were set below the level of 2.5. Based on predictive modelling, the estimated maximum number of dwellings that could be added to the contributing area without exceeding the threshold value was established. This number of dwellings was set as a limit for development in the LUB. Policy in the MPS enables application for a permit with a development having "near-zero impact" through site standards or performance standards. Primarily this condition is expected to be met with septic field fill with a 20 year phosphorus input retention and a requirement to replace the fill every 20 years. A condition in adopting these limits was implementation of an annual monitoring program for a minimum of six years. The sampling required was to be completed by volunteers.

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Table of values:

#	Lake and the community (other relevant info)	Deep station values (shallow zone values may differ considerably)				
		SWCSMH's models	Queen's University Diatom Inference Model	LCC/Threshold TP	LCC/Threshold TP	HRM's artificially high threshold TP
		Pre-cultural (+0.173 kg/ha.yr precipitation)	Pre-1850 (Bottom layer of core)	Based on CCME (2004) framework	Based on paleolimnological research	Objective - Early warning
		µg/l	µg/l	µg/l	µg/l	µg/l
1	Albro Big (Dartmouth)	2.8	4.90	4	5	---
2	Little Albro (Dartmouth)	---	3.80	---	4	---
3	Anderson (Bedford)	---	6.03	---	6	---
4	Banook (Dartmouth)	---	5.75	---	6	<20 – 15
5	Barrett (Beaverbank)	4.6	---	7	---	<20 - 15
6	Bayers (Halifax)	5.6	4.47	8	4	---
7	Beaverbank	5.7	---	9	---	---
8	Bell (Dartmouth)	2.2	4.79	4	5	---
9	Bissett (Cole Harbour)	3.7	5.13	4 or 6	5	---
10	Black Duck Pd. (Lakeside)	4.3	---	6	---	---
11	Black Point Lake (high colour; Hubley)	5.3	---	High colour	---	---
12	Charles (Dartmouth)	4.7	4.79	7	5	<20 - 15
13	Chocolate (Halifax)	---	20.42	---	20	---
14	Cranberry (long history with eutrophication-Dartmouth)	3.3	9.33	4 or 5	9	<20 – 20
15	Drain (Middle Sackville)	4.8	---	7	---	---
16	Duck (coloured-Beaverbank)	4.0	---	High colour	---	---
17	Echo (Lake Echo)	4.3	---	6	---	---
18	Fenerty (Beaverbank)	4.7	---	7	---	22 – 22
19	First (Lower Sackville)	2.6	5.89	4	6	<20 – 15
20	First Chain (Halifax)	---	4.07	---	4	---

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#	Lake and the community (other relevant info)	Deep station data (shallow zone values may differ considerably)				
		SWCSMH's models	Queen's University Diatom Inference Model	LCC/Threshold TP	LCC/Threshold TP	HRM's artificially high threshold TP
		Pre-cultural (+0.173 kg/ha.yr precipitation)	Pre-1850 (Bottom layer of core)	Based on CCME (2004) framework	Based on paleolimnological research	Objective - Early warning
		µg/l	µg/l	µg/l	µg/l	µg/l
21	Fish (Wellington)	5.0	---	8	---	---
22	Fletcher (Fall River)	3.6	2.09	4 or 5	2	<20 – 15
23	Fraser (Timberlea)	5.7	7.94	9	8	---
24	Frenchman (Dartmouth)	---	4.37	---	4	----
25	Frog (Jollimore)	-	4.90	---	5	---
26	Governor (Timberlea)	5.0	11.48	8	12	---
27	Half Mile (high colour; Timberlea)	5.4	---	High colour	---	---
28	Horseshoe (Beaverbank)	2.7	---	4	---	---
29	Hubley Big (high colour; Hubley)	4.2	---	High colour	---	---
30	Kearney (Halifax)	4.1	5.25	6	5	10
31	Kidston (high colour-Spryfield)	4.9	---	High colour	---	---
32	Kinsac (Windsor Jnctn.)	1.3	2.63	2	3	<20 – 15
33	Lewis (Shubie w/shed, Hants)	4.0	---	6	---	<10 - 9
34	Lamont (Dartmouth)	2.9	7.76	4	8	---
35	Little Springfield (Middle Sackville)	5.0	4.57	8	5	---
36	Lisle (Middle Sackville)	3.7	---	6	---	50
37	Long (high colour; Halifax)	4.7	5.37	High colour	5	---
38	Long Pd. (very high colour; Herring Cove)	5.5	---	High colour	---	---
39	Loon (Westphal)	2.5	7.94	4	8	<20 – 18
40	Lovett (Lakeside)	4.1	---	6	---	---

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#	Lake and the community (other relevant info)	Deep station data (shallow zone values may differ considerably)				
		SWCSMH's models	Queen's University Diatom Inference Model	LCC/Threshold TP	LCC/Threshold TP	HRM's artificially high threshold TP
		Pre-cultural (+0.173 kg/ha.yr precipitation)	Pre-1850 (Bottom layer of core)	Based on CCME (2004) framework	Based on paleolimnological research	Objective - Early warning
		µg/l	µg/l	µg/l	µg/l	µg/l
41	Major (Preston)	---	4.79	---	5	---
42	Maynard (Dartmouth)	---	3.72	---	4	---
43	McCabe (very high colour; Lucasville)	6.3	6.03	High colour	6	---
44	MicMac (Dartmouth)	---	2.29	---	2	<20 – 15
45	Miller (Fall River)	4.2	7.94	6	8	---
46	Morris (Dartmouth)	3.4	3.89	4 or 5	4	15
47	Oathill (Dartmouth)	3.6	11.22	4 or 5	11	---
48	Papermill (Bedford)	4.6	4.37	7	4	10
49	Penhorn (Dartmouth)	2.3	5.37	3.4	5	---
50	Pockwock (Hammonds Plains)	3.2	2.29	4	2	---
51	Porters-Upper (very high colour)	5.6	--	High colour	---	---
52	Porters-Lower	4.6	---	7	---	---
53	Powder Mill (Waverley)	2.3	6.61	3.4	7	<20 - 15
54	Powers Pd. (Herring Cove)	5.5	5.89	8	6	---
55	Rocky (Bedford)	2.9	6.76	4	7	<20 – 18
56	Russell (Dartmouth)	4.7	23.44	7	23	15
57	Sandy (Bedford)	6.3	8.91	9	9	---
58	Sandy (Glen Arbour)	3.2	---	4 or 5	---	---
59	Second (Sackville/Windsor Jnct.)	4.3	7.24	6	7	<20 – 15
60	Second Chain	---	4.37	---	4	---

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#	Lake and the community (other relevant info)	Deep station data (shallow zone values may differ considerably)				
		SWCSMH's models	Queen's University Diatom Inference Model	LCC/Threshold TP	LCC/Threshold TP	HRM's artificially high threshold TP
		Pre-cultural (+0.173 kg/ha.yr precipitation)	Pre-1850 (Bottom layer of core)	Based on CCME (2004) framework	Based on paleolimnological research	Objective - Early warning
		µg/l	µg/l	µg/l	µg/l	µg/l
61	Settle (Dartmouth)	3.2	7.94	4 or 5	8	---
62	Sheldrake (very high colour; Hubley)	4.7	4.68	High colour	5	---
63	Shubie Grand (Wellington)	3.1	5.50	4 or 5	6	<10 – 9
64	Soldier	4.2	6.61	6	7	---
65	Springfield (Middle Sackville)	3.1	5.01	4 or 5	5	<20 – 18
66	Stillwater (Hubley)	4.9	---	7	---	---
67	Third (Windsor Jnctn.)	3.0	12.02	4 or 5	12	<20 – 15
68	Thomas (Waverley)	3.9	3.39	4 or 6	3	<20 – 15
69	Three Mile (Waverley)	2.4	---	4	---	---
70	Topsail (Dartmouth)	2.5	4.79	4	5	--
71	Tucker (Beaverbank)	4.0	---	4 or 6	---	<20 – 15
72	Whimsical (Halifax)	---	13.80	---	14	---
73	William (Waverley)	3.5	8.51	4 or 5	8	<20 – 18
74	Williams (Jollimore)	3.9	4.07	4 or 6	4	---
75	Winder (North Preston)	5.7 (questionable due to its natural history of hyper eutrophy)	---	---	---	---

(Acronyms & brief explanation on next page)

Acronyms & brief explanation of the aforesaid table

SWCSMH's predictive modelling- Computer modelling carried out by the Soil & Water Conservation Society of Metro Halifax over a decadal period
HRM- Halifax Regional Municipality
Thiyake- Thiyake Rajaratnam's MSc thesis (2009) at the Queen's University in Kingston, Ontario under a major NSERC grant. The grant was for the first ever paleolimnology conducted on lakes across Nova Scotia (I calculated the antilog values from her reported log values based on the diatom inference model)

HRM set the following artificially high Threshold/LCC values of TP:-

HRM had set 15 μg/l as the Threshold/LCC values for Lakes Morris and Russell, and 10 μg/l for Lakes Kearney and Papermill.

Scan from the HRM's Shubenacadie Lakes Sub-watershed Study Report d/September 20, 2013:-

Lake	Trophic State Objective	Numerical Objective	Early Warning	Evaluation
Grand, Lewis	Oligotrophic	< 10 μg/L	9 μg/L	Based on 3 year running average
Charles, Micmac, Banook, First, Second, Third, Thomas, Fletcher, Tucker, Kinsac, Barrett, and Powder Mill	Mesotrophic	< 20 μg/L	15 μg/L	
Loon, William, Rocky, Springfield	Mesotrophic	< 20 μg/L	18 μg/L	
Cranberry	Mesotrophic	< 20 μg/L	20 μg/L	
Fenerty	Meso-Eutrophic	22 μg/L	22 μg/L	Fenerty should be maintained at its current average phosphorus concentration of 22 μg/L.
Duck and Lisle	Both Duck (43 μg/L) and Lisle (50 μg/L) are eutrophic lakes. Water quality should not be allowed to deteriorate further and should be improved where feasible.			
Miller, Beaverbank, Fish and Beaver Pond	Insufficient data exist. More sampling is required to set WQO for these lakes.			

Canadian Water Quality Guidelines for the Protection of Aquatic Life

PHOSPHORUS: CANADIAN GUIDANCE FRAMEWORK FOR THE MANAGEMENT OF FRESHWATER SYSTEMS

Phosphorus (P; CAS No. 7723-14-0, atomic mass 30.97376) is a highly reactive, multivalent, non-metal of the nitrogen group in the period table that is never found free in nature. Phosphate rock, which contains the mineral apatite, an impure tri-calcium phosphate, is an important source of phosphorus. Phosphorus is an essential nutrient for all living organisms; living matter contains about 0.3 percent dry weight phosphorus (Horne and Goldman 1994). It plays a major role in biological metabolism, and when compared to other macronutrients required by biota, phosphorus is the least abundant and commonly the first nutrient to limit biological productivity (Wetzel 2001). Water bodies containing low phosphorus concentrations (i.e., unimpacted sites) typically support relatively diverse and abundant aquatic life that are self-sustaining and support various water uses. However, elevated phosphorus concentrations can adversely affect aquatic ecosystems (Chambers et al. 2001).

The phosphorous guideline follows a framework-based approach that accommodates the non-toxic endpoints associated with phosphorus and can be incorporated into existing management strategies. The framework offers a tiered approach where phosphorus concentrations should not (i) exceed predefined 'trigger ranges'; and (ii) increase more than 50% over the baseline (reference) levels. 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 of the range is exceeded, or is likely to be exceeded, further assessment is required. When assessment suggests the likelihood of undesired change in the system, a management decision must be made.

Phosphorus in the Aquatic Environment

Phosphorus in aquatic systems occurs in three forms: inorganic phosphorus, particulate organic phosphorus, and dissolved (soluble) organic phosphorus. Aquatic plants require inorganic phosphate for nutrition, typically in the form of orthophosphate ions (PO_4^{3-}). This is the most significant form of inorganic phosphorus, and is the only form of soluble inorganic phosphorus directly utilized by aquatic biota. This form of phosphate is transferred to consumers and decomposers as organic phosphate. Most of the phosphorus (up to 95%) in fresh water occurs as organic phosphates, cellular constituents of organisms, and within or adsorbed to inorganic and dead particulate organic matter (Wetzel 2001). This is subsequently made available for recycling via mineralization and decomposition.

Phosphate concentrations tend to increase with increases in total phosphorus (TP), but the proportion of phosphate declines with increasing TP (Hudson et al. 2000). The turnover rate of PO_4^{3-} in phosphorus limited systems is extremely rapid, thus making its measurement difficult. Filtration of the water sample prior to analysis for PO_4^{3-} can overestimate biologically available phosphorus (Fisher and Lean 1992) and conventional methods for measuring PO_4^{3-} generally overestimate phosphate concentrations (Hudson et al. 2000). Based on these limitations, TP is generally recommended as a meaningful measurement of phosphorus in surface waters (Wetzel 2001).

In the majority of lakes, phosphorus is normally the limiting nutrient for algal growth. However, in some areas (prairie lakes and rivers) nitrogen is increasingly being found to be the most important nutrient. TP concentrations in non-polluted natural waters extend over a very wide range from <1 $\mu g \cdot L^{-1}$ in ultra-oligotrophic waters, to >200 $\mu g \cdot L^{-1}$ in highly eutrophic waters; however, most uncontaminated freshwaters contain between 10 and 50 $\mu g \cdot L^{-1}$ of TP (Wetzel 2001). Phosphorus levels of freshwaters are generally lowest in mountainous regions of bedrock geomorphology (e.g., Boreal and Pre-Cambrian Shields), and increase in lowland waters derived from sedimentary rock deposits (e.g., the Boreal Plains of Alberta). Lakes rich in organic matter, and bogs, tend to exhibit high TP concentrations.

Sedimentation of particulate phosphorus results in a slow but continuous loss from the water column. Phosphate is precipitated as insoluble iron, calcium, or aluminium phosphate and then released slowly. Exchange of phosphorus across the sediment/water interface is regulated by oxidation-reduction (redox) interactions, which are dependent on oxygen supply, mineral solubility and sorptive mechanisms (Stumm and Morgan 1996), the metabolic activities of bacteria and fungi, and turbulence from physical and biotic activities (Wetzel 2001). Lake

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sediments contain much higher concentrations of phosphorus than water. Under aerobic conditions, the exchange equilibria are largely unidirectional toward the sediments; however, under anaerobic conditions, inorganic exchange at the sediment-water interface is strongly influenced by redox conditions. Sediment phosphorus release (internal loading) can be an important source of phosphorus and can maintain high phosphorus concentrations in the water column, even in the absence of significant external loading (Marsden 1989; Holz and Hoagland 1999).

The first response of an aquatic system to phosphorus additions is increased plant and algal productivity and biomass. Although this may be desirable in some cases, beyond a certain point, further phosphorus additions to phosphorus-limited systems can cause undesirable effects, such as: (i) decrease in biodiversity and changes in dominant biota; (ii) decline in ecologically sensitive species and increase in tolerant species; (iii) increase in plant and animal biomass; (iv) increase in turbidity; (v) increase in organic matter, leading to high sedimentation; and (vi) anoxic conditions (Mason 1991; Environment Canada 2004). When the excessive plant growth includes certain species of cyanobacteria, toxins may be produced, causing increased risk to aquatic life, livestock, and human health (Chambers et al. 2001).

The potential human quality of life concerns that may relate to eutrophication are: (i) treatment of potable water may be difficult and costly; (ii) the supply may have an unacceptable taste or odour problem; (iii) the water may be injurious to health; (iv) the aesthetic/ recreational value of the water may decrease; (v) macrophyte growth may impede water flow and navigation; (vi) commercially important species (such as salmonoids and coregonids) may disappear (Mason 1991; Environment Canada 2004).

Water Quality Guideline Derivation

Currently, no national environmental quality guidelines exist for phosphorus, although individual provinces may have guidelines or objectives (Environment Canada 2004). The Protocol for the Derivation of Guidelines for the Protection of Aquatic Life (CCME 1991) is intended to deal specifically with toxic substances, and provide numerical limits or narrative statements based on the most current, scientifically defensible toxicological data. Phosphorus does not fit this model because it is non-toxic to aquatic organisms at levels and forms present in the environment; however, secondary effects, such as eutrophication and oxygen depletion are serious concerns. Because aquatic communities are generally adapted to ambient conditions, it is neither feasible nor desirable to establish a single guideline value for phosphorus. Some of the effects of phosphorus are aesthetic and thus include an element of subjectivity. What is considered nuisance plant growth to some may be desirable to others. Based on these realities, guidelines for phosphorus are not derived; rather a guidance framework (Figure 1) that is consistent with CCME guideline principles is developed. The framework accommodates the non-toxic endpoints associated with phosphorus loading and permits site-specific management of phosphorus.

The framework provides a tiered approach where water bodies are marked for further assessment by comparing their trophic status to predefined ‘trigger ranges’. The trigger ranges are based on a range of phosphorus concentrations in water that define the reference status for a site. Using such a scheme, sites with similar characteristics are classified together irrespective of whether they might possess these features naturally or as a result of human influence. Since the reference condition for the water body in question is defined at the onset of the framework, this problem is readily overcome; predefined states, whether determined through hindcasting or by using best available data, are always used to set the trigger range.

Steps in Guidance Framework

Set Ecosystem Goals and Objectives

As a first step, it is crucial to set ecosystem goals and objectives (e.g., enhance, protect, or restore). The objective can be set for a healthy aquatic ecosystem, with the goals being unimpaired human uses, and a diverse and functioning aquatic ecosystem. By setting the diverse aquatic ecosystem as a goal, a desire to prevent the loss of species is established. Similarly, the desire for a functioning aquatic ecosystem recognizes that ecosystems do things that are both inherently of value and of value for human uses and desires. These objectives are important because they will guide management decisions made later.

Define Reference/ Baseline Conditions

Establishing the reference condition is the most important step in the framework because it determines the trigger range that is used for comparison. In some cases, historical data may be available, but in most cases there will be a need to estimate reference (baseline) phosphorus

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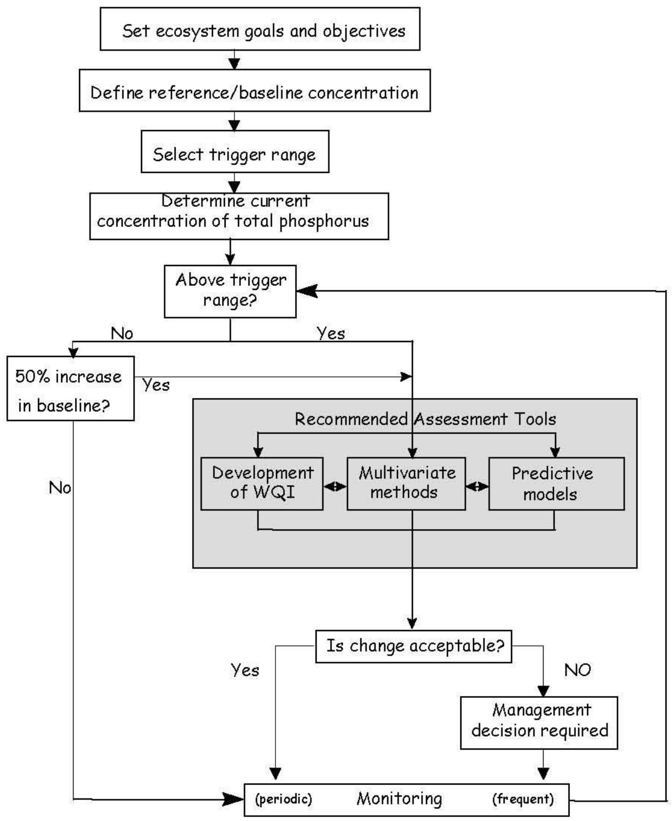

Figure 1. Canadian Guidance Framework for the management of phosphorus in freshwater systems.

concentrations. Several options are available for this, ranging from use of available historical data to derivation and application of predictive models to hindcast pre-development phosphorus values (Environment Canada 2004). Many jurisdictions (e.g., British Columbia and Ontario) which are actively managing phosphorus, have already established reference conditions that could be used in the framework. In addition, reference conditions will be relatively simple to determine in areas with little or no development. In geographical areas where there is a high density of water bodies, a single reference condition may be established for the entire area.

Select Trigger Ranges

Australia, New Zealand (NWQMS 1999), and the USEPA (EPA 2000) consider ecosystem classification in setting their nutrient guidelines. In the Canadian framework, trigger ranges are based on the trophic classification of the baseline condition or the status of reference sites.

Internationally accepted OECD (Organisation for Economic Co-operation and Development) trophic status values (Vollenweider and Kerekes 1982) are the recommended trigger ranges (Table 1). The only proposed variation is that the OECD meso-eutrophic category (10-35 $\mu g{\cdot}L^{-1}$) is subdivided into mesotrophic (10-20 $\mu g{\cdot}L^{-1}$) and meso-eutrophic (20-35 $\mu g{\cdot}L^{-1}$). This subdivision was necessary because considerable variation in community composition and biomass exist in Canadian waters over the OECD range of 10-35 $\mu g{\cdot}L^{-1}$. These trigger ranges are recommended for both rivers and lakes.

A trigger range is a desired concentration range for phosphorus; if the upper limit of the range is exceeded, it indicates a potential environmental problem, and therefore, "triggers" further investigations. Natural physical and chemical water quality variables (e.g., salinity, pH, nutrients) inherently vary within and between ecosystem types, and so the preferred method for determining the trigger ranges is to use similar, high quality reference sites to determine natural levels. These ranges are then categorised according to the trophic status of the reference site (Table 1). This approach provides a trigger range that is relevant to the ecosystem type and locality. These phosphorus limits allow management to define where their water bodies lie, and define a trigger range for that water body.

Table 1. Total phosphorus trigger ranges for Canadian lakes and rivers.

Trophic Status	Canadian Trigger Ranges Total phosphorus ($\mu g{\cdot}L^{-1}$)
Ultra-oligotrophic	<4
Oligotrophic	4-10
Mesotrophic	10-20
Meso-eutrophic	20-35
Eutrophic	35-100
Hyper-eutrophic	>100

The selection of appropriate trigger ranges and reference conditions can potentially benefit from the development and application of an ecoregional approach (Environment Canada 2004). Ecoregions provide a means of classifying ecologically distinct areas, where each region can be viewed as a discrete system made up of areas of similar geographical landform, soil, vegetation, climate, wildlife, water, etc. The use of ecoregions can improve predictability of nutrient enrichment effects. They can help differentiate between natural and anthropogenic contributions to nutrient enrichment, reduce variability in trigger ranges within a class and among classes, and contribute to improved assessment and development of trigger ranges.

Determine Current Phosphorus Concentration

Under normal conditions, TP is the only meaningful measurement of phosphorus for water (Wetzel 2001). TP can be expressed as a single measurement taken at spring turnover or as an average of several observations made on a seasonal basis; it may be an estimate for a specific zone (e.g., euphotic zone), or as a whole lake approximation. It is important that an appropriate number of samples are collected to accurately reflect TP concentrations in a system. Specific attention should be given to sites that are receiving variable phosphorus loads or exhibiting marked morphological and hydrological differences (Environment Canada 2004).

Compare Current or Predicted Concentration to Trigger Range

The upper concentration of the trigger range represents the maximum acceptable concentration of phosphorus within each of the trophic categories. If the upper limit of the trigger range is exceeded, or is likely to be exceeded, there is a risk of an impact either occurring or having occurred. At this stage, additional information on local environmental factors needs to be considered, and thus further assessment is recommended. The assessment could potentially lead to remedial advice and the restoration of a degraded water body. If the trigger range is not exceeded, the risk of an impact is regarded as low.

Compare Current or Predicted Concentration to Baseline Condition

Due to the general nature of the trigger values and the size of some of the phosphorus ranges defined, a second precaution is taken in the assessment of possible effects of phosphorus. In the event that the trigger value has not been exceeded, the question is now raised as to the degree of increase in phosphorus levels from the baseline. Up to a 50% increase in phosphorus concentrations above the baseline level is deemed acceptable (OMOE 1997). In large lakes, the 50% increase should be applied to the most sensitive areas (e.g., river mouth, point sources, or the littoral zone) rather than averaged over the whole lake. The 50% increase check is also applied to river systems. It is important to recognize that the 50% increase limit in lakes that already have high phosphorus baseline (up to 12 $\mu g{\cdot}L^{-1}$) may not protect against decreases in dissolved oxygen. However, in the absence of empirical data to recommend an alternative, the 50% increase limit is deemed preferable to no limit. If a 50% increase from the baseline is not observed, then there is considered a low risk of adverse effects, and only monitoring is required for these sites. If the increase from the baseline is greater than 50%, the risk of observable effects is considered to be high, and further assessment is recommended.

Recommended Assessment Tools

The recommended assessment options currently in use in Canada, the US, and other parts of the world are presented in detail in Environment Canada (2004). In summary, the tools fall into the following three categories:

i. A water quality index can be used as a surrogate for phosphorus as it can provide a single value that identifies the current state of the ecosystem, including the percent change from the reference/baseline condition (e.g., Johnes et al. 1994).

ii. Multivariate methods can also assist in comparing current conditions to baseline conditions, and the degree of impairment can be identified both spatially and temporally (Reynoldson and Day 1998; Kilgour et al. 1998; OMOE 1999).

iii. Predictive models can be applied for the management of phosphorus. For example, Lakeshore Capacity (Dillon and Rigler 1975) and paleoecology based phosphorus reconstruction (Dixit et al. 1999) models have been successfully used to estimate baseline phosphorus concentrations and to assess the magnitude and the rate of change.

These assessment tools should be viewed with the caveat that many of them were developed for specific water types or for specific areas with underlying topographic and geological assumptions. Although many of these methods can be adapted to the specific user's situation/need, care must be taken in selecting an approach that is both technically feasible and realistic to the user's needs. Furthermore, the application of any assessment tool in defining phosphorus concentration may not be exclusive, and it may be necessary to adapt a combination of approaches.

Management Decisions

Once the potential increases in phosphorus concentrations have been assessed, the results are compared to the original goals (i.e., reference or baseline conditions) set at the beginning of the framework. The degree of change is then assessed on a management level, and the question raised, "are these changes acceptable?".

Management decisions are a critical step in the framework that links back to the objectives and outcomes of the program via monitoring. Management of phosphorus should include both short-term management strategies and options, which primarily focus on operational activities; and long-term management strategies, which focus on nutrient reduction, flow management, education, monitoring, and research.

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Sampling frequency as recommended by the 18-member nation OECD

CRITICAL ASSESSMENT OF SOME ASPECTS OF THE OVERALL INFORMATION TREATED IN THE OECD EUTROPHICATION REPORT

The OECD was charged to develop a unified approach

1. Data Base used in the OECD Eutrophication Programme

The success of the programme depended on well-coordinated monitoring projects. Therefore, great effort was devoted to the kind of variables measured, the selection of reliable practical analytical methods, sampling procedures and minimum sampling frequency. This was to ensure that adequate and comparable data could be obtained for later elaboration and analysis and that participants with relatively modest technical facilities could contribute.

Throughout the monitoring programme in 1975, the Technical Bureau issued guidelines to ensure uniform and comparable procedures for reporting the essential variables. These were revised in 1976 (OECD 1975, 1976).

It was stressed that several sampling stations were required to describe conditions in lakes with complex morphometry, but if this was not possible, the minimum provision was that the lake should be sampled at the deepest point (or points). Only this minimum provision was followed in many cases and often a distorted picture of the average lake concentration resulted. Guidelines were also given on the choice of depths at which to sample. It was proposed that during the period of stratification, samples are essential from above and below the thermocline and from lower down in the hypolimnion. Samples from the hypolimnion very close to the lake bottom were particularly important. An absolute minimum sampling frequency of four times per year was recommended (winter, summer, spring and autumn overturn) and a sampling frequency of at least once a month during periods of stratification. The frequency of sampling affects the various measurements differently. Infrequent sampling usually gives a distorted picture of the resultant variables which have short-term variability (Table 3.3) and it is inadequate for the determination of peak values of chlorophyll *a* and daily primary production.

The Technical Bureau also defined the units for the essential variables and clarified several uncertainties which arose during the workshps. The eutrophic zone was defined as the depth at which the light intensity of the photosynthetically active spectrum (400-700 nm) equals 1 per cent of the subsurface light intensity (from photometric measurements). Where this information is not available, a Secchi disc reading (in metres) in which $z_e = 2.5$ Secchi was used. The latter is of course only a rough estimation of the euphotic zone which may vary considerably, depending on the spectral composition (colour of the water). Calculation methods for annual mean and seasonal mean values were defined. The seasons were given as "winter, spring, summer and autumn". For water bodies showing irregular circulation patterns, it was recommended that breakdowns be made for two seasons only, "summer" and "winter". This made it possible to present the data in terms of annual means, which are essential for use in the nutrient loading formulae, while seasonal variation and seasonal peak values could still be recognised. Both these features are essential for understanding of the process of eutrophication.