DEVELOPMENT OF ECOREGION BASED PHOSPHORUS GUIDELINES FOR CANADA: ONTARIO AS A CASE STUDY

Report Prepared for:

Water Quality Task Group
Canadian Council of Ministers of the Environment

Initial Report Prepared by:

Gartner Lee Limited
300 Town Centre Blvd., Suite 300
Markham, Ontario L3R 5Z6

Report Finalized by:

National Guidelines and Standards Office
Science and Risk Assessment
Environment Canada
Gatineau, Quebec K1A 0H3

PN 1373

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Executive Summary

Increase in nutrient concentrations in surface waters can contribute to increased growth of algae and aquatic macrophytes and distinct shifts in species composition. In some systems, blooms of cyanobacteria contribute to a wide range of water quality problems including summer fish kills, foul odours, and tainted drinking water. Furthermore, certain cyanobacteria produce and release toxins that can kill livestock and may pose a serious health threat to humans.

In an effort to develop national environmental quality guidelines for phosphorus, the "Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems" was developed by the Canadian Council of Ministers of the Environment (CCME, 2004; Environment Canada, 2004). The framework discussed the potential of developing ecoregion-based phosphorus guidelines in the context of overall management of phosphorus in freshwater systems because regional differences exist in geology, soil, vegetation and climate and that these factors may influence water quality.

This study was initiated to investigate the feasibility of developing ecoregion-based phosphorus guidelines in Canada by using Ontario as a case study. Ontario provided a suitable combination of variation in geology, soil types, and anthropogenic influences, coupled with a good database of phosphorus measurements, to test the feasibility of developing ecoregion-based phosphorus guidelines. Nutrient data from a variety of sources was collected, assessed and screened for quality. Relationships between phosphorus and other descriptors of water chemistry were also examined. Subsequently, spatial variations in phosphorus concentrations in rivers and lakes of Ontario were identified, and the variance in phosphorus levels between and within ecozones and ecoregions was measured.

The 25th percentile classification reduced the influence of human sources and allowed for the successful classification of ecoregions on the basis of estimated reference (natural baseline) phosphorus concentrations. The data analysis identified significant variance in phosphorus concentrations in both the lake and river data-sets that could be explained by classifying them into one of three "ecozones" (Hudson Plains, Boreal Shield, and the Mixed Wood Plains) for the Province, or into the fourteen "ecoregions". The ecoregional phosphorus concentrations were within the trophic state categories proposed in the phosphorus framework.

The ecoregion concept is feasible as a means of classifying natural trophic status of lakes and rivers, and is proposed as a means of identifying "trigger ranges" in phosphorus concentration that would stimulate further assessment. However, the approach may not provide sufficient resolution of phosphorus concentrations to serve as the sole basis for nutrient management. Finer resolution may be useful to limit changes in trophic status, or to identify surface waters where phosphorus has increased by 50% above background. It may be possible to improve the resolution of the variance in phosphorus concentrations within ecoregions by incorporating data

from the bedrock and surficial geology, GIS mapping of wetlands, and lake surface and watershed areas.

The ecoregion approach is proposed as a means of estimating the reference or "background" phosphorus condition, of differentiating between natural and anthropogenic contributions to nutrient enrichment; of selecting region specific trigger ranges; and therefore contributing to improved assessment and development of management tools. The phosphorus ecoregion approach is not intended for use as the only tool in assessing and managing eutrophication. However, it is an initial screening step that managers may find useful when applying it within a tiered approach developed for managing phosphorus in surface waters.

Résumé

Une augmentation des concentrations d’éléments nutritifs dans les plans d’eau peut entraîner une croissance excessive des algues et des macrophytes et provoquer des changements visibles dans la composition des espèces. Dans certains systèmes, un excès de phosphore peut causer des fleurs d’eau de cyanobactéries, ce qui entraîne quantités de problèmes de qualité de l’eau, notamment des mortalités massives de poissons en été, de mauvaises odeurs et la contamination de l’eau potable. De plus, certaines cyanobactéries émettent des toxines qui peuvent causer la mort des animaux d’élevage et constituer une sérieuse menace pour la santé humaine.

Dans le but d’établir des recommandations pour la qualité de l’environnement visant le phosphore, le Conseil canadien des ministres de l’environnement a produit un document intitulé *Le phosphore : cadre canadien d’orientation pour la gestion des réseaux hydrographiques* (CCME, 2004; Environnement Canada, 2004). Considérant que les caractéristiques géologiques, le sol, la végétation et le climat varient d’une région à l’autre et que ces facteurs peuvent avoir un impact sur la qualité de l’eau, le cadre mentionne la possibilité d’élaborer des recommandations pour le phosphore en fonction des écorégions, dans le but d’assurer une gestion globale du phosphore dans les réseaux hydrographiques.

La présente étude avait pour objectif d’évaluer la possibilité d’établir des recommandations pour le phosphore sur la base des écorégions du Canada, en utilisant l’Ontario comme étude de cas. En plus de posséder une bonne base de données sur le phosphore, l’Ontario présentait des caractéristiques géologiques, des types de sol et des influences anthropiques suffisamment variés pour cet exercice exploratoire. Des données de différentes sources ont été recueillies, dont la qualité a ensuite été évaluée. Les liens entre le phosphore et d’autres descripteurs de la chimie de l’eau ont également été examinés. Ensuite, la variabilité spatiale des concentrations de phosphore dans les lacs et les rivières de l’Ontario a été constatée. Des différences de concentrations de phosphore ont été mesurées entre les différentes écozones et écorégions et à l’intérieur de celles-ci.

La règle du 25^{e} centile a permis de réduire l’influence des sources anthropiques et d’estimer des concentrations de phosphore de référence (concentrations jugées naturelles) pour les écorégions. L’analyse des données a mis en évidence de grandes variations dans les concentrations de phosphore, tant du côté des lacs que des rivières. Il est apparu que les concentrations variaient

d'une écozone à l'autre (plaines hudsonniennes, bouclier boréal et plaines à forêts mixtes) et d'une écorégion à l'autre (14 écorégions). Les concentrations écorégionales de phosphore entraient dans l'une ou l'autre des classes trophiques proposées dans le cadre d'orientation pour la gestion du phosphore.

Les auteurs concluent à l'effet que la notion d'écorégion est utile pour montrer l'influence du milieu naturel sur l'état trophique des lacs et des rivières et peut servir à établir des « intervalles d'intervention » dont le dépassement donne lieu à une nouvelle évaluation. Cependant, cette approche ne donne probablement pas une représentation assez précise des concentrations de phosphore pour assurer à elle seule une gestion satisfaisante des éléments nutritifs. Une meilleure résolution peut aider à limiter les changements d'états trophiques ou à identifier les plans d'eau où les concentrations de phosphore ont dépassé les concentrations naturelles de 50 % et plus. Pour avoir une représentation plus précise des différences de concentrations à l'intérieur des écorégions, il suffirait d'incorporer d'autres données – des cartes géologiques du substratum rocheux et des formations superficielles, de même que des cartes SIG des milieux humides, des lacs et des bassins versants.

L'étude propose d'utiliser l'approche par écorégion pour estimer les concentrations de référence ou « naturelles » de phosphore, pour faire une distinction entre les contributions naturelles et anthropiques à l'enrichissement des eaux en éléments nutritifs et pour établir des intervalles d'intervention adaptés à chaque région, ce qui contribuerait, en bout de ligne, à améliorer l'évaluation et le développement des outils de gestion. Il n'est pas recommandé d'utiliser cette approche comme seul outil d'évaluation et de gestion de l'eutrophisation. Les gestionnaires chargés de la gestion du phosphore dans les eaux de surface gagneraient toutefois à intégrer cette mesure d'évaluation préalable à une méthode de gestion à plusieurs étapes.

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1. Water Quality Characteristics for Lakes and Rivers in Ontario Ecoregions.

1. Introduction

Increase in nutrient concentrations (mainly phosphorus and nitrogen) in surface waters can adversely affect the ecosystem in many ways. One of the most important consequences is increased growth of algae and aquatic macrophytes and distinct shifts in species composition. The senescence and decomposition of these organisms, as well as nocturnal oxygen consumption by community respiration, create shortages in dissolved oxygen (DO) resulting in fish kills. In some freshwater systems, blooms of cyanobacteria in particular are a prominent symptom of eutrophication. These blooms contribute to a wide range of water quality problems including summer fish kills, foul odours, and tainted drinking water. Furthermore, certain cyanobacteria produce and release toxins that can kill livestock and may pose a serious health threat to humans.

Owing to these environmental concerns, phosphorus is on the list of priority pollutants for the Canadian Council of Ministers of the Environment (CCME). The CCME "Protocol for the Derivation of Guidelines for the Protection of Aquatic Life" is intended to help to protect all plants and animals that live in our lakes, rivers, and oceans by establishing acceptable levels for substances or conditions that affect water quality such as toxic chemicals, temperature and acidity. Phosphorus does not easily fit into this protocol because it is non-toxic to aquatic organisms in the forms normally present in surface waters. Secondary effects, such as proliferation of algae and aquatic macrophyte growth, blooms of toxic cyanobacteria and oxygen depletion, however, are associated with the enrichment of surface waters with phosphorus.

Currently there are no national guidelines for phosphorus, although several provinces have developed their own. Guideline development has been hampered by the need to consider the following factors that affect the nature of phosphorus as a pollutant:

a) it is non- toxic and is a required and limiting nutrient in fresh water, such that small increases stimulate aquatic productivity;

b) the detrimental effects of phosphorus are indirect, a result of algal growth and oxygen depletion and so there is a lot of variance in phosphorus concentrations associated with observed effects;

c) the effects of phosphorus on primary production are modified by natural factors that attenuate light (i.e., Dissolved Organic Carbon [DOC] or turbidity) and these also modify the expression of increased phosphorus as increased production;

d) the effects of phosphorus on surface water are aesthetic (i.e., decreased water clarity) and so determination of thresholds of effect is somewhat subjective; and

e) phosphorus concentrations in surface water can vary substantially across landscapes due to region or site specific differences in local conditions such as geology, soils, water chemistry (e.g. DOC concentration), population density and wetlands in the catchment area

These factors have been accommodated in the guidelines of several provinces, which set different numerical criteria for lakes versus rivers (i.e., Ontario, Manitoba and Quebec), guidelines that reflect natural differences in water quality (i.e., Ontario and Quebec) or guidelines that reflect water use (British Columbia). In the United States, the USEPA have elected to provide guidance to individual states for setting their own objectives. A full discussion is provided in Environment Canada (2004). In an effort to develop national environmental quality guidelines for phosphorus, Environment Canada (2004) and CCME (2004) developed a framework for the management of phosphorus. The framework offers a tiered approach where phosphorus concentrations should not (i) exceed predefined 'trigger ranges'; and (ii) increase more than 50% from 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.

The concepts of "reference levels" and "trigger ranges" for phosphorus depend on determining what these concentrations may be and how they may vary in different parts of the country. During the development and review of the phosphorus framework, the need for developing regional guidelines for phosphorus was identified. The recommendation was based on the fact that regional differences exist in geology, soil, vegetation and climate and that these factors may influence water quality. Reference water quality conditions may therefore reflect ecologically distinct areas. This concept has been adopted by various states in the U.S.A. (see below) and has been previously recommended as the basis for setting phosphorus objectives in Ontario (Hutchinson *et al*., 1991) and in the District of Muskoka, Ontario (Hutchinson, 2002). The ecoregion approach consists of grouping phosphorus data from the same general geographic areas with the assumption that water bodies in close proximity (i.e. similar geology and local inputs) will have less variability in phosphorus concentrations than those from disparate areas. The ecoregion approach is proposed as a means of estimating the reference or "background" phosphorus condition, of differentiating between natural and anthropogenic contributions to nutrient enrichment, of selecting region specific trigger ranges; and therefore contributing to improved assessment and development of management tools.

The USEPA has made substantial progress in developing recommendations for nutrient criteria for 14 main ecoregions that contain 84 Level III ecoregions. The EPA recommends empirically derived criteria to represent conditions of surface waters that are minimally impacted and are protective of aquatic life and recreational uses. Recommended steps include: physical classification of waterbodies, determination of current reference conditions, evaluation of historical data, application of models, expert judgment, and evaluation of downstream effects.

This project was initiated to investigate the feasibility of developing ecoregion based guidelines for phosphorus in Ontario's surface waters and was considered as a case study. If successful, the concept could potentially be applied across the country. This report presents data from a variety of sources that have been filtered for their quality, relationships between phosphorus and other descriptors of water chemistry, an analysis of the spatial variation in phosphorus concentrations in rivers and lakes of Ontario, an assessment of the variance of phosphorus between and within ecozones and ecoregions, discussion of other factors that influence phosphorus concentration and recommendations for next steps

1.1 Ecoregion Based Phosphorus Guidelines – Ontario Case Study

The National Guidelines and Standards Office of Environment Canada carried out an initial assessment and identified that good spatial coverage of phosphorus data are essential for developing the ecoregion based phosphorus guidelines. Ontario offers an opportunity to lead this initiative because it has a long history in phosphorus management and has collected high quality phosphorus data with good spatial coverage.

The development of an ecoregion approach is further aided by the ecoregional differences that exist in Ontario. For example, the northern Ontario ecosystems are controlled by the bedrock of the Canadian Shield with shallow soil and wetland influences, whereas southern Ontario exhibits sedimentary bedrock overlain by deep glacial and fluvioglacial soils. Nutrient concentrations in on-Shield areas are naturally low, as the underlying granitic rock throughout most of the ecozone provides little nutrients to the overlying soils and water. The southern off-Shield areas are higher in nutrients due to thick glacial soils underlying the rivers and lakes. In the Great Lakes and St. Lawrence ecozones of Ontario, agricultural runoff, municipal effluents and industrial wastewater contribute a substantial loading of phosphorus to the lakes and rivers. These areas represent areas of anthropogenic influence on phosphorus concentrations for which a different approach to defining reference conditions may be required.

Ontario therefore provides a suitable combination of variation in geology, soil types and thicknesses and anthropogenic influences, coupled with a good database of phosphorus measurements, to test the feasibility of developing ecoregion-based phosphorus guidelines. If the concept were to be successfully applied in Ontario, it could be expanded to cover other areas of the country.

1.2 Canadian Guidance Framework for Phosphorus

The phosphorus framework (CCME, 2004; Environment Canada, 2004) has proposed to use the ecoregion approach in the context of overall management of phosphorus in freshwater systems in Canada. The framework is a tiered approach, which begins with setting a goal or objective for a particular system – such as no impairment of human use and a diverse and functioning aquatic ecosystem.

Assessment of whether or not a water body is impaired requires comparison of its existing phosphorus concentration to a “trigger range” of phosphorus concentrations. The trigger ranges are based on a range of phosphorus concentrations that define the "reference condition" for the water body. The reference condition can be defined as the natural "background concentration". Background concentration is determined by measurement at relatively pristine sites, by modelling (Hutchinson, 2002), by paleoecological methods (Dixit *et al*. 1999, Hall and Smol, 1999); or by statistical analyses such as the upper 25th percentile in a sample of reference water bodies or the lower 25th percentile in a sample of reference and impacted water bodies (USEPA, 2000). The phosphorus framework (CCME, 2004; Environment Canada, 2004) recommend use of data that are specific to the water body in question or the use of percentile approach of the USEPA as the preferred means of defining the reference condition.

A trigger range is the upper limit of a desired state for the aquatic ecosystem. If it is exceeded then management action is "triggered", to define the problem and its causes and to implement solutions. For lakes and rivers, trophic status classifications have been developed as ranges of phosphorus concentrations which define the range of natural variability, and the classification of trophic status. The upper end of a range can be considered as a trigger, because water bodies that have increased to that point will shift into a more eutrophic state, further away from their reference state. The phosphorus framework provided the following classification of trophic status for lakes and rivers.

Table 1. Trophic status-based trigger ranges for Canadian waters (CCME, 2004; Environment Canada, 2004).

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

Under this classification, a water body would be placed into a reference condition of one of the trophic status classifications in Table 1. If a monitoring program showed that the trophic status of the water body was to increase to the upper end of that trigger range then management action would be warranted. The upper concentration in the trigger range therefore represents the maximum acceptable concentration of total phosphorus within each of the trophic status categories. A secondary trigger would be warranted for more sensitive water bodies, in which a 50% increase in total phosphorus above the reference condition would stimulate management action.

Under the terms of the framework, the phosphorus ecoregion approach is proposed as an initial screening tool to predict and determine reference (background) phosphorus concentrations in different regions of the country and to place water bodies in those regions into a trophic status classification. Other methods, such as direct measurement, paleoecology or modelling are more suited for site specific assessments because their implementation over large areas and over the hundreds of thousands of lakes in Ontario would require substantial resources. A phosphorus ecoregion approach, if successful, would allow water managers to apply the framework in different areas of the country to identify ecoregion-specific reference conditions and trigger ranges.

Application of the framework to the phosphorus ecoregion approach requires, at a minimum, sufficient resolution to distinguish between the trophic status classifications presented in Table 1. This would allow broad characterization of lakes or rivers into categories of trophic status. Although the framework would use the ecoregion approach to define reference conditions, it also requires ongoing monitoring, to determine whether or not a water body is approaching a trigger. Therefore, use of the framework presupposes the existence of a water quality monitoring program. The ecoregion approach may prove to be useful in determining if a lake or a river has become enriched, but the need for a monitoring program provides the opportunity to sample local water bodies (or conditions upstream) directly, as a means of establishing the reference condition.

2. Review of Different Approaches to Developing Region-Wide Phosphorus Guidelines

The phosphorus framework (Environment Canada 2004) and classification scheme presents a good initial description of ecological factors that may influence the natural or reference water quality of lakes and rivers in Ontario. The Province of British Columbia and various jurisdictions in the USA have developed ecoregion approaches. These were reviewed for their potential application to Ontario.

2.1 Aquatic Ecozone Classification for British Columbia

In 1998, British Columbia investigated the application of aquatic ecozone classifications in managing water quality. One purpose of the exercise was to provide a framework for setting water quality objectives for ecozones; smaller biophysical classifications that may be more ecologically relevant than establishing province-wide objectives. Researchers developed an “Aquatic Ecozone Classification Database” (AECD) that contained more than 300,000 records of water quality data for lakes and streams in the province.

Statistical clustering techniques were used to group the data into regions of chemical homogeneity. The initial output indicated that the amount of water quality data in the province was biased to the southern areas, with a poor distribution of data in northern areas. This uneven distribution of data made the clustering technique inconclusive.

A workshop held by limnologists, water quality and GIS specialists concluded that the classifications should be based on a Watershed Group approach. A watershed group is a precinct enclosing aquatic features at the sub-basin scale that is practical for detailed mapping of water quality characteristics. Levels of total dissolved solids (TDS), pH, alkalinity, total phosphorus (TP), true colour, total suspended solids (TDS), and turbidity were determined for each of the 245 Watershed Groups in British Columbia by overlay analysis with GIS. The workshop selected three hierarchical levels of ecozones. These included: Watershed Group (the smallest unit); Ecoregions, (several watershed groups); and Ecoprovinces, (groups of Ecoregions).

Summary tables of statistical attributes were used in combination with other reference material to describe general water quality among and within ecoprovinces. A customized ArcView 3.0 interface was developed to allow for searches of data in large or small zones of interest and to summarize data in any region to provide information on background chemical characteristics for an area of interest. The interface was intended as a tool for distribution to users of the draft aquatic ecozone classification and its database, however, the framework was not implemented.

2.2 United States Environmental Protection Agency Approach

The USEPA have adopted an ecoregion approach to assist the States and Tribes of the USA in developing specific nutrient criteria for lakes and reservoirs (USEPA, 2000). Initially, the continental US was divided into 14 separate ecoregions of similar geographic characteristics, and nutrient criteria derived for each. This approach reflects the fact that, although the lake management community generally agree on the nutrient characteristics that define water quality impairment, regional differences in soils, precipitation and geology mean that the numeric definitions of impairment may vary with ecoregion. As a result, the USEPA has not defined specific nutrient criteria for the States and Tribes to use, but have developed a process, or a framework, that can be used to set regionally specific and scientifically defensible guidelines for nutrient management. The process uses the ecoregion as a classification to help develop nutrient criteria based on designated water uses for different States as follows:

a) historic data are reviewed for quality and utility and then classified within each ecoregion;
b) reference sites within each ecoregion are compared and smaller classifications developed, if appropriate, to reduce variance within an ecoregion;

c) technical working groups at the EPA and within each region ensure consistency in classification and approach; and

d) reference conditions are combined with modelling, downstream considerations and other elements of criteria development to set regional water quality standards, either by States or Tribes, or by the EPA itself.

The following case studies were considered to be the best applications of the ecoregion concept and so were summarized from USEPA (2000).

2.3 State of Georgia Lake Specific Guidelines

In 1990 the Georgia General Assembly adopted a lake standards bill that required the Georgia Environmental Protection Division (EPD) to conduct comprehensive studies and develop quality standards for each lake with a surface area of ≥ 1000 acres. The legislation requires that a multiparameter approach for lake standards to be adopted. Numerical criteria were developed for pH, fecal coliform bacteria, chlorophyll *a*, total nitrogen, total phosphorus loading, and D.O. in the epilimnion during periods of thermal stratification. The standards for each lake take into account the geographic location of the lake within the state, the location of the lake within its watershed, and the horizontal and vertical variations of the hydrological conditions within each lake. Nutrient limits for major tributaries discharging into and emerging from the lake were also to be established.

This approach incorporates the ecoregion concept through direct measurements of lake trophic status, which will reflect the influences of the local ecosystem on trophic status. Lake specific guidelines reflect lake use and can incorporate the reference condition and trigger values. It is cost intensive, however, as it requires a dedicated monitoring, assessment and management program for each lake. It does not consider the ecoregion as an ‘a-priori” determinant of trophic status.

2.4 Ecoregional Classification of Minnesota Lakes

The state of Minnesota has over 12,000 lakes. A large portion of these lakes (98%) are within four of its seven ecoregions. Two of these ecoregions are characterized by forested regions (Northern Lakes and Forests and North Central Hardwood Forest Ecoregions), and the other two are the Northern Glaciated Plains and the Western Corn Belt Plains. Minnesota uses the ecoregions as a framework for analyzing data, developing strategies, assessing use patterns, and developing phosphorus goals and criteria for lakes.

The Minnesota Pollution Control Agency (MPCA) and other agency groups collected data on total phosphorus (TP), total nitrogen (TN), Secchi transparency, and chlorophyll *a* concentrations in 90 reference lakes between 1985 and 1987. Reference lakes were chosen to represent minimally impacted sites within each ecoregion. Criteria used in selecting reference lakes included maximum depth, surface area, fishery classification, and recommendations from the Minnesota Department of Natural Resources. In addition to the reference lake database, MPCA examined a state-wide database containing data collected by these same groups on approximately 1,400 lakes from 1977 to 1987.

Differences in TP, TKN, Secchi transparency, and chlorophyll *a* concentrations were found between lakes in different ecoregions. Lakes in forested ecoregions were deeper, smaller and had a significantly lower concentration of chlorophyll *a* than those in the plains ecoregion. Variance in water quality across the state were therefore influenced by ecoregion, land cover (forest vs. plain), soils and differences in lake morphometry.

The strength of the Minnesota approach was that the initial reference lakes were selected based on a-priori characteristics including human use, morphometry, fisheries and input from managers. This allowed for control of factors influencing trophic status and use of a standard sampling protocol, to reduce variance from factors that may not influence the expression of phosphorus on an ecoregion basis.

2.5 Wisconsin Phosphorus Criteria Development

In 1991 the Wisconsin Department of Natural Resources began the development of water quality criteria for phosphorus in lakes and impoundments. The Phosphorus Technical Workshop (PTW) was selected to develop scientifically defensible phosphorus water quality criteria. The PTW collected historical TP data from a state-wide database (STORET). The dataset was censored in the following way:

a) minimum surface area greater than 25 acres;
b) sample dates restricted to those collected between June 1 and September 15; and
c) surface water samples used were defined as samples collected from 4” or less.

The reduced dataset was further characterized by drainage type (surface drainage or groundwater seepage) and known thermal stratification patterns (mixed/stratified). The dataset was overlaid on Wisconsin’s 21 sub-ecoregions.

Evaluation of the data in the sub-ecoregions led to the conclusion that minimal data restricted the ability to accurately derive water quality criteria. Therefore, the data were grouped into larger classes representing the north, central and south regions of Wisconsin and re-evaluated. Water quality in lakes and impoundments differed between some of the regions and therefore lakes and impoundments were classified separately within each region. The data were further combined for each region by drainage type and potential for thermal stratification.

Lower quartiles of water quality were generated for each sub-ecoregion using all TP values in the censored dataset. An analysis was conducted using the lower quartile and the mean TP values to determine the proportion of water bodies in a region that would likely exceed the lower quartile estimate. Draft lake and impoundment criteria were developed based on the above analysis. A review of scientific information on phosphorus and phosphorus related impacts, however, led to conclusions that:

a) meaningful stand-alone state-wide phosphorus standards could not be developed on a state or regional-wide basis and,

b) the determination of whether lakes and impoundments have undesirable phosphorus related impacts should be made on a site-specific basis, utilizing technical information and partner input.

It was recommended that the numbers developed for use as water quality criteria be used as “triggers” or as “flags” to stimulate further action, if necessary. The PTW endorsed the use of a watershed based regulatory approach that looked holistically at water quality within the watershed and utilized partner involvement to prioritize and implement water quality initiatives within the watershed.

The Wisconsin initiative therefore represents an interesting test case. The initial assumptions regarding the ecoregion approach were tested on a dataset that was selected with a-priori knowledge of factors influencing trophic status and with the use of expert judgment. Statistical analysis showed that there were differences between ecoregions and lake type and categories were established at 5 μg/L increments in total phosphorus concentration. This represents an excellent resolution of phosphorus concentrations and a promising approach. Nevertheless, the final assessment concluded that state-wide or ecoregion-based standards were not the best approach to lake management, and that water bodies should be assessed on a site specific basis, with knowledge of their individual characteristics.

2.6 Summary

The review of applications of an ecoregion concept provided useful information to guide the evaluation for Ontario. Previous studies showed that results were most useful, and resolution of differences between ecoregions was most likely, when survey programs were designed and implemented with the expressed purpose of deriving differences between ecoregions. This allowed a stratified approach to sampling by regions, lake type, morphometry and land cover and standardization of the sampling program to reduce sources of variance. It showed that ecoregions that had been predefined (i.e., by terrestrial or landscape ecologists) were effective descriptors of trophic status and that they need not be developed or described specifically for lake management.

The review showed that the ecoregion concept is valid as a description and classification of water bodies. In spite of this, it was not adopted as the sole basis for lake management in the test cases, but used as one step of a process in which site and lake specific assessment were used as a final approach to management. This may reflect that the time and effort required to develop and implement a dedicated sampling program results in considerable specific knowledge of where the problem lakes and rivers are and what their problems may be. The test cases also acknowledged the input of lake users into defining the reference or desired lake conditions.

The case studies therefore showed that this approach can be used to draw regional assessments and provide direction to dedicated sampling programs to identify site specific characteristics. This suggests that a tiered approach to phosphorus management is useful, as proposed in the framework (Environment Canada 2004) and discussed in Section 1.2 of this report. Under these terms, the approach offered by the "Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems (Environment Canada, 2004) would provide a "Tier 1" framework for phosphorus management across the country.

Development and classification of phosphorus ecoregions would be used as "Tier 2", to predict phosphorus concentrations in different regions of the country and to place water bodies in those regions into a trophic status classification. This would allow water managers to identify ecoregion-specific reference conditions and trigger ranges.

Regional monitoring programs would comprise "Tier 3" to determine whether or not a water body was approaching a trigger for more detailed assessment.

The detailed assessment and development of management plans would take place, if required, as "Tier 4".

3. Methods

The review of case studies showed that pre-defined ecoregions could be used as a starting point for the analysis. The nature of this study was, however, to use existing phosphorus survey data instead of developing a dedicated program. This may limit the resolution that is possible, compared to that achieved in the successful U.S. and draft B.C. applications. Data sets from Ontario were sorted for lake and river and screened for obvious human influence such as known point sources.

Phosphorus surveys are often undertaken in response to known or perceived problems with water quality, or in response to public concern. As a result, most data are collected from potential "problem areas". However, this was not considered to be a significant factor for the present exercise because much of the data came from the Precambrian Shield areas of Ontario and there are no widespread indications of nutrient enrichment. Much of the data could be considered to represent baseline conditions, or any changes could be accommodated by using comparison of the 25th and the 75th percentile or other statistical approaches. In all cases, obvious human influences were removed from the dataset. For southwestern Ontario, non-point source phosphorus inputs occur from agricultural and urban land uses. In these cases, statistical approaches (i.e., use of the 25th percentile or comparison of the 25 and 75th percentile values) are considered to be acceptable methods of accounting for human sources.

Nevertheless, the 25th percentile values were selected for all comparisons, to accommodate uncertainty in the degree of human influence that was present in each dataset. The analyses also showed that the absolute concentration differences between the 25th and 75th percentile statistics were similar across all ecoregions except for southwestern Ontario. In that region, the 25th percentile concentration was only slightly higher than the equivalent statistic for other ecoregions, suggesting a slight increase in baseline. The 75th percentile, however, was 2-3 times greater than the 75th percentile value on other regions. This shows substantial relative enrichment of the waters in southwestern Ontario, compared to those elsewhere in the Province. This confirmed that use of the lower 25th percentile would accurately reflect baseline conditions across the Province. This is discussed further in Section 5.2.

3.1 Data Sources

Water quality data for Ontario lakes and rivers were obtained primarily from the various programs of the Ontario Ministry of the Environment (MOE). Data were provided for lakes in the Algoma Region from Environment Canada, and for two river sites in the James Bay Lowlands from the Environmental Baseline Study submitted in support of the Environmental Assessment for the Victor Diamond Project by DeBeers, Canada (DeBeers, 2004). Access to water quality modelling that was completed by Gartner Lee Limited for the District Municipality of Muskoka was provided by the District Municipality of Muskoka. The co-operation of all of these parties is gratefully acknowledged.

A summary of all data that were used for this report is provided as text and Excel files on a CD-ROM.

The Ontario Ministry of the Environment maintains an extensive database of water quality measurements obtained through:

a) the Provincial Water Quality Monitoring Network (PWQMN) which maintains a record of samples taken approximately monthly from a variety of sites (generally from rivers or lake outflows) across the province;

b) the "Lake Partner" program of the Ontario Ministry of the Environment, in which lake residents sample phosphorus once each year during the spring overturn period; and

c) various research programs over the years, such as the Lakeshore Capacity Study and the Acidic Precipitation in Ontario Study.

The various agencies were contacted to provide information. They were requested to provide data in electronic format, annual average phosphorus concentrations (indicating the number of samples) for phosphorus data that has been collected since 1985. The date of 1985 was chosen to reflect current analytical methods. The diversity of the data sets provided, and the need to maximize the amount of data used meant that all data were accepted, regardless of the number of samples or years of data it included. Data were screened, however, for typographic errors and known point sources.

The database also included the dates samples were collected; and UTM co-ordinates or latitude and longitude of the sampling locations. To further aid in interpretation, lake/river names; lake surface area; dissolved organic carbon (DOC), alkalinity (alk), calcium (Ca), conductivity (cond), magnesium (Mg) and total Kjeldahl nitrogen (TKN) concentrations; location of sample (surface or euphotic zone); and detection limits for the method used to measure phosphorus were also requested. It was hoped that other water chemistry data would aid in interpretation of the phosphorus data but, in the end, there were not enough lakes or rivers represented in each part of the Province to make detailed analysis productive.

Through the “Lake Partner” program, the Dorset Environmental Science Centre was able to provide annual average TP, Ca, Mg, conductivity and alkalinity data for 939 lakes and rivers in Ontario. The Ministry of the Environment’s Provincial Water Quality Monitoring Network (PWQMN) provided TP data for 1143 lakes and rivers in Ontario, in addition to data on Ca, conductivity, alkalinity, and DOC. The Eastern Region of the Ministry of the Environment provided TP, TKN, conductivity, alkalinity and DOC levels for 144 lakes in eastern Ontario. The 1986 MOE acid precipitation survey of northwestern Ontario lakes and streams was provided in hard copy by MOE’s Northern region (D. Hollinger) and was transferred to an electronic format by Environment Canada. This survey provided data on TP, Ca, conductivity, and colour for 477 lakes and 19 rivers.

Environment Canada provided TP, TKN, Ca, Mg, alkalinity and DOC data for two lakes of the Turkey Lake Watershed located near Sault Ste. Marie. Data on TP, Ca, Mg, alkalinity and conductivity for two rivers in the James Bay Lowlands were obtained from the draft Environmental Assessment Report for the Victor Diamond Project in the James Bay Lowlands. (DeBeers Canada, 2004). Table 2 provides a listing of all of the data sources for the project.

Table 2. Data sources for ecoregion based phosphorus guidelines for Ontario.

	PWQMN MOE	Lake Partner MOE	Northwestern Region MOE	Eastern Region MOE	Turkey Lakes EC	DeBeers
Data	TP	TP, Ca, Mg,	TP, Ca,	TP, TKN,	TP, TKN,	TP, Ca,

Provided		Cond, and Alk	Cond, Colour	Cond, Alk, and DOC	Ca, Mg, Alk, and DOC	Mg, Cond, and Alk
Number of Sites	1143 Lakes and Rivers	939 Lakes and Rivers	477 lakes 19 Rivers	144 Lakes	2 Lakes	2 Rivers

3.2 Data Editing

After the datasets from all sources were compiled the data were assessed for anthropogenic influences. Two data editing routines were followed. The first focussed on sites downstream of cities, landfills, sewage treatment plants, pulp and paper mills, mines, and other industrial or point source influences. The station description file for the MOE PWQMN dataset identified sites where the data were potentially influenced by these sources and these stations were removed from the dataset. In the second, a GIS georeferenced interpretation program was used to identify extreme values and outliers. These were assessed visually based on the magnitude of their values and expert opinion, and removed from the dataset. The edited dataset was used as the basis for subsequent analyses. Figure 1 shows the spatial distribution of phosphorus data in the province of Ontario.

After the data exploration, the data was distinguished between lakes and rivers. Across Ontario, 1433 lakes, and 948 rivers were represented in the dataset. Data were then plotted as a 3-dimensional representation of latitude and longitude of the location and the measured phosphorus concentrations. Figure 2 shows the result of this analysis. The geographic representation shows a solid spatial coverage across most of the province, a paucity of data in northern Ontario and a clear trend to high concentrations in southwestern Ontario.

4. Classification of Data

The intent of classification is to identify groups of lakes or rivers that have comparable characteristics (i.e., biological, ecological, and physical) that may form the basis of the ecoregions. Two approaches to classification were considered.

The first was to complete an *a-priori* statistical analysis of the data to reveal any clusters of similar phosphorus concentrations and then to explore and describe the ecological characteristics that distinguished or explained clusters of similar data. This is the approach that was used by the Province of British Columbia. The second approach is that which was followed in the case studies from the United States that were reviewed in Section 2 – that is to use pre-defined ecological regions and to test for statistical differences in phosphorus concentrations between them.

The second approach was chosen for this study. The Province of Ontario has been classified into discrete ecological units. These units were defined by many of the same characteristics that influence natural phosphorus concentrations in surface waters and have been used for classification across the country. There is a framework in place to apply the ecoregion approach across the country. This is described in the following section.

4.1 National Ecological Framework for Canada

In the late 1970s and early 1980s, the Canada Committee on Ecological Land Classification (CCELC) developed a hierarchical ecological classification of Canada, with seven levels of generalization. From the broadest to the smallest, they are: ecozones, ecoprovinces, ecoregions, ecodistricts, ecosections, ecosites and ecoelements. Ecozones are representative of large and very generalized units characterized by interactive and adjusting abiotic and biotic factors. Ecoregions are subdivisions of the ecozone characterized by distinctive large order landforms or assemblages of regional landforms, small order macro- or mesoclimates, vegetation, soils, water, and regional human activity patterns/uses.

For this exercise the data were classified based on the existing ecological framework for Canada and Ontario. Environment Canada's *National Ecological Framework for Canada* (Marshall and Schut, 1999) classified ecozones and ecoregions based on geologic, hydrologic, climatological and vegetational differences. These factors vary substantially across the Province of Ontario and were identified in the case studies (Section 2.0) as those physical and ecological factors that were important in defining the natural nutrient status for rivers and lakes. Therefore, even if the first approach of developing statistical associations was chosen, it would ultimately still require review and evaluation of the same or similar physical and ecological factors to explain the associations.

Use of the Environment Canada National Ecological Framework was also considered important in the long range exercise of applying the phosphorus ecoregion concept nationally. Use of nationally defined ecozones and ecoregions provides the framework for national consistency and allows for future amalgamation of the approach with datasets from other provinces. The following provides a summary of the National Ecological Framework for Canada and was taken from Marshal and Schut (1999).

- **Ecozone**

  Ecozones define the ecological mosaic of Canada on a sub-continental scale. They represent an area of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors. Canada is divided into 15 terrestrial ecozones.

- **Ecoprovince**

  A subdivision of an ecozone is characterized by major assemblages of structural or surface forms, faunal realms, and vegetation, hydrology, soil, and macro climate**.** Canada is divided into 53 Ecoprovinces.

- **Ecoregion**

An ecoregion is a subdivision of an ecoprovince and is characterized by distinctive regional ecological factors, including climate, physiography, vegetation, soil, water, and fauna. Canada is divided into 194 ecoregions.

- **Ecodistrict**

An Ecodistrict is a subdivision of an ecoregion which is characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna. Canada is divided into 1024 Ecodistricts.

4.2 Classification for Ontario

The compiled dataset for total phosphorus was therefore classified into three ecozones and further divided into the eighteen ecoregions within the Province of Ontario. Further subdivision into smaller elements was considered but was rejected because such subdivision would reduce the number of data points within each element and limit the utility of the analysis. Classification by ecozone and ecoregion provided the best balance between ecological detail and the amount of data available to test for differences.

The province of Ontario is broken into three ecozones: the Hudson Plains, Boreal Shield and the Mixed Wood Plains, and eighteen ecoregions. These are: Coastal Hudson Bay Lowland, Hudson Bay Lowland, James Bay Lowlands, Abitibi Plains, Hayes River Upland, Big Trout Lake, Lac Seul Upland, Lake of the Woods, Rainy River, Thunder Bay-Quetico, Lake Nipigon, Lake Temiscamingue Lowland, Algonquin-Lake Nipissing, St-Laurent Lowlands, Frontenac Axis, Manitoulin-Lake Simcoe, Lake Erie Lowlands and the Southern Laurentians. Figure 3 presents the ecozones and ecoregions of Ontario.

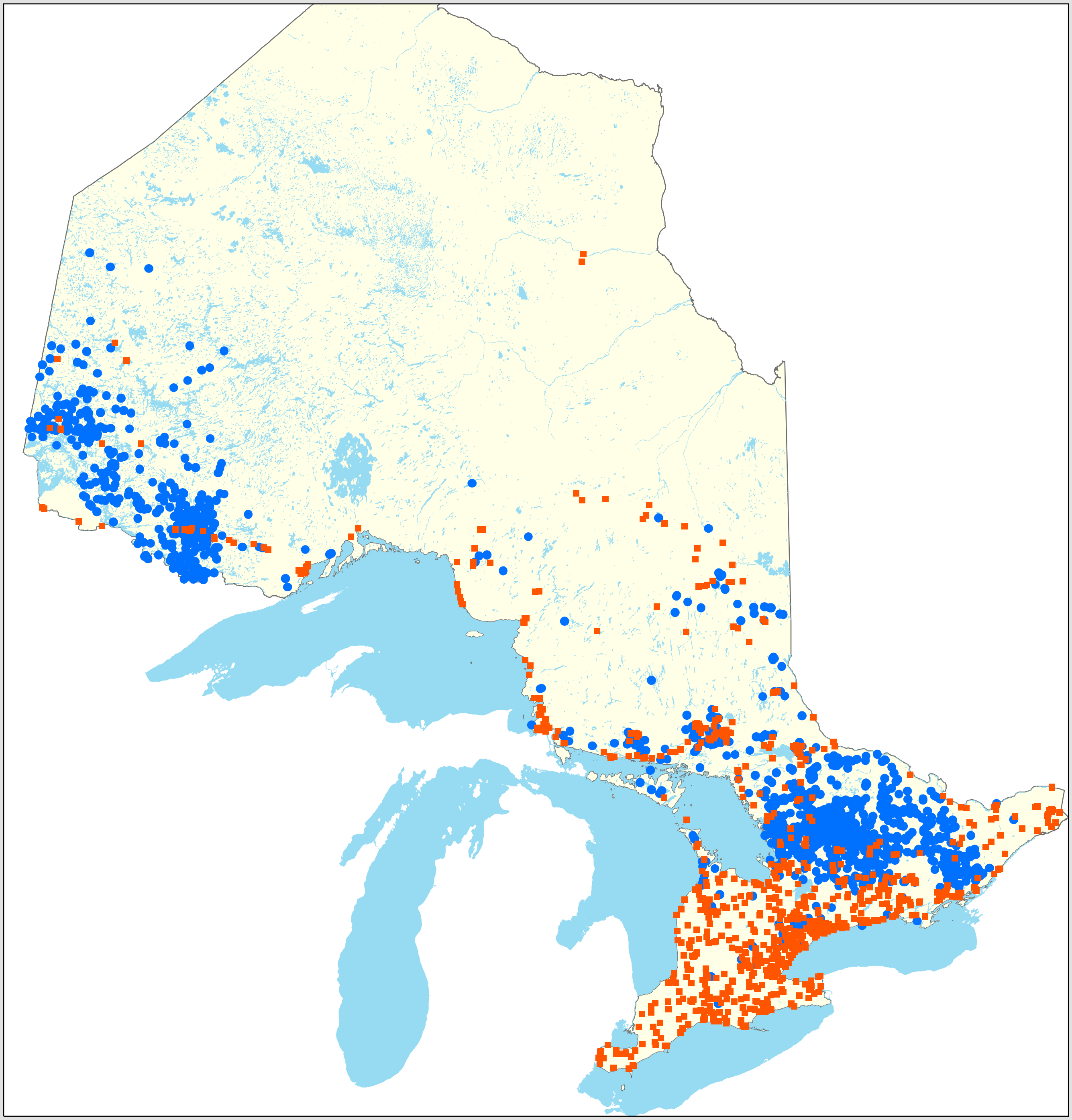
5. Data Analysis

Data on phosphorus concentrations were first summarized and reviewed for Ontario's three ecozones and then for the 18 ecoregions.

5.1 Ontario Ecozones

Phosphorus data were available for all three Ontario ecozones (Boreal Shield, Mixed Wood Plains, and Hudson Plains). The data, however, were not evenly distributed throughout the province. Much of it was located in central Ontario in the Boreal Shield Ecozone. Of the 1433 lake sites for which data were available, 1315 were from the Boreal Shield. The Mixed Wood Plains Ecozone was not as well represented and had data for only 113 surveyed lakes. No data were available for lakes in the Hudson Plains Ecozone.

The large lake TP dataset in the Boreal Shield Ecozone reflects the large numbers of lakes in this region (compared to the Mixed Wood Plains Ecozone), past monitoring programs to assess sensitivity to acid deposition, and its status as Ontario's "Cottage Country" where MOE's "Lake Partner" program co-ordinates volunteer efforts to monitor water quality in recreational lakes. Lakes in northern Ontario (Hudson Plains) are not as readily accessible or populated compared to the lakes in the Boreal Shield and Mixed Wood Plains, and therefore no data were available for this region.



Legend

- Lake Data
- River Data

Ecoregion Based Phosphorus Guidelines for Ontario

Figure 1

Locations of Phosphorus Data in Ontario

Project 50031, July 2005

Gartner Lee Limited

0 50 100 200 Km

1:9,000,000

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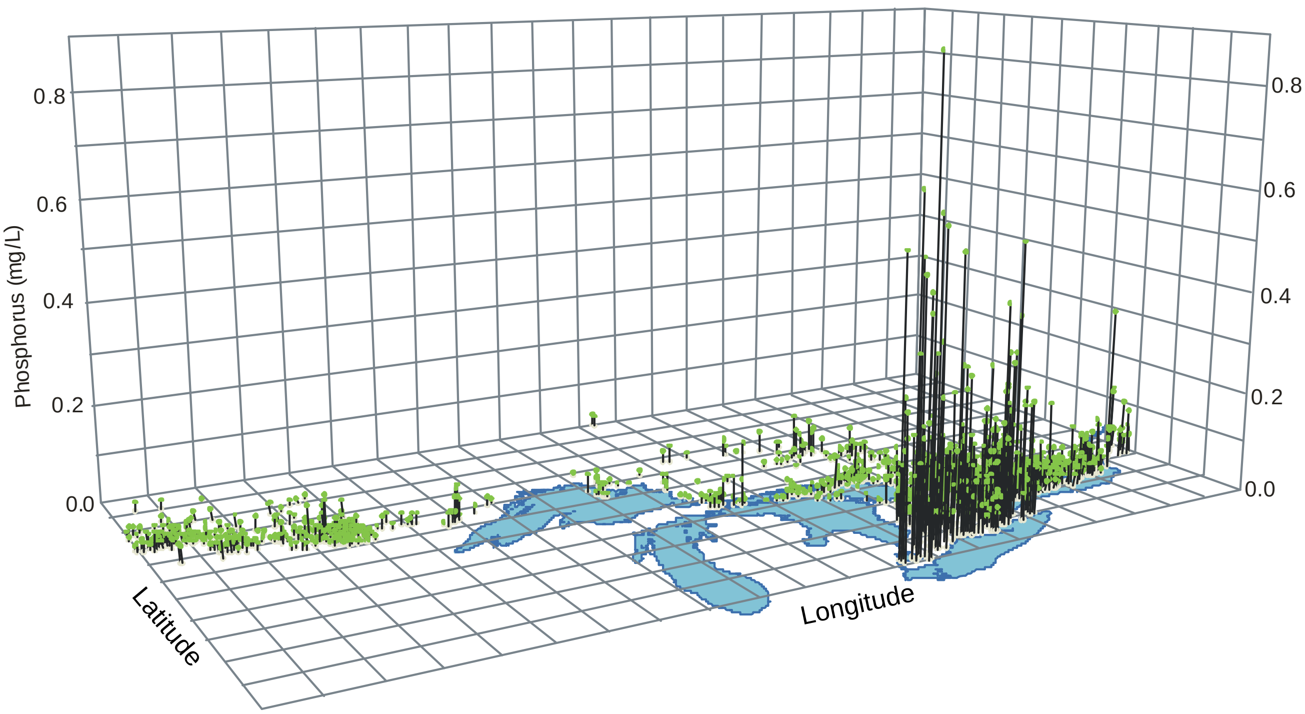
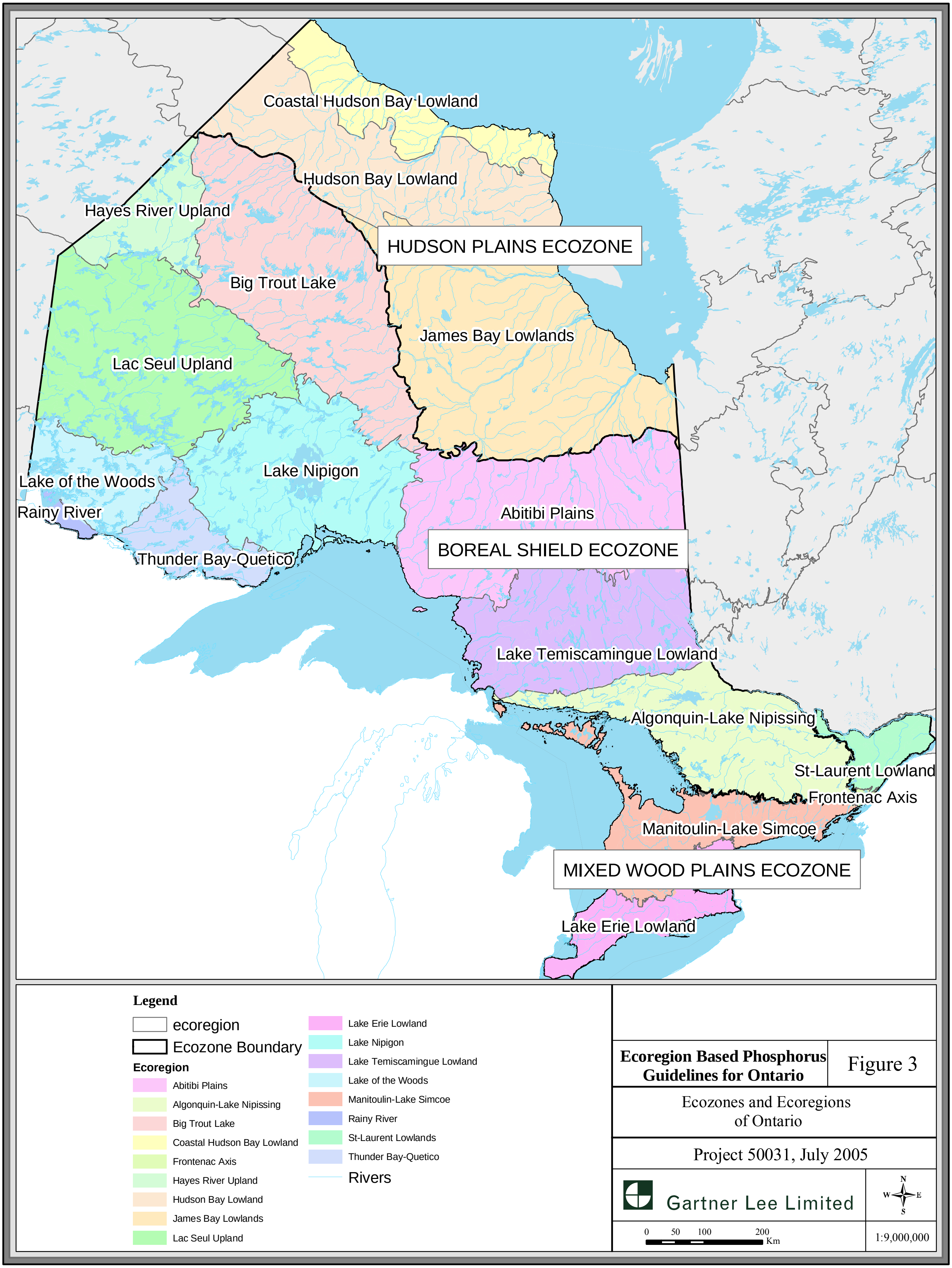


Spatial Distribution of Phosphorus Concentration in Ontario	**Phosphorus Data Spatial Trend**	Figure 2
	Phosphorus by Ontario Ecoregions	
	Project 30024, July 2005	
	Gartner Lee Limited	



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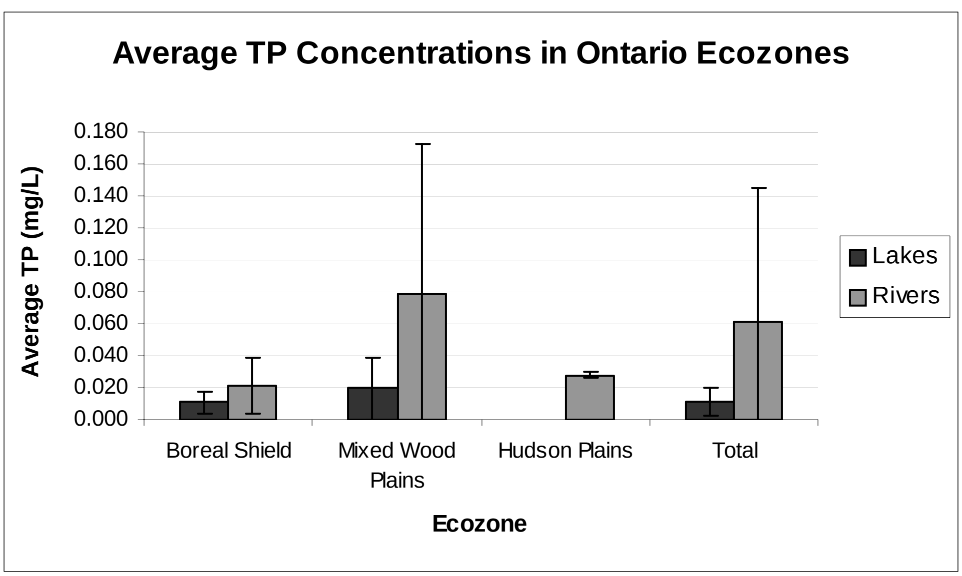
For rivers, TP data for the Mixed Wood Plains was available for 667 rivers and creeks in Southern Ontario. Data were available for 279 riverine sites on the Boreal Shield, and for two in the Hudson Plains. Much of the riverine data was obtained through MOE’s PWQMN, which monitors sites in Southern Ontario. Many of these sites are associated with areas of high population density or specific anthropogenic influences and so are monitored regularly. Only sites upstream of known direct discharges or point sources were incorporated into the dataset (see Section 3.2).

5.1.1 TP analysis

Lake and riverine TP data were summarized as the mean, standard deviation, minimum, maximum, and 25 and 75% quartiles for the entire province and for each of the three ecozones. Results are presented in Table 3, and graphically in Figure 4. The overall average in TP concentration for Ontario Lakes in the dataset was 0.011 mg/L but concentrations ranged from 0.001 to 0.162 mg/L. The distribution of phosphorus concentrations was also summarized following classification scheme for trigger ranges (Figure 5) that was provided in Table 1.

In the Boreal Shield, the concentration of phosphorus in lakes ranged from 0.001 to 0.079 mg/L, averaging 0.011 mg/L. In the Mixed Wood Plains ecozone of Southern Ontario, the phosphorus concentrations were more variable, and ranged from 0.004 to 0.162 mg/L, averaging 0.020 mg/L.

Figure 4. Average total phosphorus concentrations in Ontario ecozones.

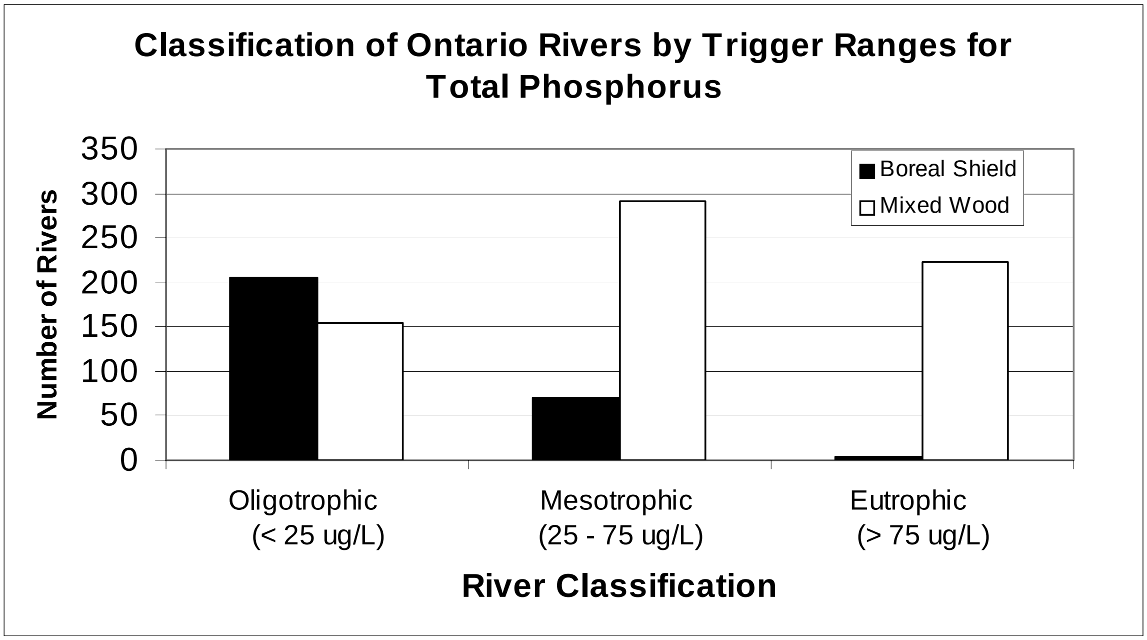


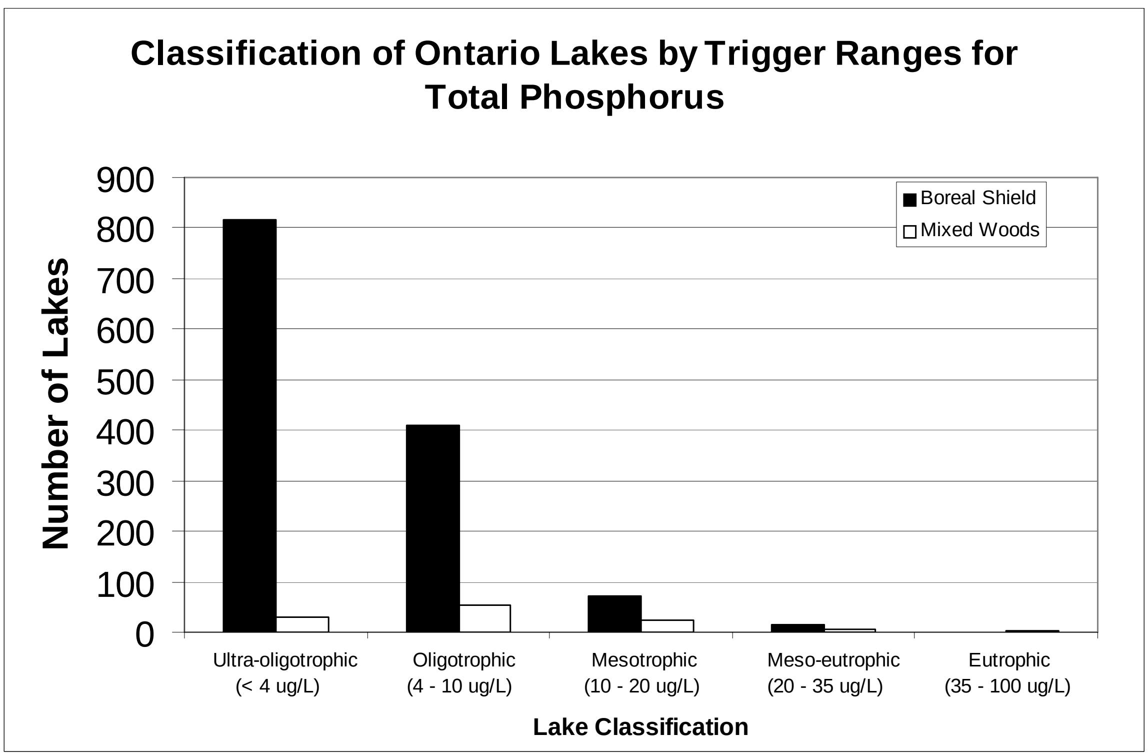
Note: Error bars represent one standard deviation above the average concentration.

Table 3. **Water quality characteristics for lakes and rivers in Ontario ecozones.**

Ecozone		Lakes					Rivers				
		TP	Alk	Cond	Ca	DOC	TP	Alk	Cond	Ca	DOC
Boreal Shield	average	0.011	19.2	76.7	5.9	3.9	0.021	36.2	283.4	25.1	7.7
	stdev	0.007	27.8	132.7	9.3	1.2	0.017	27.5	476.6	39.3	4.5
	count	1315	719	1050	731	10	279	207	270	131	83
	min	0.001	0.1	14.0	0.9	1.0	0.002	0.1	27.0	2.2	1.6
	max	0.079	199.0	2872.2	208.0	4.9	0.128	141.0	3597.0	268.8	23.0
	25%ile	0.007	3.5	30.9	2.8	3.7	0.010	16.9	67.4	6.1	5.0
	75%ile	0.013	20.8	78.0	5.9	4.7	0.027	50.4	234.4	26.6	8.6
Mixed Wood Plains	average	0.020	104.1	229.3	31.7	5.4	0.079	189.4	598.3	68.4	4.9
	stdev	0.019	46.2	81.5	10.4	2.0	0.093	47.2	338.0	30.7	2.6
	count	118	44	48	31	8	667	381	663	522	274
	min	0.004	10.4	45.8	5.4	3.1	0.004	23.6	49.0	0.0	1.2
	max	0.162	224.0	436.0	48.6	10.0	0.902	293.5	5750.0	477.0	20.0
	25%ile	0.010	77.9	200.6	30.6	4.7	0.027	175.2	453.6	57.2	3.2
	75%ile	0.023	134.2	290.3	36.7	5.2	0.092	219.1	670.4	80.5	5.9
Hudson Plains	average						0.028	78.5	168.0	25.1	
	stdev						0.001	20.9	76.9	5.8	
	count	0	0	0	0	0	2	2	2	2	0
	min						0.027	63.7	113.6	20.98	
	max						0.029	93.3	222.4	29.14	
	25%ile										
	75%ile										
Province Wide	average	0.011	24.1	83.4	7.0	4.5	0.062	135.3	506.4	59.6	5.6
	stdev	0.009	35.3	134.6	10.7	1.8	0.083	84.0	408.7	36.9	3.3
	count	1433	763	1098	762	18	948	590	935	655	357
	min	0.001	0.1	14.0	0.9	1.0	0.002	0.1	27.0	0.0	1.2
	max	0.162	224.0	2872.2	208.0	10.0	0.902	293.5	5750.0	477.0	23.0
	25%ile	0.007	3.6	31.0	2.8	4.1	0.019	43.6	235.7	36.1	3.4
	75%ile	0.013	25.8	87.0	6.4	4.9	0.071	209.9	633.6	78.5	6.4

Figure 5. **Classification of Ontario lakes and rivers within each ecozone by Environment Canada trigger ranges for total phosphorus.**





5.1.1.1 Average Concentrations

Within each ecozone, phosphorus concentrations were higher in rivers and creeks than in lakes and the differences were significant ($p < 0.000001$). The TP ranged from 0.002 to 0.128 mg/L, and averaged 0.021 mg/L in Boreal Shield streams. In the Mixed Wood Plains, the average TP concentration was greater and ranged from 0.004 to 0.902 mg/L, averaging 0.079 mg/L. In the Hudson Plains, only two data points were available, concentrations were 0.027 and 0.029 mg/L. Higher concentrations in rivers reflects the fact that the residence time for water in lakes is much greater than that in rivers, such that phosphorus settles to the bottom of lakes and is retained in the sediments. Any ecoregion approach to establishing reference phosphorus concentrations must therefore accommodate this difference, as has been done by various jurisdictions (i.e., Ontario) when setting different water quality objectives for phosphorus in rivers and lakes.

The average TP concentrations of lakes and rivers in Ontario differed between ecozones. The hypothesis was tested using a One Way Analysis of Variance (ANOVA), with a significance level of 0.05 and differences between zones were tested using a z test for differences between means. The analysis determined that ecozone was a significant source of variation in phosphorus concentrations. The average TP concentration of lakes (Table 3) in the Boreal Shield differed from the average TP concentration for lakes in the Mixed Wood Plains ecozones ($p < 0.00001$). River analysis showed similar results, as ecozone was a significant ($p <0.00001$) source of variation in TP concentration in rivers. The differences in average TP concentrations of rivers in the Boreal Shield, Mixed Wood Plains, and Hudson Plains (Table 1) were significant ($p < 0.00001$).

Phosphorus concentrations were significantly higher in lakes and rivers in the Mixed Wood Ecozone than in the Boreal Shield Ecozone. This reflects the thicker soils and calcareous geology in the Mixed Wood Ecozone, but the difference may also reflect greater anthropogenic activity in the mixed wood ecozone. Trigger ranges can be set using the 75^{th} percentile in a sample of reference water bodies or the 25^{th} percentile in a sample of reference and impacted water bodies (USEPA, 2000). It was not possible, however, to confirm the presence or absence of human inputs for the dataset used in this study. We therefore assumed that both data from both ecozones included reference and impacted water bodies and so classified the ecozones using the 25^{th} percentile statistic.

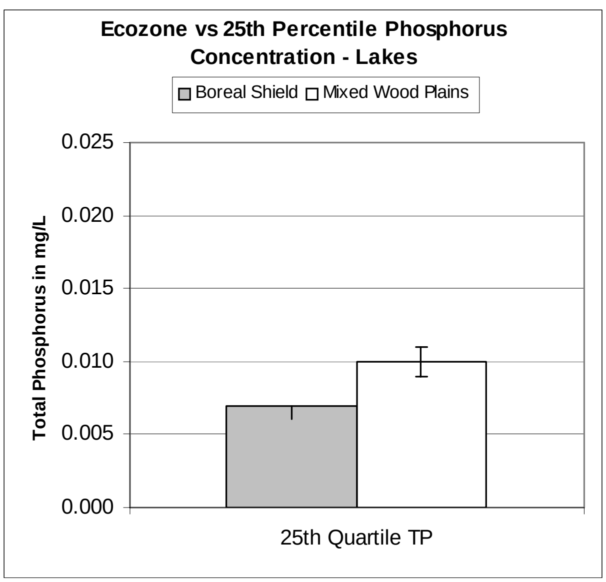
5.1.1.2 25^{th} Percentile Concentrations

Use of both the 25^{th} and 75^{th} percentile phosphorus concentrations showed significant and distinct differences in phosphorus concentrations between ecozones (Figures 6 and 7). Confidence intervals were calculated and tests of significance completed using non-parametric methods and a normal approximation of a binomial distribution (USGS, 2002).

For lakes (Figure 6), the 25th percentile concentrations of 0.007 mg/L and 0.010 mg/L for the Boreal Shield and Mixed Wood Plains respectively were significantly different ($p<0.05$). This is a slight difference, and compares with a near two-fold difference for average and 75th percentile concentrations (Table 3), suggesting that average and 75th percentile concentrations may reflect human influence in the more populated and developed Mixed Wood Ecozone. The relative differences may also be skewed by the small sample size (44 measurements) for lakes in the Mixed Wood Ecozone, compared to 1315 measurements for lakes in the Boreal Shield.

For rivers (Figure 7), the 25th percentile concentrations of 0.010 and 0.027 mg/L for the Boreal Shield and Mixed Wood ecozones, respectively, were also significantly different ($p<0.05$). For rivers, the 75th percentile concentration for the heavily populated Mixed Wood ecozone was nearly four times greater than the 75th percentile for the less developed Boreal Shield. The 25th percentile values differed by approximately two fold. This smaller differential suggests that the 25th percentile is a valid description of the natural baseline concentration for the ecozones.

Figure 6. 25th and 75th percentile phosphorus concentrations for lakes in the Boreal Shield and Mixed Wood ecozones.



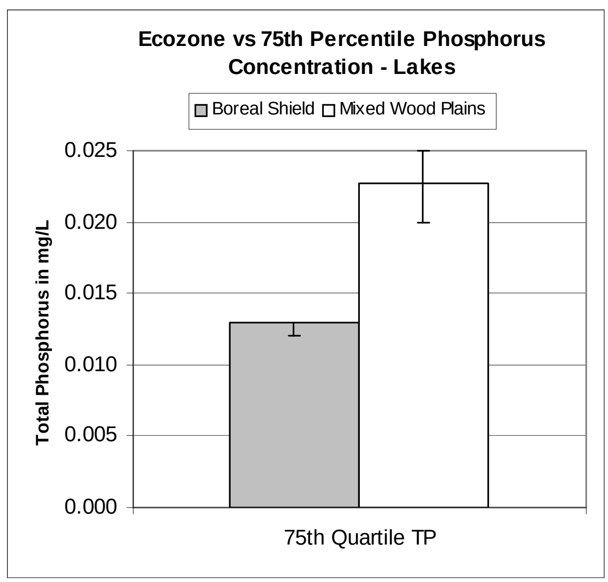
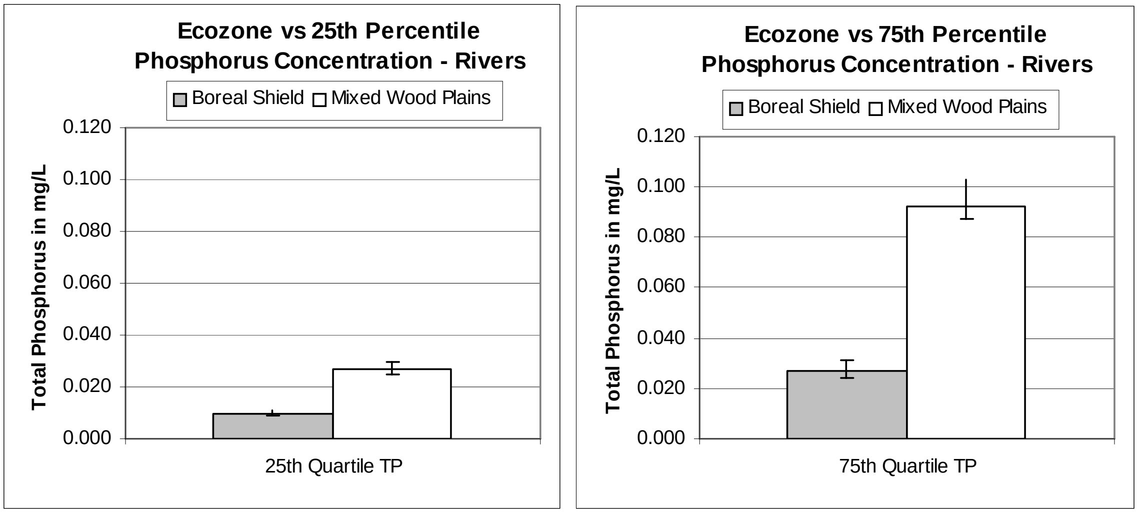


Figure 7. 25th and 75th percentile phosphorus concentrations for rivers in the Boreal Shield and Mixed Wood ecozones.



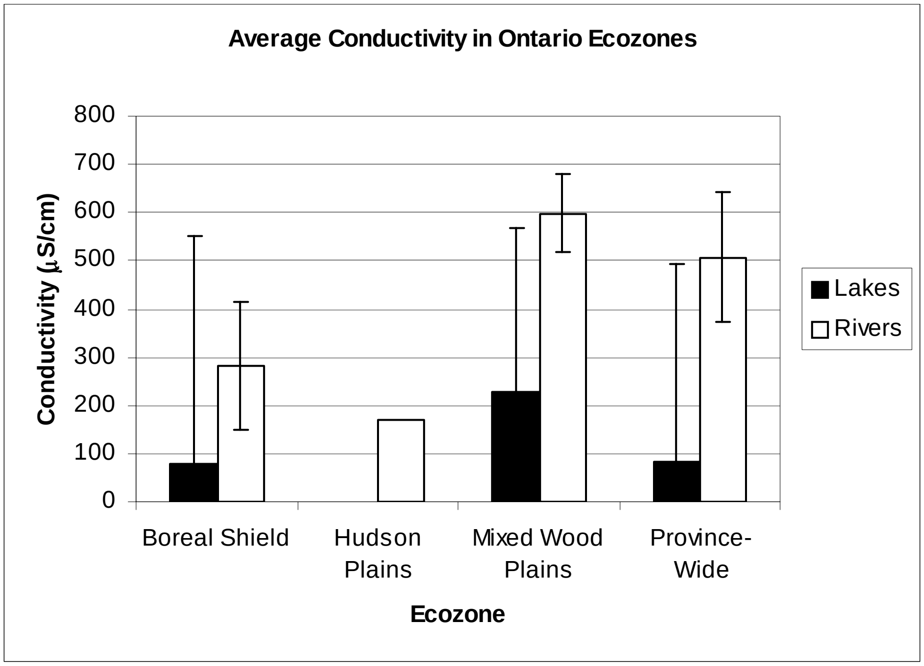
Use of the 25th percentile approach to setting triggers in ecozones was therefore able to distinguish between the two major ecozones of Ontario. The low 25th percentile phosphorus concentrations and comparison of the relative differences between the 25th and 75th percentiles for each ecozone suggest that the 25th percentile statistic did not include many data points that were significantly elevated by human activities. Although the approach appeared sensitive to sample size, it was carried forward for subsequent analysis at the ecoregion level.

In summary, classification of Ontario lakes and rivers allowed discrimination of significant differences in phosphorus concentrations at the ecozone level of classification. The analysis was therefore carried forward to the ecoregion level (Section 5.2) to improve the resolution of differences within the province.

5.1.2 Calcium and Conductivity Analysis

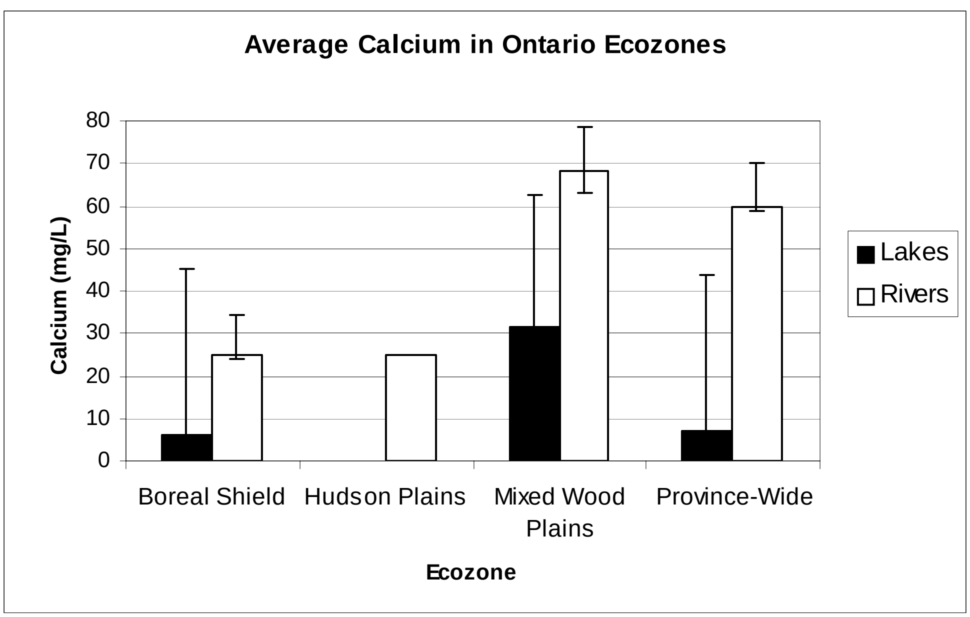
Calcium and conductivity concentrations in surface waters are related to the underlying geologic materials and soils and not to human influences, with the exception of road salt runoff which will influence conductivity in populated areas. The existence of similar relationships of these indicators with ecozones as was observed for total phosphorus would suggest that the underlying influence of ecozone on total phosphorus (Section 5.1.1) was due to geologic differences. The dataset was reviewed and the relationship between ecozones, and calcium and conductivity was tested. A statistical summary of the dataset (for all cases where data for total phosphorus data were also available) is presented in Table 3, and graphically in Figures 8 and 9.

Figure 8. Average conductivity concentrations in Ontario ecozones.



Note: Error bars represent one standard deviation above the average concentration.

Figure 9. Average calcium concentrations in Ontario ecozones.



Note: Error bars represent one standard deviation above the average concentration.

The average conductivity of the Boreal Shield rivers was significantly lower ($p < 0.0001$) than that calculated for rivers in the Mixed Wood Plains ecozone. In the Boreal Shield rivers, the conductivity ranged from 27 to 3597 μ*S*/cm; and averaged 283 μ*S*/cm. In the Mixed Wood Plains, conductivity ranged from 49 to 5750 μ*S*/cm, averaging 598 μ*S*/cm.

In the Boreal Shield, the average conductivity of lakes was significantly lower ($p < 0.0001$) than that calculated for rivers. The average conductivity for Boreal Shield lakes was 77 μ*S*/cm, ranging from 14 to 2,872 μ*S*/cm and was significantly lower than the average of 283 μ*S*/cm (range 27 to 3,597 μ*S*/cm) for rivers in the Boreal Shield. Conductivity in the Mixed Wood Plains lakes (average = 229 μ*S*/cm, range = 46 to 436 μ*S*/cm) was also significantly lower than that calculated for rivers in the same ecoregion, which averaged 598 μ*S*/cm and ranged from 49 to 5750 μ*S*/cm.

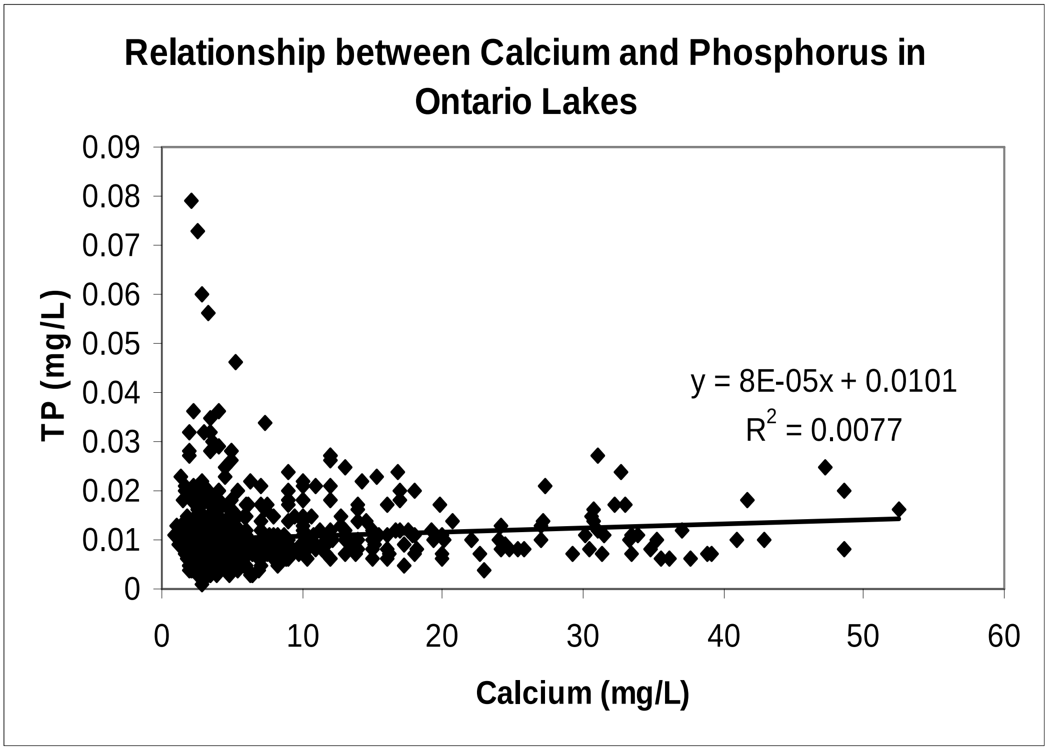
The average calcium concentration of rivers in the Boreal Shield was significantly lower than that measured in rivers of the Mixed Wood Plains. In the Boreal Shield, calcium concentrations ranged from 2 to 269 mg/L, averaging 25 mg/L. In the Mixed Wood Plains, calcium concentrations ranged from 6.5 to 477 mg/L, averaging 68 mg/L. The average calcium concentration of lakes was significantly lower in the Boreal Shield, 6 mg/L, and concentrations ranged from 1 to 208 mg/L. In the Mixed Wood Plains, the average calcium concentration was 32 mg/L, and ranged between 5 and 49 mg/L.

The three ecozones of Ontario, as defined by Environment Canada, exert a significant and consistent influence on water quality in rivers and lakes, as shown by concentrations of calcium and conductivity. The patterns are the same as those described for phosphorus and suggest a consistent geologic influence on water quality differences between ecozones.

Regression analysis of the relationship between geology (as indicated by calcium and conductivity) and trophic status (total phosphorus) showed, however, that there was no significant relationship between the two for lake-to-lake or river-to-river comparisons. This is likely a result of a) the wide ranges of calcium and conductivity observed within each ecozone) and b) other natural and human factors that exert a stronger influence on total phosphorus concentrations than geology.

Calcium explained less than 1% of the variance in lake phosphorus concentrations and < 4% of the variance for rivers (Figure 10). Conductivity explained less than 3% of the variance in lake phosphorus concentrations and less than 1% of the variance in rivers (Figure 11). Therefore, although there appears to be a consistent and broad effect of ecozone on conductivity, calcium and phosphorus; the relationship is not strong enough to warrant a focused investigation, nor to account for calcium and conductivity in the ecoregion framework. As a result, the rest of this document focuses only on phosphorus.

Figure 10. Relationship between calcium and phosphorus in Ontario lakes (top) and rivers (bottom).



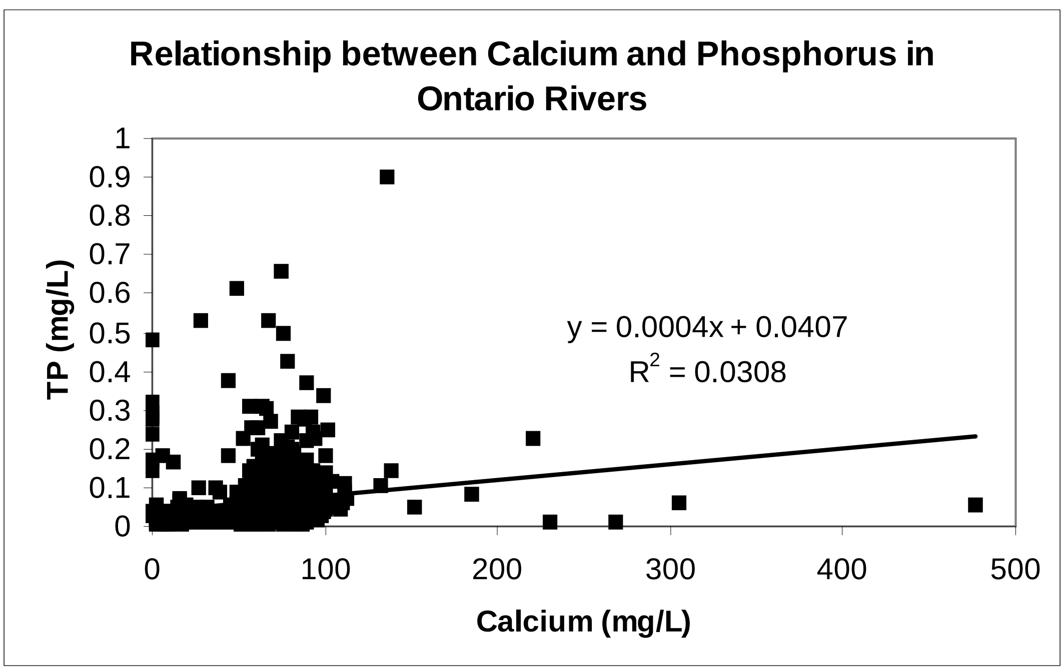
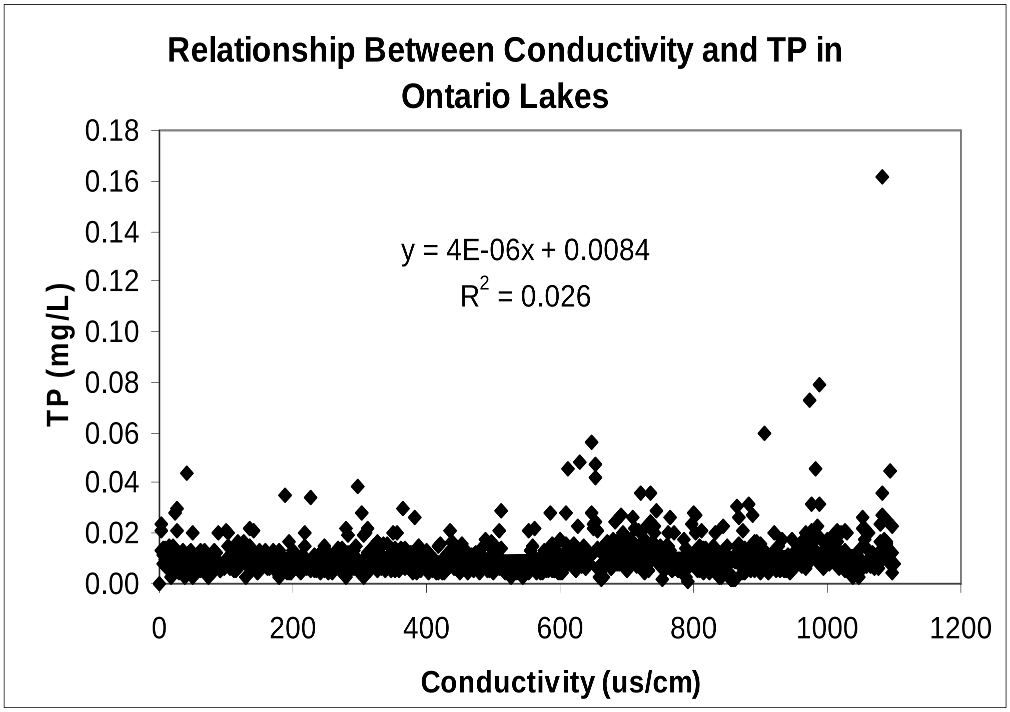
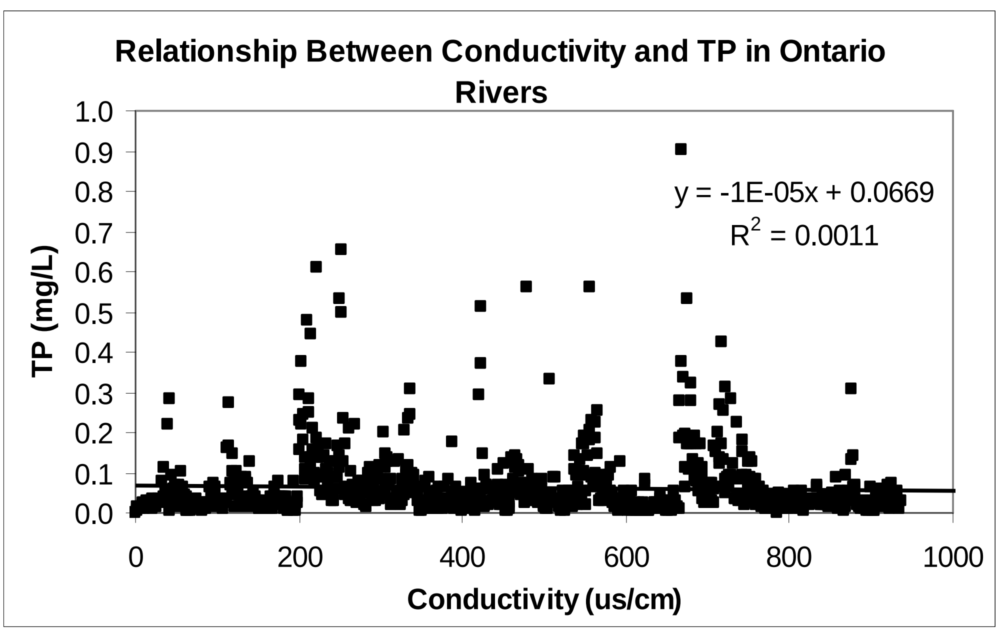


Figure 11. Relationship between conductivity and phosphorus in Ontario lakes (top) and rivers (bottom).





5.2 Phosphorus in Ontario Ecoregions

There was significant variance in the concentrations of phosphorus measured in lakes and rivers between the Mixed Wood and Boreal Shield ecozones in the Province of Ontario. Phosphorus concentrations were approximately twice as high in lakes and four times as high in the rivers of the Mixed Wood Ecozone. These results support use of the ecoregion approach and so the analysis was repeated at the finer scale of resolution of the 18 ecoregions defined for Ontario.

Fourteen Ontario ecoregions were represented with TP data in the dataset. These included: James Bay Lowlands, Abitibi Plains, Lac Seul Upland, Lake of the Woods, Rainy River, Thunder Bay-Quetico, Lake Nipigon, Lake Temiscamingue Lowland, Algonquin-Lake Nipissing, St-Laurent Lowlands, Frontenac Axis, Manitoulin-Lake Simcoe, Lake Erie Lowlands and the Southern Laurentians.

The data were not evenly distributed throughout all ecoregions. Much of the data came from central Ontario in the Boreal Shield Ecozone. Of 1433 lake sites used in the study, 871 were located in the Algonquin-Lake Nipissing Ecoregion. This reflects the popularity of this area as "Cottage Country", the number of "Lake Partner" sampling sites in this region and monitoring programs for acidic deposition. Lake of the Woods, Thunder Bay-Quetico, and Manitoulin-Lake Simcoe were also well represented with 145, 184, and 83 lakes respectively in the TP database. This again reflects the number of recreational lakes in the region, as well as dedicated surveys of water quality in northwestern Ontario that were carried out by MOE's Northern Region.

None of the three ecoregions within the Hudson Plains ecozone (Coastal Hudson Bay Lowland, Hudson Bay Lowland, and James Bay Lowland) were represented with lake sites. Lake data were available for all ecoregions within the Mixed Wood Plains ecozone. Within the Boreal Shield Ecozone, no data existed for lakes in the Southern Laurentians and Rainy River Ecoregions.

More ecoregions were represented with riverine sites, but in many (Lac Seul Upland, Lake Nipigon, Lake of the Woods, Southern Laurentians, Rainy River, Frontenac Axis, and James Bay Lowlands) data existed for 10 rivers or less. Many of the 948 riverine locations were dispersed between the Abitibi Plains (279), Algonquin-Lake Nipissing (136), Lake Erie Lowland (315) and Manitoulin-Lake Simcoe (309) ecoregions respectively.

5.2.1 TP analysis – Lakes

Lake and riverine TP data were summarized as the mean, standard deviation, minimum, maximum, and 25 and 75% quartiles for each ecoregion. Results are presented Appendix 1, summarized in Table 4 for lakes and rivers, and presently graphically for lakes in Figures 12 to 15. Results for lakes are presented first.

Table 4. Comparison of mean, 25th and 75th percentile phosphorus concentrations between ecoregions for Ontario lakes and rivers.

		Mean	25th %'ile	75th %'ile	N
Lakes	Lake Temiscamingue Lowland	0.009	0.004	0.013	56
	Algonquin	0.01	0.006	0.012	871
	Thunder Bay-Quetico	0.012	0.007	0.013	184
	Lake of the Woods	0.013	0.008	0.016	145
	Lac Seul	0.013	0.009	0.017	36
	Abitibi Plains	0.014	0.008	0.019	13
	Nipigon	0.016	0.012	0.018	10
	St-Laurent Lowlands	0.016	0.010	0.02	16
	Frontenac Axis	0.019	0.015	0.022	9
	Manitoulin-Lake Simcoe	0.019	0.010	0.02	83
	Lake Erie Lowland	0.031	0.014	0.038	10
Rivers	Southern Laurentians	0.013	0.010	0.016	3
	Lake Temiscamingue Lowland	0.014	0.006	0.019	60
	Lac Seul	0.019	0.017	0.021	3
	Nipigon	0.019	0.019	0.023	5
	Lake of the Woods	0.020	0.019	0.025	6
	Abitibi Plains	0.021	0.010	0.027	279
	Algonquin	0.023	0.011	0.028	136
	James Bay Lowlands	0.028			2
	Thunder Bay-Quetico	0.028	0.014	0.044	25
	Rainy River	0.033	0.031	0.039	4
	Frontenac Axis	0.034	0.019	0.048	5
	Manitoulin-Lake Simcoe	0.051	0.024	0.061	309
	St-Laurent Lowlands	0.056	0.026	0.065	38
	Lake Erie Lowland	0.109	0.032	0.139	315

Average TP concentrations varied between ecoregions and a one way ANOVA showed a significant ($p < 0.00001$) influence of ecoregion on TP concentration. The analysis was therefore carried forward for assessment of differences between 25^{th} and 75^{th} percentile concentrations. On average, the 75^{th} percentile concentration was 0.006 to 0.01 mg/L greater than the 25^{th} percentile, for all ecoregions except the Lake Erie Lowland (Figure 12). The Lake Erie Basin contains the highest population density and most intense agricultural activity in the Province and Lake Erie itself is recovering from decades of eutrophication. One would therefore expect that the 75^{th} percentile concentrations would reflect enrichment in this region.

Figure 12. Comparison of 25th and 75th percentile statistics for lakes between ecoregions.

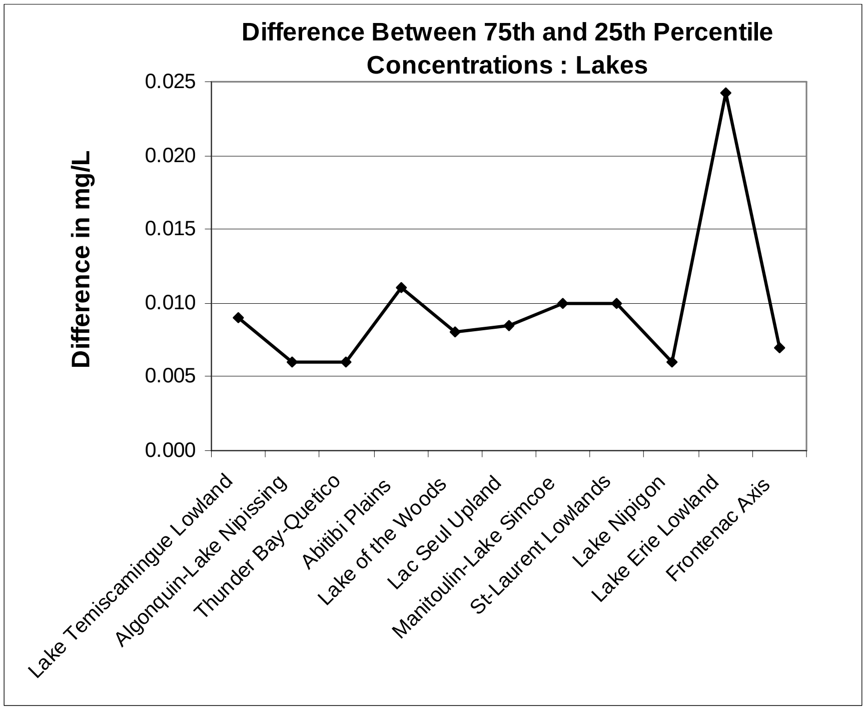
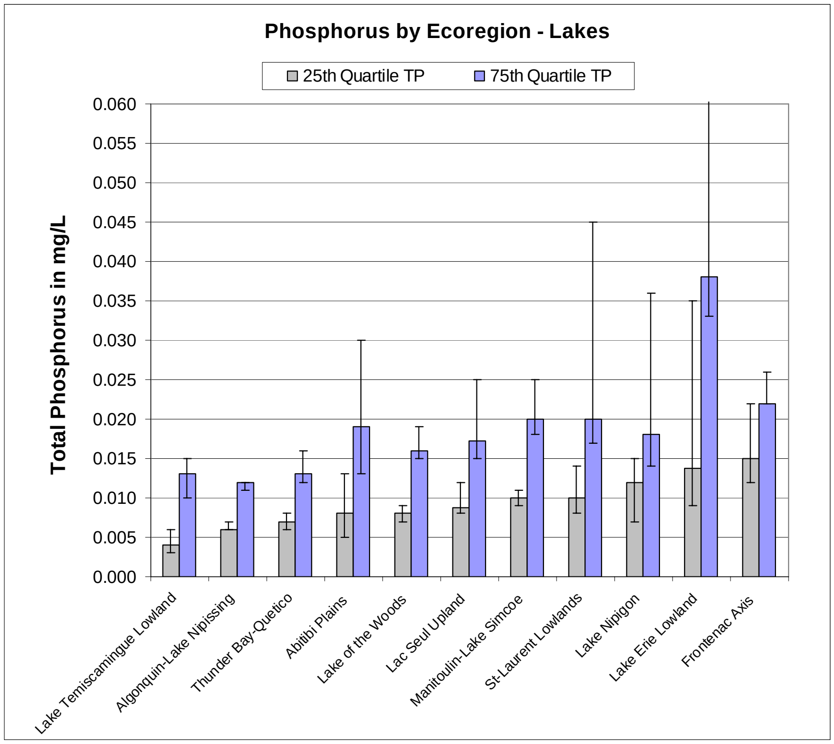


Figure 13 shows that the 25th percentiles increased gradually with transition from igneous to sedimentary geology and thin to thick soils. The 75th percentile values showed a similar gradual increase across ecoregions, in concert with the 25th percentiles, but did not follow the same order. This pattern, plus the greatest difference in the most populous and disturbed ecoregion (Lake Erie Lowlands) suggests that the 25th percentile is a good metric for description of the baseline phosphorus for all ecoregions.

The 25th percentile TP concentration was lowest (0.004 mg/L) in the Lake Temiscamingue Lowland and highest (0.015 mg/L) in the Lake Erie Lowland (0.014 mg/L) and Frontenac Axis ecoregions (Figure 13, Table 4). The high concentrations in the Lake Erie Lowland reflect the nutrient rich soils in the region while the Frontenac Axis concentrations indicate the thicker soils and sedimentary geology in the region. Runoff of phosphorus from agricultural practices in the Lake Erie Lowlands would be more common than in other ecoregions as shown by the 75th percentile concentration of 0.038 mg/L, but the rich soils would also have produced more nutrient rich surface waters, even in the absence of humans (25th percentile value of 0.014 mg/L).

Figure 13. Total phosphorus concentrations for lakes in Ontario ecoregions.



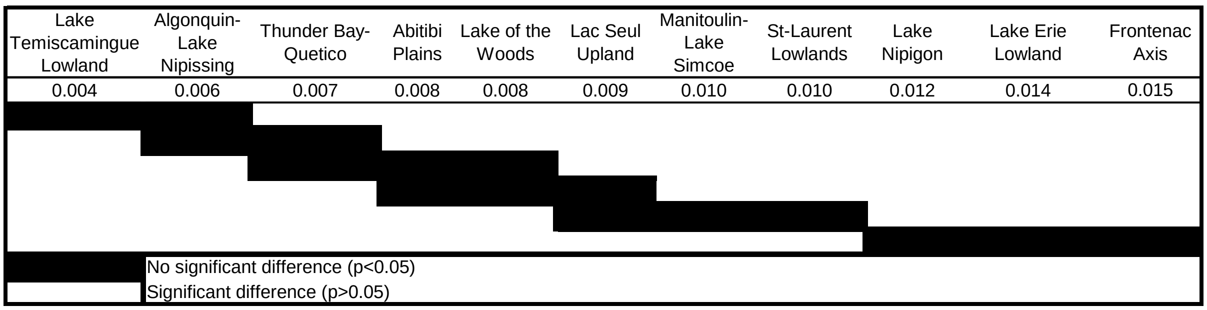
Note: Error bars represent the 95% confidence interval about percentile concentrations.

Use of the 25th percentile phosphorus concentrations showed significant and distinct differences in phosphorus concentrations between ecoregions (Figures 13 and 14). Confidence intervals were calculated and tests of significance completed using non-parametric methods and a normal approximation of a binomial distribution (USGS, 2002).

Figure 14 shows the results of the statistical comparisons. Ecoregions are presented across the top of the figure in order from lowest to highest phosphorus concentrations. Comparisons are made from left to right across the figure. Ecoregions joined by black bars are those for which the 25th percentile concentrations were not statistically different. Ecoregions joined by white bars are those for which the 25th percentile concentrations were significantly ($p<0.05$) higher than concentrations in the ecoregions represented by black bars on the same line. Thus, for each line, the figure compares black bars (not significantly different) with white bars (significantly higher than black bars).

The comparisons show that the 25th percentile phosphorus concentrations (0.004 to 0.006 mg/L) in the Lake Temiscamingue and Algonquin-Lake Nipissing ecoregions were significantly lower than those in the rest of the ecoregions. There were no clear groupings of lakes by phosphorus concentrations but general patterns can be seen in Figure 14. Phosphorus concentrations ranged from 0.007 to 0.008 mg/L in the Abitibi Plains, Thunder Bay-Quetico and Lake of the Woods Ecoregions. These were, on average, significantly lower than concentrations of 0.009 to 0.010 mg/L in the Lac Seul Uplands, Manitoulin – Lake Simcoe and St. Laurent Lowland Ecoregions and 0.012 to 0.015 mg/L in the Lake Nipigon, Frontenac Axis and Lake Erie Lowland Ecoregions.

Figure 14. Statistical comparisons of phosphorus concentrations for lakes in different Ontario ecoregions. White bars represent statistically significant ($p < 0.05$) differences.



The geographic distribution of 25th percentile lake phosphorus concentrations for Ontario ecoregions is presented in Figure 15. This plot shows the same patterns revealed by statistical testing. Lakes in the Southern Ontario ecoregions (Lake Erie Lowlands, Manitoulin-Lake Simcoe, Frontenac Axis and St. Laurent Lowlands) had higher phosphorus concentrations than lakes in the Algonquin-Lake Nipissing and Lake Temiscamingue Lowland Ecoregions. The average phosphorus concentration of lakes located in Lake Nipigon, Lac Seul Upland, Abitibi Plains, Thunder Bay-Quetico and Lake of the Woods Ecoregions were also greater than those in lakes of the Algonquin-Lake Nipissing and Lake Temiscamingue Lowlands Ecoregions.

The analysis of lake data therefore concludes that it is viable to distinguish phosphorus ecoregions for lakes in Ontario and that the 25th percentile values can be used to establish region reference or background phosphorus concentrations for lakes. These ecoregional 25th percentile values are suitable to classify lakes using the specific trigger ranges in phosphorus framework. The resolution provided by these percentile values will also accommodate the trigger value of a 50% increase above the baseline as recommended in the framework. Means to further finer resolution of phosphorus concentrations, if desired, are discussed in Sections 5.2.3 and 6.0.

Legend

25th Percentile Lake Phosphorus Concentration (mg/L)

- No Data
- 0.001 - 0.004
- 0.0041 - 0.008
- 0.0081 - 0.012
- 0.0121 - 0.015
- Ecoregion
- Rivers

Ecoregion Based Phosphorus Guidelines for Ontario

Figure 15

Geographic Classification of 25th Percentile Lake Phosphorus Concentrations in Ontario

Project 50031, May 2006

Gartner Lee Limited

0 50 100 200 Km

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N W E S

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5.2.2 TP Analysis – Rivers

Total phosphorus statistics for rivers were summarized as the mean, standard deviation, minimum, maximum, and 25 and 75% quartiles for each ecoregion in Table A1 (Appendix 1) and summarized in Table 4. Results are presented graphically for rivers in Figures 16 to 19.

Average TP concentrations varied between ecoregions and a one way ANOVA showed a significant ($p < 0.00001$) influence of ecoregion on TP concentration in rivers. The analysis was therefore carried forward for assessment of differences between 25th and 75th percentile concentrations. On average, the 75th percentile concentration was 0.01 to 0.04 mg/L greater than the 25th percentile, for all ecoregions except the Lake Erie Lowland, where the difference exceeded 0.1 mg/L (Figure 16). The Lake Erie Basin contains the highest population density and most intense agricultural activity in the Province. Rivers in the region reflect these influences as well as enrichment from the disposal of treated sewage. One would therefore expect that the 75th percentile concentrations would reflect human influence in this region.

Figure 16. Comparison of 25th and 75th percentile statistics for rivers between ecoregions.

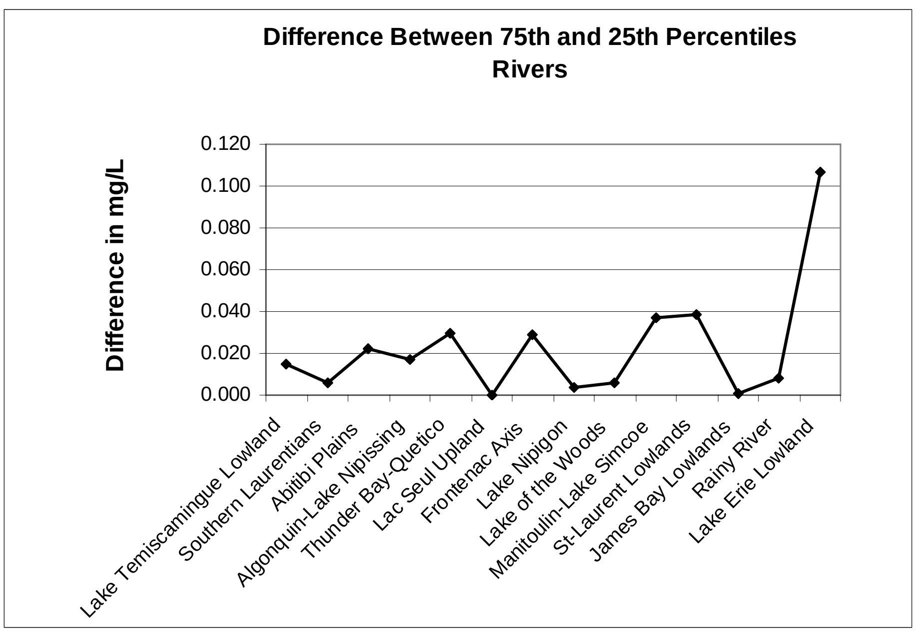
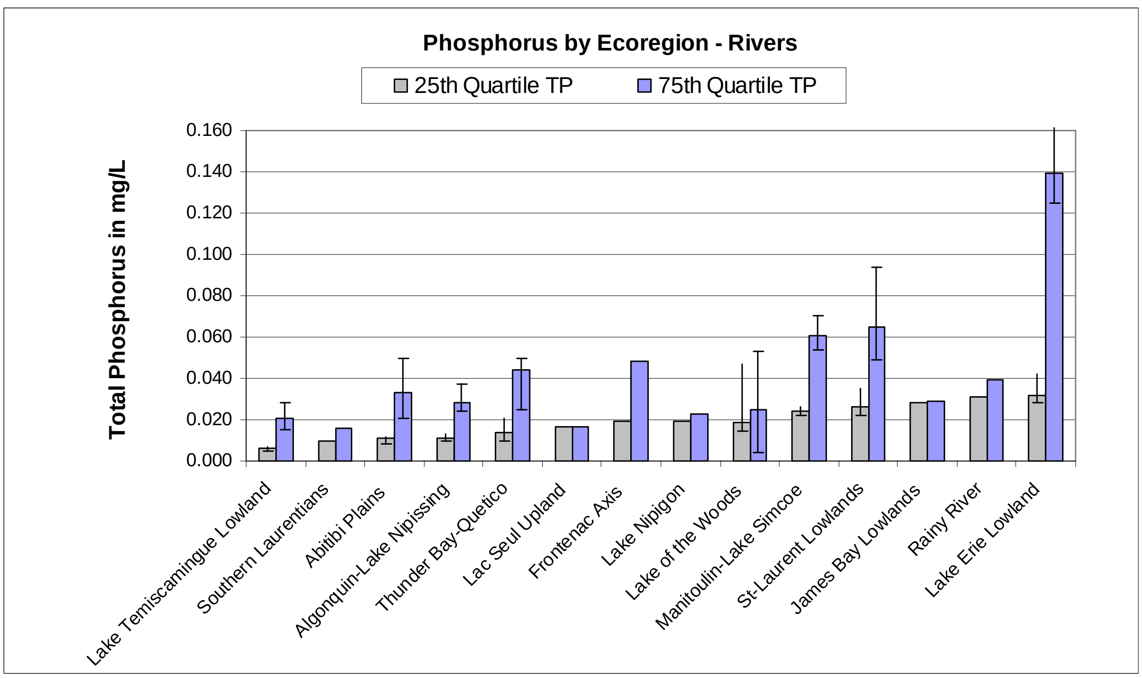


Figure 17 shows that the 25th percentile concentrations increased gradually with transition from igneous to sedimentary geology and thin to thick soils. The 75th percentile values were higher in southern Ontario (off-Shield) than on-Shield but showed no consistent pattern of increase as the 25th percentiles did. Several ecoregions showed large differences between the two metrics (i.e., Algonquin – Lake Nipissing, Manitoulin -Lake Simcoe, Frontenac Axis, Thunder Bay- Quetico), suggesting either human influence or unexplained increases in natural phosphorus. This pattern, plus the greatest difference in the most populous and disturbed ecoregion (Lake Erie Lowlands) shows that the 25th percentile is a good metric for description of the baseline phosphorus in rivers for all ecoregions.

The 25th percentile TP concentration was lowest (0.006 mg/L) in the Lake Temiscamingue Lowland and highest in the Lake Erie Lowland (0.03 mg/L) and James Bay Lowland (0.05 mg/L) ecoregions (Figure 17, Table 4). The high concentrations in the Lake Erie Lowland reflect the nutrient rich soils in the region while the James Bay Lowland values indicate the influence of high dissolved organic carbon on natural phosphorus concentrations. Phosphorus enrichment from agricultural practices and other human sources in the Lake Erie Lowlands would be more common than in other ecoregions as shown by the 75th percentile concentration of 0.14 mg/L. The rich soils would also have produced more nutrient rich surface waters, even in the absence of humans (25th percentile value of 0.03 mg/L).

Figure 17. Total phosphorus concentrations for rivers in Ontario ecoregions.



Note: Error bars represent the 95% confidence limits about the percentile statistics.

Use of the 25th percentile phosphorus concentrations showed significant and distinct differences in riverine phosphorus concentrations between ecoregions (Figures 17 and 18). Confidence intervals were calculated and tests of significance completed using non-parametric methods and a normal approximation of a binomial distribution (USGS, 2002).

Figure 18 shows the results of the statistical comparisons. Ecoregions are presented across the top of the figure in order from lowest to highest phosphorus concentrations. Comparisons are made from left to right across the figure. Ecoregions joined by black bars are those for which the 25th percentile concentrations were not statistically different. Ecoregions joined by white bars are those for which the 25th percentile concentrations were significantly ($p<0.05$) higher than concentrations in the ecoregions represented by black bars on the same line. Thus, for each line, the figure compares black bars (not significantly different) with white bars (significantly higher than black bars).

The comparisons show that the 25th percentile phosphorus concentration of 0.006 mg/L in the Lake Temiscamingue Ecoregion was significantly lower than all other ecoregions. Concentrations of 0.010 – 0.011 mg/L in the Southern Laurentian, Abitibi Plains and Algonquin- Lake Nipissing ecoregions formed a statistically distinct grouping, as did concentrations of 0.014 – 0.019 mg/L in the Thunder Bay-Quetico, Lac Seul Upland., Frontenac Axis, Lake Nipigon and Lake of the Woods ecoregions. The Lake of the Woods Ecoregion (0.019 mg/L) grouped with the Manitoulin – Lake Simcoe Ecoregion (0.024 mg/L), St. Laurent Lowlands (0.025 mg/L) and James Bay Lowlands (0.025 mg/L) ecoregions. The final grouping consisted of the St. Laurent Lowland, James Bay Lowland, Rainy River and Lake Erie Lowland Ecoregions (0.026 – 0.032 mg/L).

Figure 18. Statistical comparisons of 25th percentile phosphorus concentrations for Rivers in different Ontario ecoregions. White bars represent statistically significant ($p < 0.05$) differences.

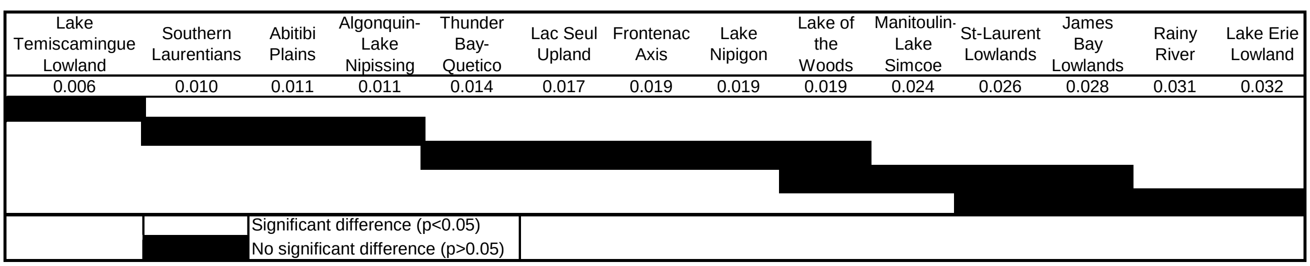


Figure 19 geographically presents the 25th percentile of river phosphorus concentrations for each ecoregion. This plot shows the same patterns revealed by statistical testing. There was a definite distinction between ecoregions with respect to riverine TP concentration, with rivers showing a greater geographic variability than lakes but no clear trend from north to south.

The analysis of river data therefore supports the lake analysis and concludes that it is viable to distinguish phosphorus ecoregions for rivers in Ontario. The 25th percentile statistic provides good resolution of estimated natural baseline concentrations of phosphorus and these can be linked to trigger ranges in phosphorus framework.

Legend

25th Percentile River Phosphorus (mg/L) by Ecoregion

- < 0.010
- 0.011 - 0.015
- 0.0151 - 0.0200
- 0.0201 - 0.025
- 0.0251 - 0.030
- >0.030

Ecoregion Based Phosphorus Guidelines for Ontario

Figure 19

Geographic Classification of 25th Percentile River Phosphorus Concentrations in Ontario

Project 50031, July 2005

Gartner Lee Limited

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5.2.3 Comparison of 75th and 25th Percentile Concentrations

Previous sections of this report showed that statistically significant differences in phosphorus concentrations of lakes and rivers were related to their ecoregion classification. A high level of resolution between ecoregions was provided by the 25th percentile statistic. The difference between the 25th and 75th percentiles of phosphorus concentration revealed those lakes and rivers with significant human influences on phosphorus concentrations.

We therefore recommend that ecosystem classifications be based on the 25th percentile of phosphorus concentration, as it appears to reflect statistically significant differences in baseline phosphorus concentrations between ecoregions. The difference between the 25th and 75th percentiles can then be used as a preliminary screening tool to assess the likelihood that a water body has been enriched and should therefore be triggered for further investigation under the phosphorus framework.

5.2.4 Summary – Ecoregion Classifications

Statistically significant differences in average phosphorus concentrations between Ontario ecoregions were determined from existing data on phosphorus concentrations in lakes and rivers. Data were available for 14 of the 17 ecoregions for rivers and for 11 of 17 ecoregions for lakes. Use of the 25th percentile produced estimates of natural phosphorus concentrations sufficient to classify Ontario's ecoregions and to assign specific trigger ranges recommended in phosphorus framework.

6. Phosphorus Variance within Ecoregions

The analysis above shows that there are significant differences in the populations of phosphorus values in lakes and rivers between ecoregions in Ontario. The review and analyses show, however, that there can be spatial variance in concentrations even within ecoregions.

When examining the utility of an ecoregion as an organizing principle for water quality data, it will be important to keep in mind that there are other factors that may significantly influence differences in phosphorus concentrations. Other influences that may allow improved prediction of phosphorus concentrations and recommend approaches to improve the prediction of baseline phosphorus concentrations are discussed here.

6.1 Northwestern Ontario

Two ecoregions from northwestern Ontario (the Lake of the Woods and the Thunder Bay-Quetico ecoregions) were selected because they were adjacent to each other and had significant (> 100) numbers of lakes sampled in each one.

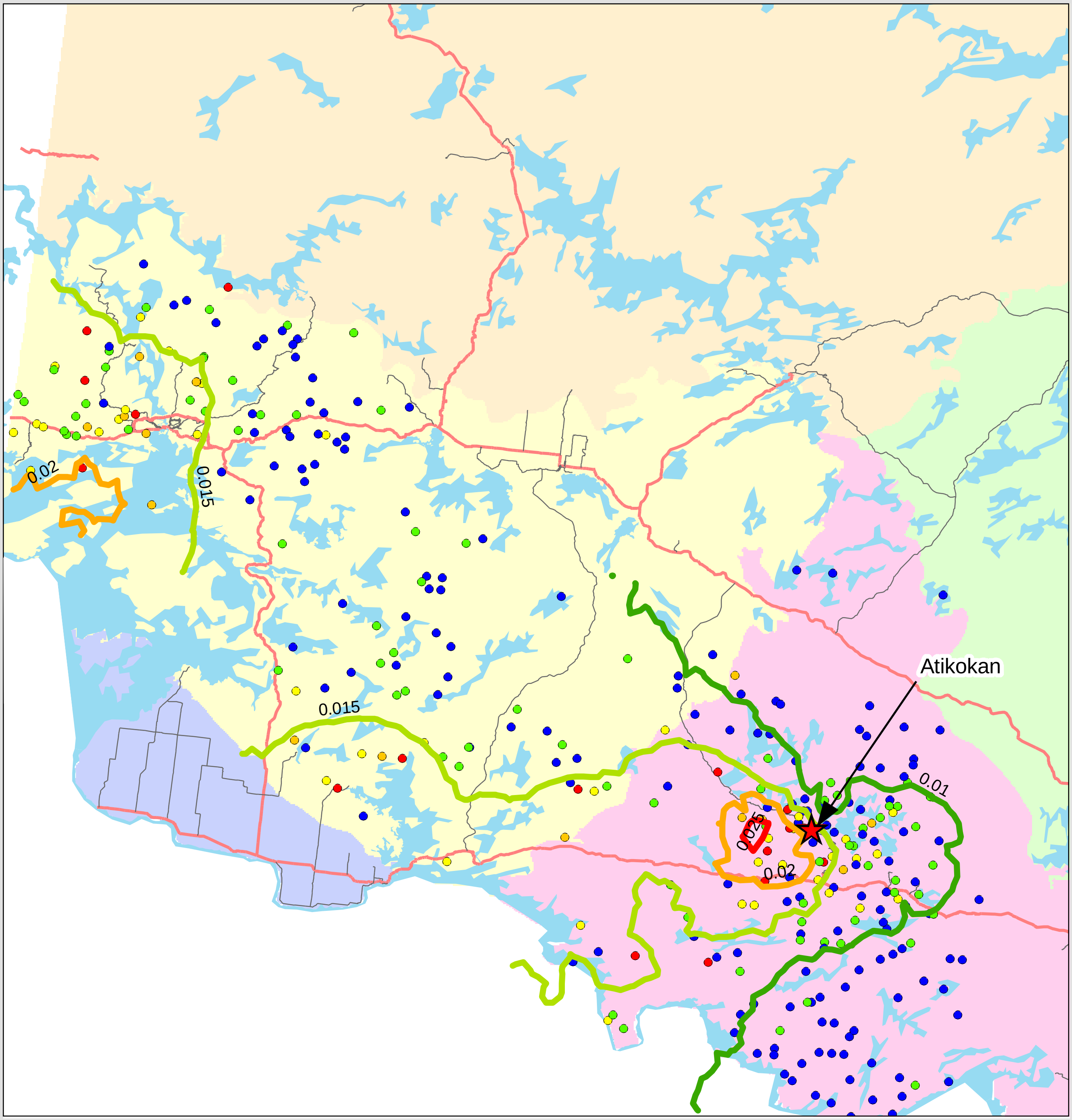
Statistical analysis of the 25th percentile phosphorus concentrations for lakes in these ecoregions showed that there was no significant difference between them of phosphorus concentrations, as was previously shown in Figure 14. Inspection of Figure 2, however, shows that there is an apparent 'hot spot' of elevated phosphorus in the vicinity of Atikokan. Figure 20 shows a Kriging[1] interpolation of phosphorus concentrations that shows an increase of phosphorus concentrations around Atikokan.

In order to test the significance of this 'hot spot', lakes from the Thunder Bay-Quetico Ecoregion were split into two subpopulations: those within 25 km from Atikokan (called 'Atikokan Lakes'), and those greater than 25 km from Atikokan (referred to as 'non-Atikokan Lakes'). An analysis of variance showed that the "Atikokan Lakes" in the vicinity of Atikokan had significantly ($p < 0.001$) higher phosphorus concentrations than the "non-Atikokan lakes" greater than 25 km from Atikokan.

An examination of the influence of bedrock geology on the set of lakes in this ecoregion revealed that differences in bedrock geology were not readily apparent, but that proximity to Atikokan was important.
The phosphorus 'hot spot' near Atikokan may be associated with the operation of a large thermal power generation plant near the town. Phosphorus is a typical trace component of coal, averaging 0.015% (Bernhardt, 1978) and so the lakes may have become enriched either by atmospheric deposition of phosphorus from the plant stacks, or through alterations in natural phosphorus export through acidic deposition. Further analysis is warranted to determine the reasons for this variation and similar sources of variation may be present in other ecoregions as well.

---

1. *(Kriging details: Ordinary Kriging interpolator).*
Number of Points: 312
Semivariogram/Covariance Model:
*0.000024701 * Gaussian (52630) + 0.000073751 * Nugget,*
Error modeling Microstructure: 0.000073751 (100%), Measurement error: 0 (0%)).



Legend

Lake Data

TP (mg/L)

- < 0.010
- 0.011 - 0.015
- 0.016 - 0.020
- 0.021 - 0.025
- >0.026

Kriged Contours (mg/L)

Value

- 0.010
- 0.015
- 0.020
- 0.025

Ecoregion

- Lac Seul Upland
- Lake Nipigon
- Lake of the Woods
- Rainy River
- Thunder Bay-Quetico

Ecoregion Based Phosphorus Guidelines for Ontario

Figure 20

Kriging Interpolation of Phosphorus Concentrations near Atikokan, Ontario

Project 50031, July 2005

Gartner Lee Limited

N W E S

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6.2 Algonquin – Lake Nipissing Ecoregion

A second set of lakes was examined for indications of significant variance within an ecoregion. The lakes selected were those from the Algonquin – Lake Nipissing Ecoregion. This ecoregion was selected because it was the best-sampled ecoregion – a total of 871 lakes. The spatial variation of phosphorus in lakes is shown in Figure 20 and Table 4 showed that one standard deviation about the mean concentration of 0.010 mg/L enclosed a range of 0.004 to 0.016 mg/L.

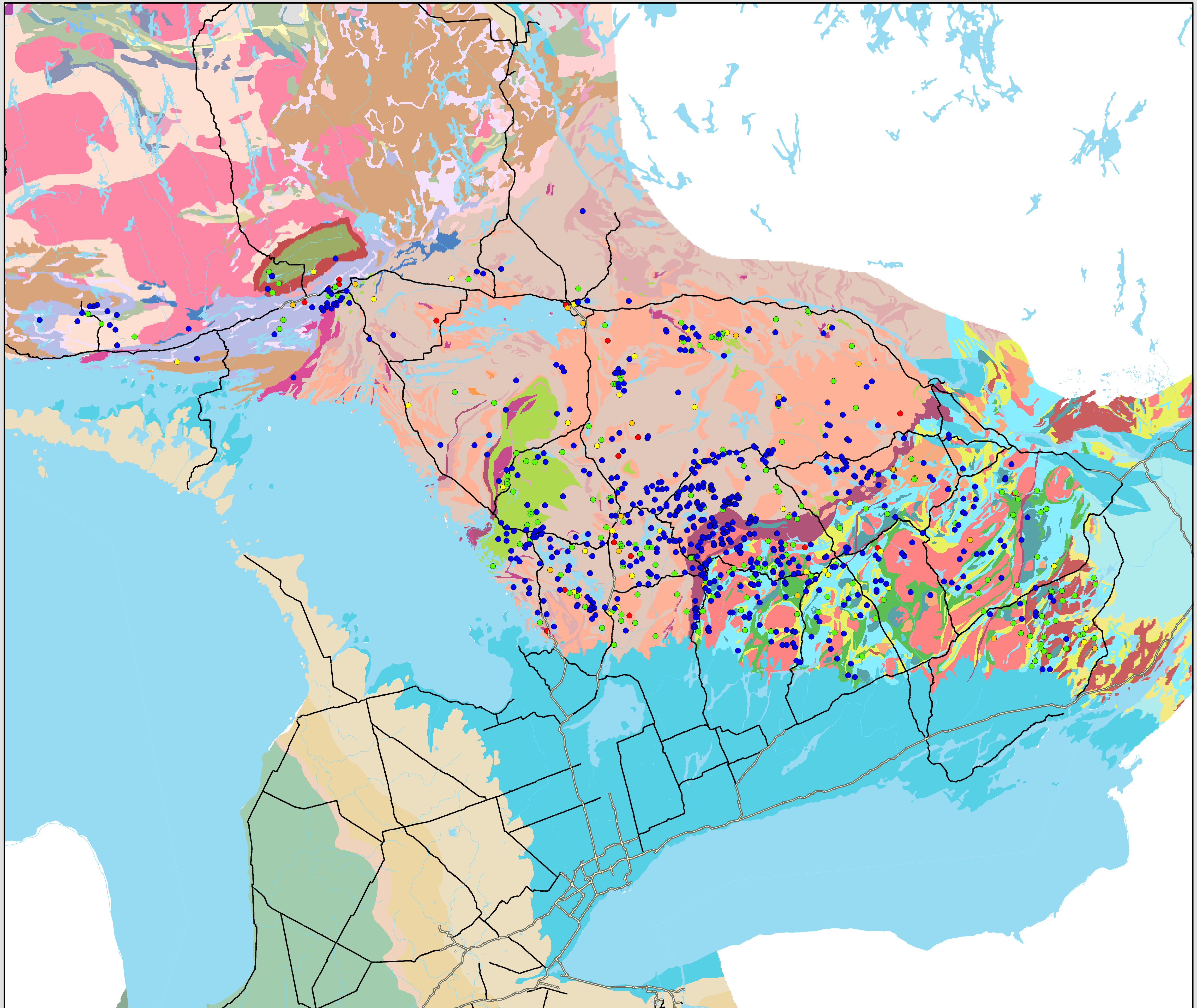
This variance was explored by positioning each lake in the ecoregion with respect to bedrock geology. Figure 21 shows the bedrock geology of the area that was established from Ontario Geological Survey (2000) mapping of the area. The influence of bedrock geology on the variance in phosphorus concentrations in this subset of lakes was explored using rock types with more than 20 sampled lakes as categories for an analysis of variance. Bedrock type was associated with each of the lakes in the Algonquin-Lake Nipissing Ecoregion using a 'spatial join' within the GIS. Table 5 shows the number of lakes in each generalized rock type (for those rock types with 20 or more lakes) in the ecoregion.

The results show that differences in bedrock type had a significant ($p<0.004$) overall effect on the variance in phosphorus concentrations in the sampled lakes. In particular, lakes in the "Late felsic plutonic rocks Group" appear to have higher phosphorus than those in other rock types. This suggests that finer resolution of baseline phosphorus concentrations may be achieved at a finer scale than ecoregion, or through some combination of ecoregion and bedrock geology. Additional analyses, and formal testing for significant differences between rock groups are recommended for subsequent studies.

Table 5. Influence of geology on phosphorus concentrations for lakes in the Algonquin-Lake Nipissing ecoregion.

Rock Type	n	Average Phosphorus	25th Percentile
• Tectonite	51	0.007	0.005
• Early felsic plutonic rocks	96	0.008	0.006
• Felsic igneous rocks	119	0.009	0.006
• Carbonate metasedimentary rocks	104	0.010	0.008
• Clastic metasedimentary rocks	39	0.010	0.008
• Mafic rocks	32	0.010	0.007
• Migmatitic rocks and gneisses of undetermined	292	0.010	0.006
• Mafic to felsic metavolcanic rocks	20	0.012	0.008
• Quirke Lake Gp.; Hough Lake Gp.; Elliot Lake	29	0.013	0.006
• Late felsic plutonic rocks	20	0.016	0.012

Note: units are mg/L



Legend

Lake Phosphorus (mg/L)

- < 0.010
- 0.011 - 0.015
- 0.016 - 0.020
- 0.021 - 0.025
- >0.026

Bedrock Type

1 Metasedimentary rocks and mafic to ultramafic metavolcanic rocks
2 Felsic to intermediate metavolcanic rocks
3 Mafic metavolcanic and metasedimentary rocks
4 Mafic to ultramafic metavolcanic rocks
5 Mafic to intermediate metavolcanic rocks;
6 Felsic to intermediate metavolcanic rocks
7 Metasedimentary rocks;
8 Migmatized supracrustal rocks
9 Coarse clastic metasedimentary rocks
10 Mafic and ultramafic rocks
11 Gneissic tonalite suite
12 Foliated tonalite suite
13 Muscovite-bearing granitic rock
14-Diorite-monzodiorite-granodiorite suite
15 Massive granodiorite to granite
16 Diorite-nepheline syenite suite
17 Mafic and ultramafic intrusive rocks
18 Quirke Lake Gp.; Hough Lake Gp.; Elliot Lake Gp.
19 Cobalt Gp.
20 Felsic intrusive rocks
21 Mafic and related intrusive rocks
22 Sedimentary Rocks
23 Mafic intrusive rocks
24 Carbonatite-alkalic intrusive suite (ca. 1.9 Ga)
25 Whitewater Gp.
26 Sudbury Igneous Complex (1850 Ma)
27 Felsic intrusive rocks
28 Sibley Gp.
29 Osler Gp.; Mamainse Point Fm., Michipicoten Island Fm.
31 Mafic and related intrusive rocks (Keweenawan age)
32 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
33 Jacobsville Gp.; Oronto Gp
34 Mafic intrusive rocks
35 Carbonate-alkalic intrusive suite (450 to 600 Ma)
36 Gneisses of metasedimentary origin
37 Mafic rocks
38 Migmatitic rocks and gneisses of uncertain protolith
39 Anorthosite and alkalic igneous rocks
40 Felsic igneous rocks
41 Mafic to felsic metavolcanic rocks
42 Clastic metasedimentary rocks
43 Carbonate metasedimentary rocks
44 Early felsic plutonic rocks
45 Alkalic plutonic rocks
46 Mafic to ultramafic plutonic rocks
47 Late felsic plutonic rocks
48 Tectonite unit
49 Conglomerate, sandstone, shale, dolostone
50 Dolostone, sandstone: Beekmantown Gp.
51 Limestone, dolostone, shale, arkose, sandstone
53 Sandstone, shale, dolostone, siltstone
54 Limestone, dolostone, shale, sandstone, gypsum, salt
55 Sandstone, dolostone, limestone
56 Limestone, dolostone, shale
57 Shale
58 Shale: Port Lambton Gp.
60 Kaolinitic clay, clay, sand, lignite

Credit Block

Ecoregion Based Phosphorus Guidelines for Ontario

Figure 21

Bedrock Geology of the Algonquin-Lake Nipissing Ecoregion

Project 50031, July 2005

Gartner Lee Limited

N W E S

0 25 50 100 Kilometers

1:2,000,000

Map Document: (N:\Projects\2005\50031\2005\Final\GISSpatial\50031_LakeP_Algonquin_fig21.mxd)
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6.3 Phosphorus and Surficial Geology

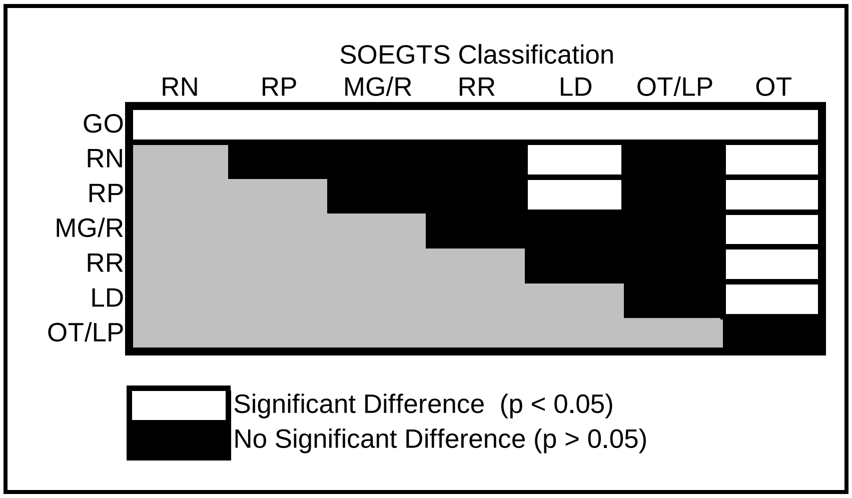
The influence of surficial geology was examined for a subset of lakes within the District Municipality of Muskoka, which is located within the Algonquin-Lake Nipissing Ecoregion. The spatial variation in phosphorus in these lakes is shown in Figure 20, and Table 4 showed that one standard deviation about the mean concentration of 0.010 mg/L enclosed a range of 0.004 to 0.016 mg/L.

Phosphorus concentrations in these lakes are routinely monitored by the District Municipality of Muskoka and results of an exercise to model natural and human-influenced phosphorus concentrations were presented in Hutchinson (2002). That exercise showed that surficial geology, especially wetland area, had a significant influence on lake phosphorus concentration. All of the lakes within the model were located upon a map of surficial geology of Muskoka which was generated by the "Southern Ontario Engineering Geology Terrain Study" (SOEGTS; Mollard, 1980). The "baseline" phosphorus concentrations were modelled and validated as in Hutchinson (2002) and compared against the surficial geology classification. Table 6 and Figure 22 show that there were significant differences in baseline phosphorus concentrations between surficial geology classifications. Phosphorus concentrations were significantly lower in lakes located on glacial outwash plains and significantly higher in lakes located on organic terrain. Differences between intermediate classifications were not statistically significant. Possible reasons for this variance are discussed in Section 6.4.

Table 6. Surficial geology and baseline phosphorus concentrations for lakes in the District Municipality of Muskoka.

SOEGTS Classification	Surficial Geology	No. of Lakes	Average TP (ug/L)	Variance
GO	Glacial Outwash Plain	8	3.83	1.37
RN	Bedrock Knob	132	5.50	9.97
RP	Bedrock Plain	33	5.56	8.59
MG/R	Ground Moraine Over Bedrock	99	6.21	9.52
RR	Bedrock Ridge	43	6.37	17.59
LD	Glaciolacustrine Delta	66	6.60	6.43
OT/LP	Organic Terrain over Glaciolacustrine Plain	7	7.81	17.32
OT	Organic Terrain	16	9.12	34.40

Figure 22. **Statistical significance of surficial geology influence on baseline phosphorus concentrations in lakes.**



6.4 Phosphorus, Wetlands and Lake Dynamics

Although the ecoregion concept is a valid predictor of baseline phosphorus concentrations in Ontario lakes, some variance is left unexplained after accounting for ecozone and ecoregion classification within Ontario, bedrock geology and surficial geology and terrain. Dissolved Organic Carbon (DOC) has been shown to have a strong influence on phosphorus concentrations in Precambrian Shield lakes (Dillon *et al.* 1986 and Dillon and Molot, 1997) and may well account for the variance in phosphorus concentrations within Precambrian Shield Ecoregions.

The influence of DOC was examined for a subset of lakes within the District Municipality of Muskoka, which is located within the Algonquin-Lake Nipissing Ecoregion. Section 6.3, above, showed that significant differences in phosphorus concentrations for these lakes were related to the presence of organic terrain and soils in their watersheds. The geographic variation of phosphorus in these lakes is shown in Figure 20, and Table 4 showed that one standard deviation about the mean concentration of 0.010 mg/L enclosed a range of 0.004 to 0.016 mg/L. The discussion that follows is taken from Hutchinson (2002).

Concentrations of total phosphorus showed a highly significant ($p < 0.000001$) relationship with DOC content in lakes in Muskoka (Figure 23). The relationship explained 39% of the variance in phosphorus concentrations in the 85 lakes for which measurements of both DOC and TP were available. This relationship is driven by the export of phosphorus with organic carbon from wetlands in the catchments of the lakes (Dillon and Molot, 1997), as shown for the 161 monitored lakes in Muskoka in Figure 24. Total phosphorus concentrations were significantly related ($p < 0.000001$, $r^2 = 0.39$) to the amount of wetland in the catchments of lakes, as determined from 1:50,000 topographical maps. Mapping at a finer resolution, and more data on measured DOC concentrations could well improve the relationship. Digital mapping of wetland areas is becoming available and may allow further resolution of natural phosphorus concentrations in lakes. Consideration of wetland coverage within an ecoregion may therefore further improve the resolution of phosphorus concentrations that is possible within an ecoregion.

Figure 23. Influence of DOC on average long-term total phosphorus concentrations in Lakes.

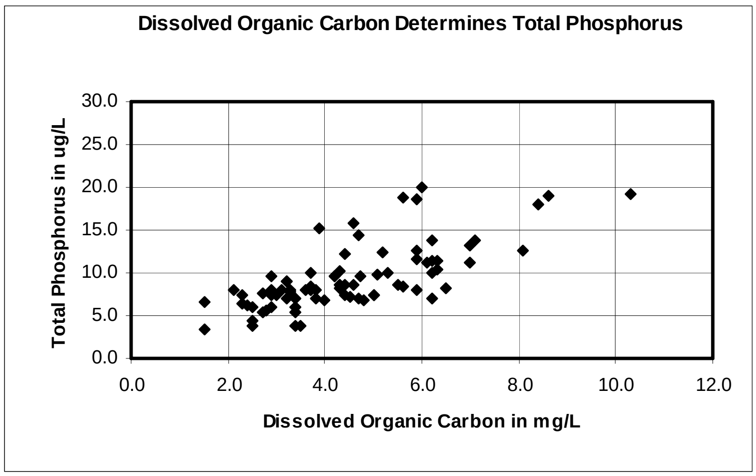
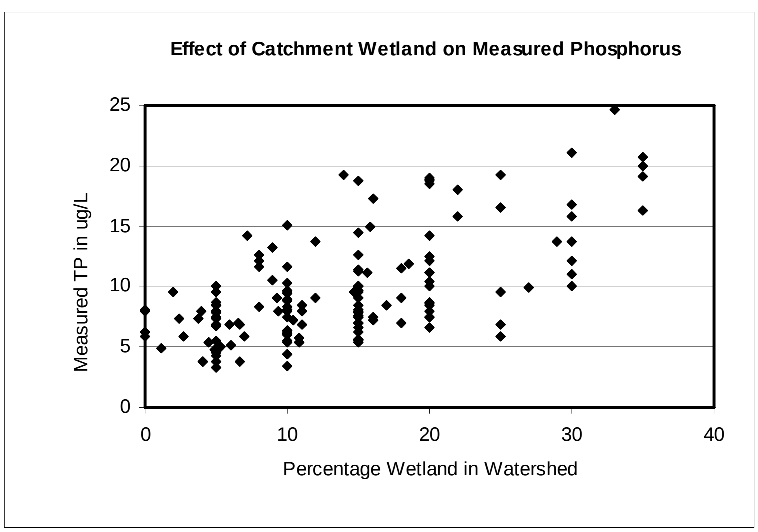


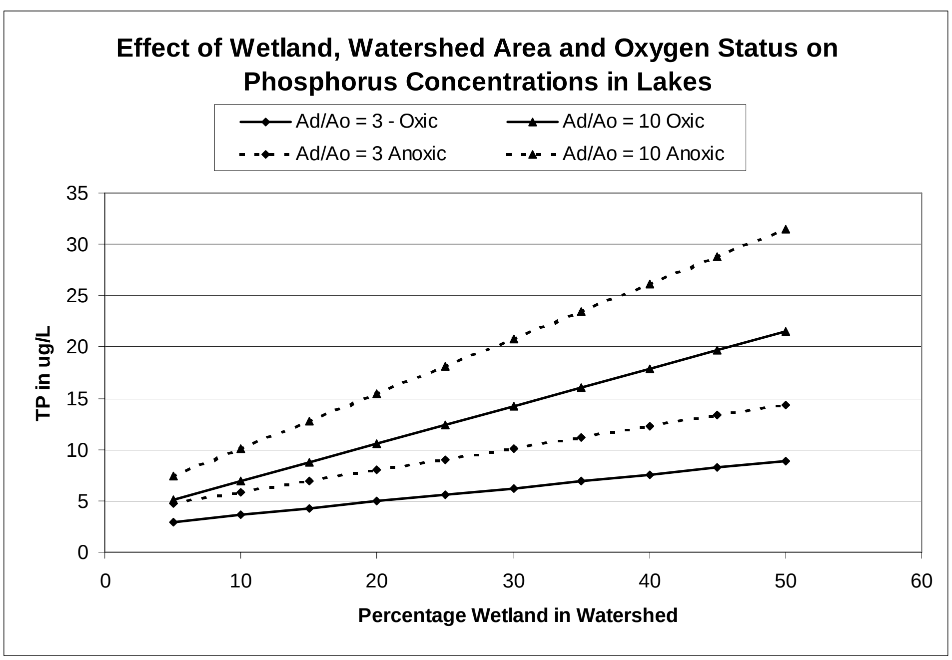
Figure 24. Relationship of average long-term measured phosphorus in lakes to wetland area in catchment.



Finally, it is noted that the concept of the ecoregion presumes that variance in phosphorus concentrations is a function of climate, precipitation, vegetation, geology and soils. These factors determine, for the most part, the potential natural loading of phosphorus to a lake from its watershed. The actual load delivered to a lake, however, will be influenced by the size of the watershed, and the expression of phosphorus loading as concentration will depend on physical factors such as the surface area of a lake (in proportion to watershed area) and the oxygen status of the lake. A lake with an anoxic hypolimnion will release phosphorus from its sediments to overlying waters, such that concentrations will be higher than if the hyplimnion was oxygenated. These concepts were first quantified for Ontario lakes by Dillon and Rigler (1975).

The influence of these factors is summarized in Figure 25, which was developed by modelling a hypothetical lake with a surface area of 100 ha, with watershed sizes of 300 and 1,000 ha, with a range of 5 to 50% of the watershed which was wetland and under scenarios of oxic and anoxic hypolimnia. The analysis showed that influence of wetland increased as watershed area increased and in anoxic lakes. This shows that there are many factors that will alter total phosphorus concentrations within an ecoregion. It is important to note, however, that, as with wetland area; lake and watershed areas have been mapped on GIS for much of Ontario and could therefore be quantified as part of a classification exercise. This could potentially reduce the variance in predicted phosphorus concentrations within an ecoregion and help resolve if lake enrichment was induced by natural or human factors.

Figure 25. Physical influences on phosphorus concentrations within a watershed or ecoregion.



7. Conclusions

Phosphorus data for a total of 1433 lakes and 948 rivers across Ontario were used to test for the significant differences that could be attributed to the classification of different areas of the province into ecozones or ecoregions. This approach, of using existing data, added variance to the classification due to the focus of data collections which are either used by humans, or which have been or may be influenced by human activity. Lake management activities tend to be focussed on waters where management may be required and, although obvious human sources were edited out of the database, some bias is apparent. Some of this bias was eliminated by using the lower 25th percentile of phosphorus concentrations instead of the average phosphorus concentration in each ecoregion to reduce the influence of high concentrations in the analysis, as recommended in EPA (2000). Use of the 75th percentile concentration (or the difference between the 75th and 25th percentiles) provided a useful metric to distinguish human sources of phosphorus from natural baseline concentrations. The greatest difference between these two metrics was observed in the Lake Erie Lowland ecoregion, where high population densities and land use practices have enriched surface waters.

Successful ecoregion classifications in the USA using data from sites that were selected with complete "a-priori" knowledge of their characteristics, and were sampled for the specific purpose of classification. This approach reduces sampling variance, equalizes sampling effort between ecoregions, allows stratification of lake types and accounts for human influence. Although the USEPA (2000) allows the use of existing data (STORET, NASQAN, NAWQA, and other relevant nutrient data from universities and States/Tribes) to set trigger values and assess reference conditions; they also advise use of the 25th percentile statistic in these cases, to reduce bias from human phosphorus sources. However, it is important to note that most regions would have to rely on the existing datasets to develop ecoregional reference values. This is mainly because the dedicated monitoring programs may take years to develop and the required resources may not be there. The present study showed that the 25th percentile classification reduced the influence of human sources and allowed for the successful classification of ecoregions on the basis of estimated reference (natural baseline) phosphorus concentrations.

The analysis showed that significant variance in phosphorus concentrations in lakes and rivers could be explained by classification into one of three "ecozones" for the Province, or into the fourteen "ecoregions". The ecoregional phosphorus concentrations were within the trophic status classifications proposed in the phosphorus framework for rivers and lakes (Environment Canada 2004).

The ecoregion approach needs to be considered further for use in longer rivers, which may originate, flow through and mature in different ecoregions. The natural baseline concentrations in a river will also increase with distance within one ecoregion, independently of human activity. It may therefore follow that the enriched downstream reaches of rivers may result in "false positive" classifications of enrichment if the phosphorus ecoregion analysis is the only classification metric used. It should be noted that the phosphorus ecoregion analysis is used in Tier 2 of the phosphorus framework, such that any bias introduced by its use would trigger Tier 3 or Tier 4 of the framework. At that point, the more detailed analyses would determine if enrichment was natural or human-induced.

In conclusion the ecoregion concept is feasible and practicable as a means of classifying natural trophic status of lakes and rivers in Ontario. It was proposed as a means of identifying a “trigger range” in phosphorus concentration that would stimulate further assessment. It is noted, however, that lake and river – specific phosphorus measurements are widely available or easily obtained in Ontario, that accurate trophic status modelling techniques exist for individual lakes and that lake management activities are generally required only in those areas where human activity has already prompted monitoring or modelling efforts.

The phosphorus ecoregion approach is not intended for use as the only tool in assessing and managing eutrophication. It is an initial screening step that managers may find useful when applying it within a tiered approach developed for managing nutrients in surface waters:

a) the approach offered by the “Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems” (CCME, 2004; Environment Canada, 2004) would provide “Tier 1”; framework for phosphorus management across the country;

b) development and classification of phosphorus ecoregions would be used as “Tier 2”, to predict natural phosphorus concentrations in different regions of the country and to place water bodies in those regions into a trophic status classification. This would allow water managers to identify ecoregion-specific reference conditions and associated trigger ranges;

c) regional monitoring programs, or more detailed estimates based on surficial geology, forestry, knowledge of human conditions or wetland area would comprise “Tier 3” to determine whether or not a water body was approaching a trigger for more detailed assessment; and

d) the detailed assessment, such as trophic status modelling and development of management plans would take place, if required, as “Tier 4”.

8. Recommendations

The ecoregion concept is feasible and practicable as a means of classifying natural trophic status of lakes in Ontario. The concept can be expanded and tested in other provinces that have a) large differences in geology and b) substantial datasets of phosphorus measurements. The three Prairie Provinces offer a wide range in geology (Boreal Shield to rich soils) and land use (large cities on rivers, intensive agriculture) and, between provincial agencies, university studies (i.e., TROLS in Alberta) and federal research groups there is the potential that large numbers of lakes and rivers have been sampled. British Columbia also offers a range in geology and vegetation and has developed a substantial nutrient dataset (see Section 2.1). The Province of Nova Scotia is likely to have a good database for phosphorus measurements, but may have confounding influences such as DOC or marine contributions. These must be incorporated into any study design.

The ecoregion concept, although valid as a description of natural influences on trophic status, may not provide sufficient resolution of phosphorus concentrations to serve as the sole basis for nutrient management. Finer resolution may be useful to limit changes in trophic status, or to identify surface waters where phosphorus has increased by 50% above background (i.e., for those lakes that are naturally 0.003 to 0.006 mg/L).

Finer resolution of the variance in phosphorus concentrations within ecoregions is feasible and will help improve the use of the ecoregion concept. Digital mapping of bedrock geology and surficial geology/terrain discriminated significant differences in lake phosphorus within ecoregions. GIS mapping of wetland area, lake surface area and watershed area is feasible and these factor were shown to provide additional resolution of lake phosphorus concentrations within the Algonquin-Lake Nipissing Ecoregion.

This study, by necessity, used data from existing data sets and the scope of the study did not allow detailed analysis of each data point. In addition, the data used were collected for a variety of different management objectives and so the database was incomplete, especially for accessory data that may help interpret phosphorus. Other successful case studies have used a dedicated monitoring program allowing standardization of sampling protocols, numbers of samples, time of year and data collected. These studies have also pre-selected water bodies to allow comparable numbers and attributes of lakes across the different ecoregions to be sampled and used. It would be useful, therefore, to test the ecoregion concept further on the basis of a dedicated sampling program and study. However, it is acknowledged that such an exercise would be a much more costly enterprise than the study reported herein.

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Appendix 1

Water Quality Characteristics for Lakes and Rivers in Ontario Ecoregions

Ecozone	Ecoregion	Data	Lakes					Rivers				
			TP	Alk	Cond	Ca	DOC	TP	Alk	Cond	Ca	DOC
Boreal Shield	*Abitibi Plains*	average	0.014	74.6	153.0	25.1		0.021	36.2	283.4	25.1	7.7
		stdev	0.008	36.5	46.0	5.1		0.017	27.5	476.6	39.3	4.5
		n	13	10	7	5	0	279	207	270	131	83
		min	0.005	0.9	81.0	16.8		0.002	0.1	27.0	2.2	1.6
		max	0.030	123.0	212.0	30.1		0.128	141.0	3597.0	268.8	23.0
		25%ile	0.008	62.7	124.5	24.1		0.010	16.9	67.4	6.1	5.0
		75%ile	0.019	98.8	184.5	27.3		0.027	50.4	234.4	26.6	8.6
	Algonquin	average	0.010	13.4	62.4	2.5	1.2	0.023	31.7	261.1	24.7	6.0
		stdev	0.006	24.4	98.7	4.9	1.9	0.019	25.5	375.2	31.7	2.0
		n	871	643	667	380	10	136	111	131	60	49
		min	0.002	0.0	0.0	0.0	0.0	0.002	5.0	28.9	2.4	3.7
		max	0.056	145.5	1457.3	52.5	4.9	0.128	126.1	2079.0	184.5	12.2
		25%ile	0.006	0.0	23.0	0.0	0.0	0.011	15.9	67.4	5.9	5.0
		75%ile	0.012	12.4	66.3	3.3	2.7	0.028	37.6	251.5	31.0	6.2
	Lac Seul	average	0.013	39.8	57.9	7.0		0.019	33.7	66.4	15.1	
		stdev	0.006		24.4	3.4		0.005		34.5	12.7	
		n	36	1	36	36	0	3	2	3	3	0
		min	0.005		25.0	2.0		0.014	25.8	27.0	3.0	
		max	0.027		102.0	13.0		0.023	41.6	90.9	28.3	
		25%ile	0.009		38.5	4.0		0.017		54.2	8.5	
		75%ile	0.017		75.0	10.0		0.021		86.2	21.2	
	Nipigon	average	0.016	46.9	70.8	9.8		0.019	69.0	120.4	7.4	
		stdev	0.008	40.6	51.0	10.5		0.006		98.6	2.1	
		n	10	4	9	7	0	5	2	5	3	0
		min	0.007	7.1	38.0	4.0		0.009	64.1	45.0	6.0	
		max	0.036	102.1	191.0	33.3		0.024	73.9	280.5	9.9	
		25%ile	0.012	23.9	39.0	4.6		0.019		50.0	6.2	
		75%ile	0.018	62.2	75.0	7.5		0.023		148.6	8.2	
	Lake of the Woods	average	0.013	18.4	48.8	7.9		0.020	49.2	96.6	12.4	8.3
		stdev	0.007	14.3	28.9	20.0		0.009	1.9	47.3	6.4	
		n	145	15	110	107	0	6	3	4	4	1
		min	0.001	6.7	23.0	2.0		0.004	47.0	27.0	2.8	
		max	0.038	51.0	165.0	208.0		0.028	50.7	129.8	16.8	
		25%ile	0.008	9.6	30.3	3.0		0.019	48.4	87.5	12.0	
		75%ile	0.016	21.3	54.0	7.0		0.025	50.3	123.8	15.4	
	Lake Temiscamingue Lowland	average	0.009	20.9	281.5	7.7		0.014	29.7	499.0	32.2	4.8
		stdev	0.006	32.6	495.9	5.0		0.012	27.8	789.1	74.7	1.9
		n	56	41	37	17	0	60	48	58	12	12
		min	0.002	0.1	29.8	2.4		0.003	0.1	36.3	4.6	1.6
		max	0.031	199.0	2872.2	16.9		0.058	141.0	3597.0	268.8	7.8
		25%ile	0.004	3.5	51.0	3.7		0.006	12.6	68.8	6.7	4.3
		75%ile	0.013	27.8	426.4	12.7		0.019	37.2	633.3	17.6	5.8
	Thunder Bay-Quetico	average	0.012	21.1	39.6	4.7		0.028	55.1	118.2	13.7	15.4
		stdev	0.010	12.2	26.0	4.2		0.018	26.8	81.5	11.1	
		n	184	5	184	179	0	25	14	25	25	1

Ecozone	Ecoregion	Data	Lakes					Rivers				
			TP	Alk	Cond	Ca	DOC	TP	Alk	Cond	Ca	DOC
		min	0.003	8.6	14.0	0.9		0.009	31.9	27.0	2.2	
		max	0.079	34.0	158.0	24.0		0.071	107.0	323.1	44.7	
		25%ile	0.007	9.5	25.0	2.3		0.014	39.5	47.0	5.1	
		75%ile	0.013	32.8	42.0	5.0		0.044	71.9	155.0	16.2	

Ecozone	Ecoregion	Data	Lakes					Rivers				
			TP	Alk	Cond	Ca	DOC	TP	Alk	Cond	Ca	DOC
	Southern Laurentians	average						0.013	19.9	67.0	7.0	7.0
		stdev						0.006		1.7	0.3	
		n	0	0	0	0	0	3	2	3	2	2
		min						0.006	19.1	66.0	6.8	6.5
		max						0.018	20.8	68.9	7.2	7.4
		25%ile						0.010		66.0	6.9	
		75%ile						0.016		67.5	7.1	
	Rainy River	average						0.033	32.5	80.9		
		stdev						0.010	4.4	18.1		
		n	0	0	0	0	0	4	3	4	0	0
		min						0.019	27.4	54.9		
		max						0.039	35.2	93.7		
		25%ile						0.031	31.1	75.2		
		75%ile						0.039	35.0	93.2		
Mixed Wood Plains	*St-Laurent Lowlands*	average	0.016	76.7	198.8	23.2		0.056	144.6	371.8	48.9	7.0
		stdev	0.010	31.5	76.8			0.052	68.7	182.4	22.2	1.9
		n	16	7	7	2	0	38	28	38	36	12
		min	0.004	10.4	45.8	5.4		0.014	26.5	89.8	9.5	4.9
		max	0.045	104.0	270.0	41.0		0.306	284.1	810.3	84.6	11.5
		25%ile	0.010	73.2	181.8			0.026	94.0	215.1	32.0	5.9
		75%ile	0.020	94.0	245.8			0.065	197.9	492.8	65.2	7.3
	Frontenac Axis	average	0.019	91.4	206.8			0.034	135.2	316.3	37.4	5.9
		stdev	0.005	28.2	48.4			0.021	39.9	100.8	9.9	
		n	9	6	6	0	0	5	3	3	3	1
		min	0.012	40.0	117.0			0.009	110.8	251.9	31.1	
		max	0.026	112.0	263.0			0.062	181.3	432.4	48.8	
		25%ile	0.015	84.0	207.0			0.019	112.2	258.2	31.7	
		75%ile	0.022	109.8	222.0			0.048	147.5	348.5	40.5	
	Lake Erie Lowland	average	0.031					0.109	187.7	706.7	76.2	4.4
		stdev	0.021					0.116	35.4	304.1	36.8	2.5
		n	10	0	0	0	0	315	147	314	264	174
		min	0.009					0.004	99.6	294.9	0.0	1.2
		max	0.080					0.902	258.5	2240.0	477.0	20.0
		25%ile	0.014					0.032	174.6	537.1	65.0	2.8
		75%ile	0.038					0.139	210.4	769.2	85.1	5.1
	Manitoulin-Lake Simcoe	average	0.019	112.8	239.3	32.2	5.4	0.051	197.6	518.5	62.6	5.8
		stdev	0.021	49.4	86.1	9.3	2.0	0.054	47.5	349.9	18.9	2.4
		n	83	31	35	29	8	309	203	308	219	87
		min	0.006	15.9	66.0	6.6	3.1	0.006	23.6	49.0	0.0	1.4
		max	0.162	224.0	436.0	48.6	10.0	0.561	293.5	5750.0	111.3	15.5
		25%ile	0.010	80.3	200.5	30.7	4.7	0.024	192.7	416.5	52.2	4.5
		75%ile	0.020	146.5	296.5	36.2	5.2	0.061	225.7	571.1	74.9	6.4
Hudson Plains	*James Bay Lowlands*	average						0.028	78.5	168.0	25.1	
		stdev										
		n	0	0	0	0	0	2	2	2	2	
		min						0.027	63.7	113.6	21.0	
		max						0.029	93.3	222.4	29.1	
		25%ile										
		75%ile										