Phosphorus and the Kawartha Lakes

(Land use, Lake Morphology and Phosphorus Loading)

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Executive Summary

The following document was prepared for the Kawartha Lake Stewards Association to address concerns over possible elevated phosphorus concentrations in the Kawartha Lakes. The project was undertaken by Michael White (Ph.D. candidate) in partial fulfilment of a reading course requirement (WEGP590) and supervised by Dr. Marguerite Xenopoulos. Submitted with this document is a CD containing all raw data used in the synthesis of this report including ArcMap® files and other pertinent information.

The development of this reading course/research was initiated by the Kawartha Lake Stewards Association (KLSA). KLSA approached Trent University with concerns regarding unnatural eutrophication of their aquatic systems due to suspected increases in phosphorus concentrations. Using archived data, KLSA would like to know the following; do lakes in their watersheds have higher than "normal" phosphorus concentrations, where are the areas of concern, what is the relationship of phosphorus with current watershed land use patterns (potential sources), and recommendations for future investigations into this issue.

The findings of this report (based on data mining sources) conclude that the morphology of many of the Kawartha Lakes, shallow with an abundance of littoral areas, geology, located between the granitic Canadian Shield to the north and glacial till to the south, along with high agricultural land use to the south make the Kawartha Lakes inherently susceptible to having above average (20-30 µg/l) phosphorus concentrations. The results found within should be viewed cautiously, as the data utilized in its synthesis was not initially collected under a unified design; therefore, the results may prove spurious should detailed field investigations be undertaken as is suggested in the conclusion of this report. All ecological studies are subject to erroneous results leaving room for misinterpretation. This report is a summation of available data on which to base direction for further/future research.

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1.0 Introduction

Area Description

The Kawartha Lakes watershed contains 31 sub-watersheds and covers an area of approximately 8,990 km^2. It contains numerous lakes, many of the largest form part of the Trent Severn Waterway. The southern half of the watershed is dominated by glacial till and littered with drumlins and of course the Oak Ridges Moraine. The northern half of the watershed is predominantly Canadian Shield and is the start of "cottage country". For a detailed history and description of the study area please see THE KAWARTHA LAKES (Walters, 2006).

Importance of Phosphorus

Human induced nutrient enrichment, or eutrophication, of aquatic ecosystems has been the focus of much research over the past two decades (Beasley et al., 1985; Hart et al., 2004; Makarewicz and Bertram, 1991; Schindler et al., 1971; Sims et al., 1998). Even though other nutrients are associated with eutrophication, phosphorus is of major concern as it is usually the most limiting nutrient in freshwater ecosystems (Schindler, 1977). The relationship between lake eutrophication (nutrient loading) and phytoplankton abundance became common knowledge about 30 years ago (Schindler, 1987; Vollenweider, 1976) and we now understand that lakes are subject to regime shifts from clear macrophyte dominated systems to turbid phytoplankton dominated systems (Bayley and Prather, 2003; Genkai-Kato and Carpenter, 2005). The driving force behind the clear to turbid shift is elevated phosphorus concentrations (Delerck et al., 2005; Jeppesen et al., 2005; Portielje and Rijsdijk, 2003). The elevated phosphorus concentrations correspond to increased phytoplankton production (Table 1.1).

The Phosphorus Cycle

Phosphorus is found in both soluble and insoluble forms, which together account for the total phosphorus (TP) in a lake ecosystem. The insoluble forms occur predominantly from dead or decaying organisms (leaf litter, aquatic macrophytes, phytoplankton, zooplankton, etc.) and eventually falls to the lake bottom, while the soluble forms stay suspended in the lake water column. Soluble phosphorus is comprised of numerous complex compounds; however, a proportion is soluble reactive phosphorus (SRP). SRP is readily used (absorbed) by phytoplankton and macrophytes and thus increases lake productivity. Almost all natural sources of phosphorus (~90%) enter a lake system in the insoluble form, whereas, phosphorus from anthropogenic (human induced) sources are predominately of the soluble form (~90%) (Mackie, 2001). This means that phosphorus entering aquatic systems from human sources is immediately available for primary production. The insoluble phosphorus, which has fallen to the lake sediment, can be converted to soluble form and is not trapped there permanently. The mobilization process can be quite complex, but in its simplest form insoluble phosphorus can be reduced to a soluble state at the sediment-water interface through decreasing redox potential and pH levels. These conditions exist when lake sediment oxygen levels decrease and become anoxic (depleted of oxygen). This anoxic condition occurs in lakes when algae die and fall to the lake bottom. As the dead algae are decomposed bacteria consume oxygen and favourable conditions for phosphorus mobilization occur (Mackie, 2001). Thus, once a lake becomes eutrophic (turbid algal state) this negative feedback loop can make restoration efforts challenging.

So what does this tell us? It is possible to limit anthropogenic sources of phosphorus, creating an initial decrease in levels; however, long-term reduction may take many years as the insoluble phosphorus is mobilized and absorbed by plant species. The easiest way to restore a lake is to prevent it from becoming eutrophic in the first place. Recent studies suggest that the degree and rate at which a lake can reduce its phosphorus concentration depends on many factors; these are discussed in the following section.

Lake Recovery Potential

The undesirable phenomenon of lake eutrophication has lead to many restoration efforts. Current research has been devoted to discovering the underling drivers in the re-oligotrophication process. Søndergaard *et al*. (2005) conducted an excellent study of 12 lakes in Denmark to determine lake response to reduced nutrient loads. Their findings demonstrate that internal loading of phosphorus can significantly delay lake recovery (up to 10 years) and that lake morphology (shallow vs. deep basins) must also be considered in restoration efforts. The shallow basins do not stratify (have one thermal layer) and are subject to more wave action thereby altering phosphorus resuspension and remobilization. A similar study by Jeppesen *et al.* (2005), which incorporated the same Danish lakes into a larger data set of 35 case studies, had similar conclusions concerning reduced nutrient loading. They found that internal loading delayed lake recovery; lower phosphorus levels did not stabilize until 10-15 years had past. Interestingly, fish biomass was found to decline in the majority of cases; however, piscivorous (fish that eat other fish) increased in 80% of the case studies. Phytoplankton community structure reverted back to oligotrophic species, but submerged macrophyte communities reappeared in only 50% of the lakes for which data was available. As Declerck *et al*. (2005) point out, phosphorus can both directly and indirectly affect aquatic diversity. It can act directly on plants, which absorb it, or indirectly through changes in macrophyte communities creating habitat and refuge for fish and zooplankton.

Two of the most important factors controlling lake response to reduced nutrient loads are mean depth (calculated as the lake volume divided by its surface area) and macrophyte abundance (Genkai-Kato and Carpenter, 2005). Curiously, the lakes most resistant in recovering to a clear state are lakes of intermediate size. These problematic lakes have a mean depth around 10 meters. They are too deep to be aided by macrophytes (which decrease water turbidity by acting as nutrient traps, thus limiting the resuspension of sediment material and negatively affecting algal growth (Portielje and Rijsdijk, 2003)) and too shallow to mitigate internal phosphorus loading through dilution in the hypolimnion (Genkai-Kato and Carpenter, 2005). This suggests that some of the

Kawartha Lakes may not be able to revert to a clear state once a shift to a turbid algal dominated one has occurred.

Table 1.0 Values for spring total phosphorus and average summer chlorophyll a levels in lakes of three trophic states. Modified from Mackie (2001).

Trophic State	Total Phosphorus µg/L	Chlorophyll *a*
Oligotrophic (Clear water)	< 10	< 2
Mesotrophic	10 – 20	2 – 5
Eutrophic (Turbid water)	> 30	> 5

Problem Formulation (What about the Kawartha Lakes?)

Of the many anthropogenic (human induced) sources of phosphorus four are likely to be the significant contributors to the Kawartha Lakes phosphorus levels; agriculture (fertilizer runoff), faulty septic systems, urban runoff, and wastewater treatment facilities. Historical anthropogenic inputs of phosphorus to sediments are also likely in the Kawartha Lakes watershed along with many other natural and unnatural sources but these would be extremely difficult, if not impossible, to reduce. Phosphorus loading by invasive animal populations is also a concern. Emerging evidence suggest that dreissenids (Zebra mussels) can negatively affect phosphorus cycling within lakes (Hecky et al., 2004). It has been postulated that the dreissenids retain phosphorus in nearshore areas where it can accumulate and may be linked with the nuisance filamentous green algae *Cladophora*. Dreissenids invasions in the Kawartha Lakes could be contributing to their high macrophyte (aquatic plants) abundances by filtering phytoplankton (and the phosphorus contained in them) and depositing it as pseudo-feces onto the lake bottom. This causes a reduction of phosphorus concentrations in open water areas but conversely increases concentrations in the sediment-water interface and littoral (nearshore) areas. Similar to dreissenids, there is evidence that geese can significantly elevate nutrient levels (Olson et al., 2005), this may be a problem in the Kawartha lakes area if populations are high.

The Kawartha Lake Stewards Association (KLSA) is concerned about the phosphorus levels in their region. The reason for this concern is that phosphorus levels are currently around 17 µg/L and it is possible that a concentration of > 20 µg/L may lead to foul-smelling algal blooms and a shift towards a turbid algae dominated lake system (KLSA, 2005). Should a shift in lake regime to a turbid system occur it would be difficult and costly, if not impossible, to remediate. The following pages are a summary of archived data with which to assess the history, patterns and possible sources of phosphorus in the Kawartha Lakes.

Study Methodology

The first step in assessing phosphorus levels is to assemble all historical data for the lakes of concern. The data contained in this report were primarily acquired through past studies conducted by the Ministry of the Environment (MOE) (Hutchinson et al., 1994; MOE, 1976), Ministry of Natural Resources (MNR) (Hutchinson et al., 1994), KLSA (KLSA, 2006), MOE's Lake Research Partner program (MOE, 2006) and the Ministry of Natural Resources (MNR) Natural Resources Values and Information System (NRVIS) data base (MNR, 2002).

Using a combination of statistical techniques, regression (Sigma Plot©, Jump©), ordination (PC-ORD©), and analyses of variance (ANOVA)(Jump©) archived data will be utilized to address the following questions:

1. What are the land use characteristics of the Kawartha Lakes watersheds?
2. Is land use correlated with phosphorus concentrations in lakes within the Kawartha Lakes watershed?
3. What lake morphological variables are correlated with phosphorus concentrations?
4. Have phosphorus levels been increasing or decreasing in the lakes within the Kawartha Lakes watershed?
5. What patterns in lake phosphorus concentrations can be determined from the archived data?

The chapters that follow will help elucidate these questions and provide insight into the complex relationships of phosphorus in the Kawartha Lakes.

2.0 Watershed Land Classification and Delineation

Introduction

The first step in determining land use relationships with lake phosphorus concentrations is establishing where and what kinds of land use are prevalent. This first chapter is devoted to determining both, the quantity and location of quaternary (MNRs most detailed watershed delineation) watersheds, and the land use within each.

Methodology

Ontario's NRVIS database (MNR, 2002) and the Water Resources and Information Project (WRIP)(MNR, 2006) were utilized to acquire land class information and watershed delineations. These datum were then overlaid and analysed using ArcMap® to determine watershed boundaries and the land uses within them.

Results

It was found that the Kawartha Lakes watershed (8,990 km^2) consists of 31 quaternary watersheds. As seen in Figure 2.1, of the possible 28 land uses identified by the NRVIS datum the Kawartha Lakes Watershed is represented by 21 different land uses. Interestingly, the chain of lakes running West/East through the middle of the watershed (Trent Severn Waterway) run parallel with a transition zone between forested Canadian Shield (metamorphosed limestone and/or granite) catchments to the north and agricultural glacial till catchments to the south. This transition zone includes a significant limestone alvar plain that runs through the Kawartha Lakes watershed. Principal Components Analysis (PCA) demonstrates a clear gradient between forested and agricultural catchments (Figure 2.2). Exact watershed areas and percent land classifications for each of the 31 watersheds are located in appendix A.

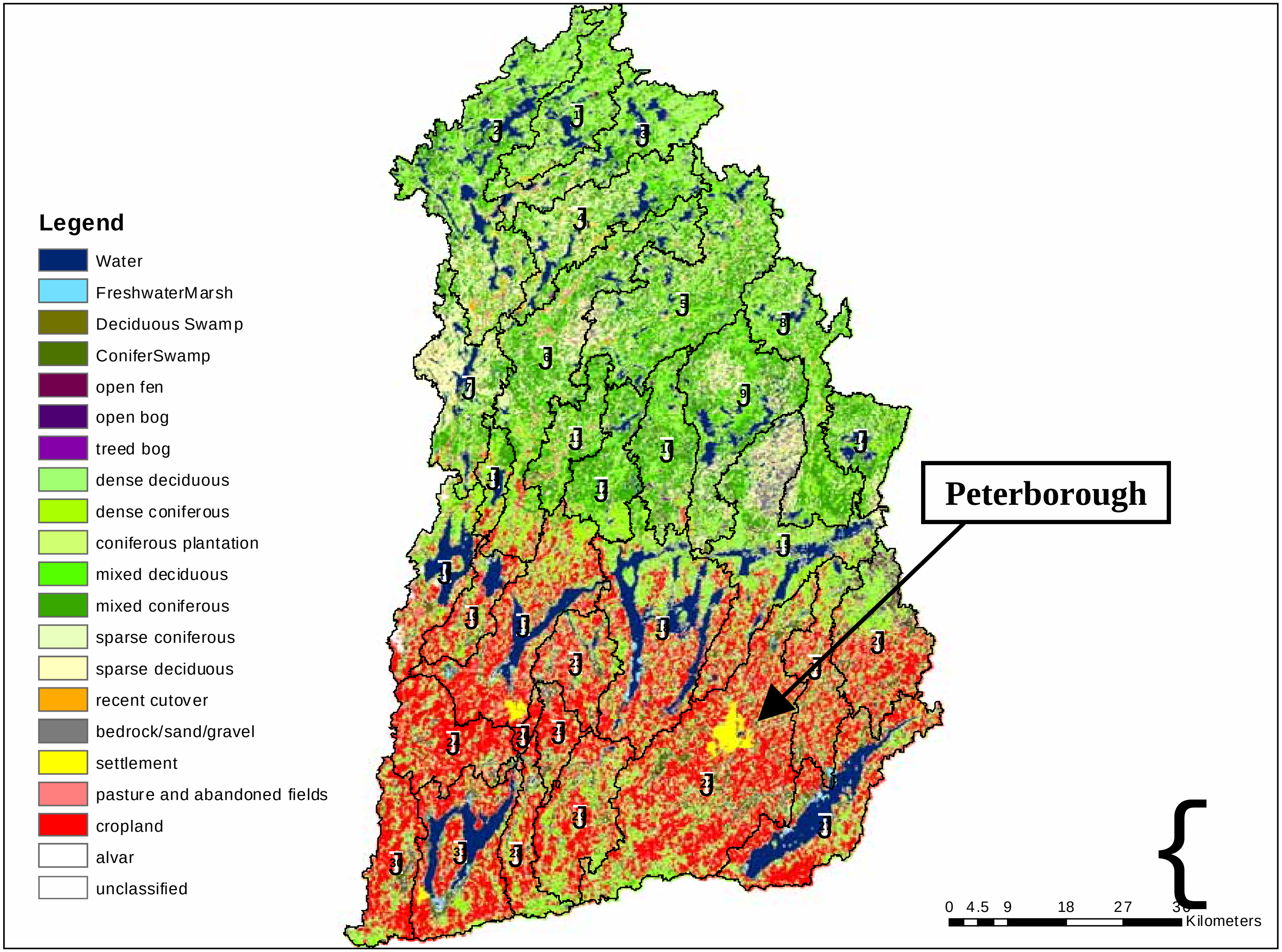

Figure 2.1 NRVIS land classification for the 31 watersheds of the Kawartha Lakes region. Note that forested areas are located in the north on the Canadian Shield and agricultural areas are located to the south on glacial till. Watershed Id's are depicted in white pentagons.

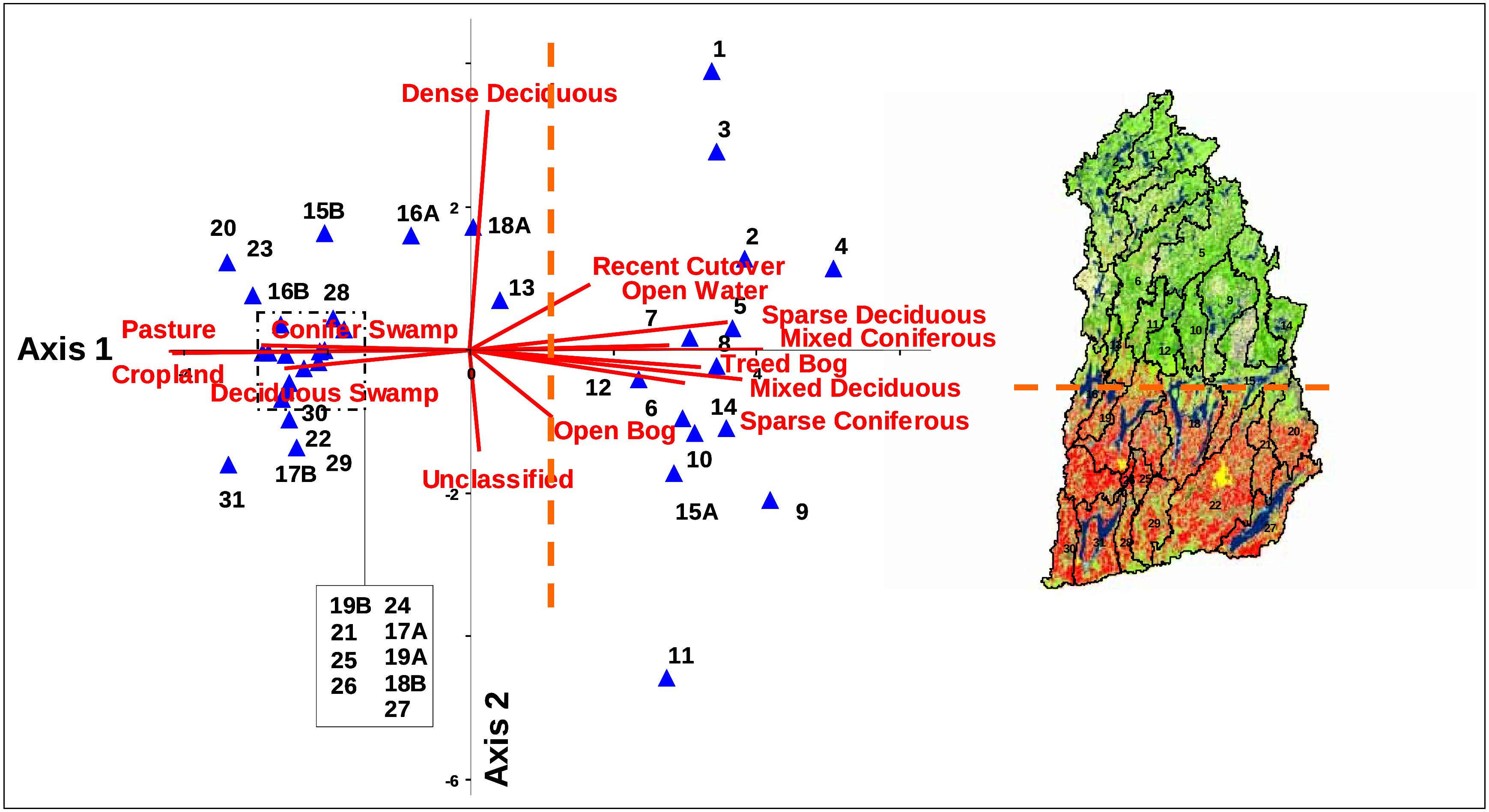

Figure 2.2 PCA ordination of Watershed characterization. Note the majority of the separation is along Axis 1, which demonstrates a clear distinction between forested and agricultural landscapes. Vector length is proportionate to it influence on site separation. This shows graphically the same separation that is shown visually from a land classification map (Figure 2.1). The dashed orange line present in the ordination (left) is transposed on the watershed schematic (right) and demonstrates that the PCA separation in land use is synonymous with the visual separation shown in a land use map. The dashed orange line also represents areas where limestone alvar plain habitat can be found.

Take Home Message

Previous models of lake phosphorus concentrations and catchment related phosphorus dynamics would be problematic if applied to the Kawartha Lakes area. This is due to the unique situation of having lakes located between two extreme geological features combined with unusually shallow lake systems (most have artificially high water levels due to dam creation for the Trent Severn Waterway, this causes the historical floodplain to be inundated with water, which decrease mean depth and increases littoral habitats where macrophytes can proliferate). The landscape to the south of the Kawartha Lakes is dominated by cultivated land with glacial till, while the area to the north is dominated by forested areas and impermeable bedrock.

3.0 Phosphorus Loading Potential

Introduction

The eutrophication of aquatic systems has been a known phenomenon for many years and much research has been undertaken to predict the potential influence of land use on aquatic phosphorus loading. An excellent application of this research in southern Ontario predicts the phosphorus-loading potential of a watershed based on base flow (minimum amount of water available to streams) and cropland. More details on the model can be found online and should be consulted to fully understand this chapter (Metcalfe et al., 2005).

Methodology

The predictive model utilized in this chapter is a direct application of research conducted by Metcalfe et al. (2005) and assigns a value to a watershed based on its potential to contribute phosphorus to watercourses. The values range from 1 – 15, with 1 having a low potential to contribute phosphorus and 15 having the highest potential. This scale was developed after analysing real data from thirteen reference watersheds scattered from Kitchener, ON, to Cornwall, ON. The model incorporates the Base Flow Index (BFI) and percent cropland for a watershed to calculate its phosphorus loading potential (Table 3.1). It then applies the equation:

Phosphorus Susceptibility Index = (% Cropland Class – BFI Class) + 8

Thus, once you figure out the % Cropland and BFI value of a watershed (using available government provided geospatial landscape datum) you can predict its phosphorus loading potential.

Table 3.1 Arbitrary division of classes used in determining the phosphorus loading potential of a watershed. Modified from (Metcalfe et al., 2005).

Class	% Cropland	Class	Upper boundary BFI (%)
1	32.5	1	0.124
2	50.7	2	0.202
3	63.4	3	0.28
4	73.2	4	0.358
5	81.8	5	0.436
6	87.8	6	0.514
7	93.6	7	0.592
8	100	8	1

Results

Although the Kawartha Lakes watershed has a relatively low phosphorus loading potential when compared to the majority of southern Ontario, Figure 3.1, it is unique in that it has an altered waterway (permanently flooded historical flood plain) with which to concentrate its nutrient loading. The 31 quaternary watersheds had percent cropland classes between 1 and 3, and BFI classes between 4 and 8. This resulted in a range of phosphorous susceptibility index values from 1 to7. Comparable to the land classification results in chapter 2, we see a distinct separation along the chain of lakes, with low phosphorus loading potential to the north and high loading potential to the south (Figure 3.2). This model predicts that the southern watersheds will contribute more phosphorus to the Kawartha Lakes than the northern watersheds.

Take Home Message

This model should be interpreted with caution as it does not take into account other morphological variables (i.e. shallow lakes, drainage basin ratio) that may compound the phosphorus loading issue. Although there are many factors that can contribute phosphorus to a watershed; sewage treatment plants, aerial deposition, faulty septic systems and animal feces (beef, poultry, hog operations and large populations of geese and zebra mussels), clearly arable land plays an important component in elevating phosphorus concentrations in water bodies.

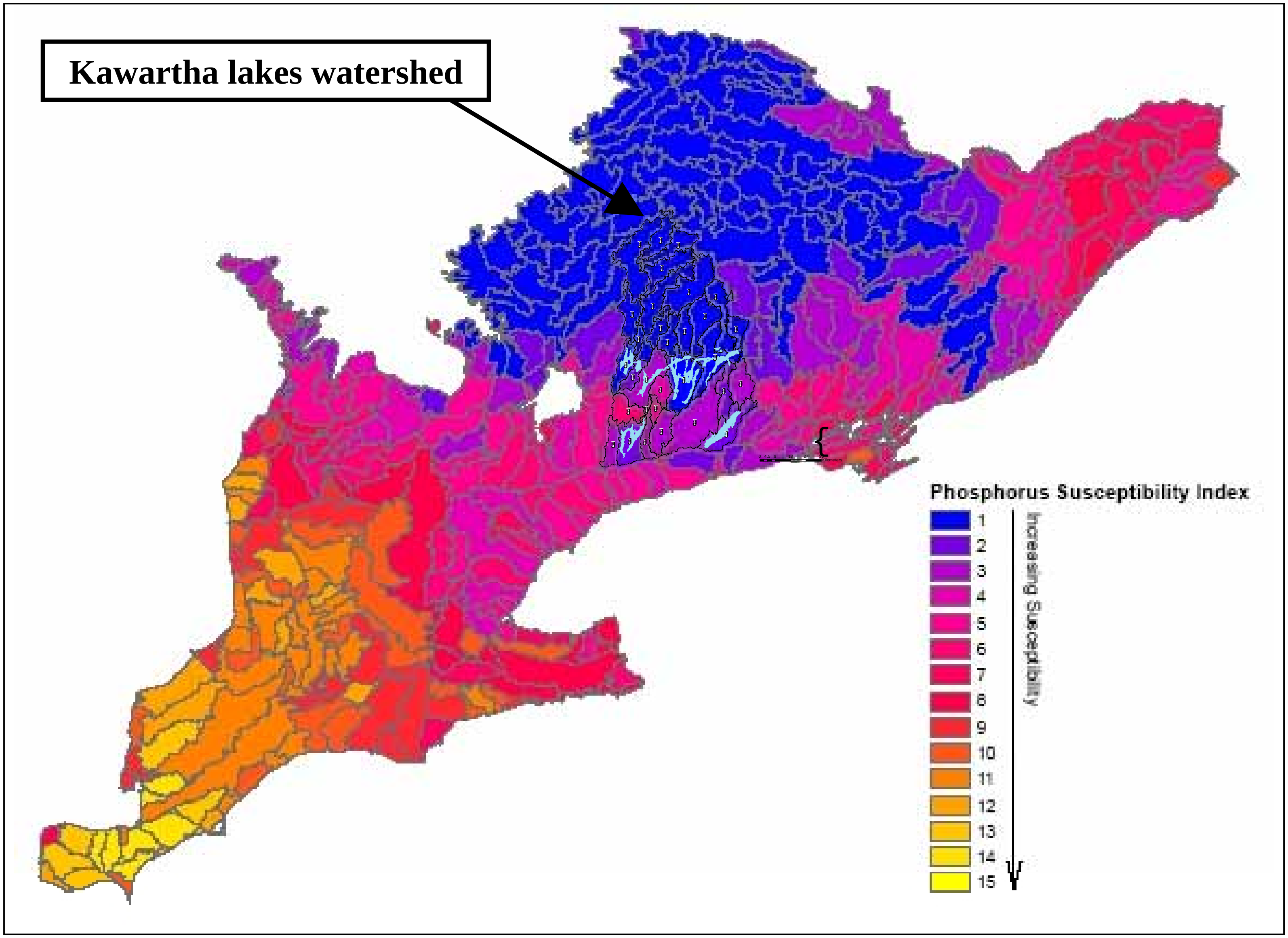

Figure 3.1 Quaternary watershed phosphorus susceptibility in Southern Ontario. Kawartha Lakes watersheds are outlined in black. Base picture taken from (Metcalfe et al., 2005).

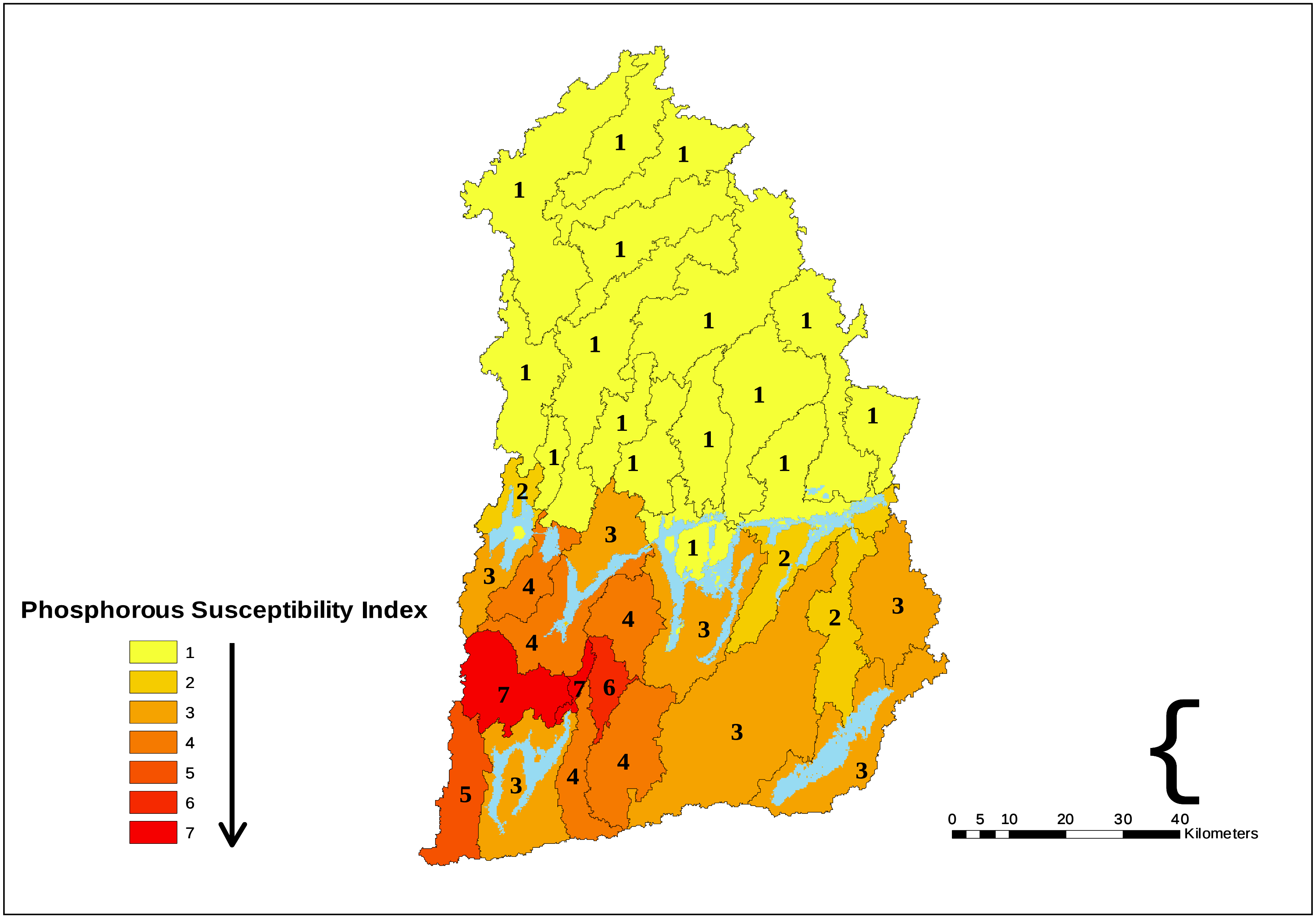

Figure 3.2 Phosphorus susceptibility for the 31 quaternary watersheds of the Kawartha lakes. Susceptibility is determined through modeled base flow and percent agricultural landscape. Note, water entering the Kawartha Lakes from southern catchments is more likely to have higher phosphorus concentrations. Watershed Id's can be found on page 6 in Figure 2.1.

4.0 Land Class and Lake Morphology Correlations with Phosphorus

Introduction

Chapter 4 focuses on one of the major goals of this report, which was to utilize the NRVIS database (outlined in chapter 1) to determine what relationships exist between land use and phosphorus concentrations in the Kawartha Lakes; as nutrient concentrations in watercourses have often been attributed to the land use activities inhabiting them (Beasley et al., 1985; Cooke and Prepas, 1998). A second focus was to resolve any relationships that phosphorus concentrations may demonstrate with lake morphology, similar to findings in other geographic areas (Genkai-Kato and Carpenter, 2005).

Methodology

Multiple linear regression analyses were employed to determine the relationship between phosphorus concentrations and land use/lake morphology characteristics. The "dependant" variable phosphorus was tested for a linear relationship with each "independent" land use/lake morphology variable. Land use information was gathered from the NRVIS database, lake morphology information from the MNR's lake database, and phosphorus concentrations were mean August 2005 values taken from KLSA's dataset. Three analyses were preformed to test for linearity with phosphorus concentrations: increasing watershed contributions, lake buffer of land use (200 m), and lake morphology. In order to test the relationship of watershed accumulation with phosphorus concentration it was necessary to establish which watersheds contribute to each particular lake. Table 4.1, outlines watershed contributions for each of the nine lakes used in analyses. The following nine lakes were the sole lakes with suitable datum for both the watershed land use analysis and lake morphology analysis; Big Bald, Upper Stony, Balsam, Cameron, Sturgeon, Pigeon, Upper Buckhorn, Lovesick, and Katchewanooka Lakes. Similarly, surrounding land use, from shore to 200m, was calculated for each lake using ArcMap®; see appendix B for exact values. A two hundred meter buffer was used as most literature emphasises that a 100-300m buffer is effective at alleviating nutrient runoff and to incorporate the effect of shoreline development. Eleven lakes had suitable datum for the 200m lake buffer analysis; Upper Stony, Upper Buckhorn, Sturgeon, Pigeon, Lovesick, Lower Stony, Katchewanooka, Chemong, Cameron, Big Bald, and Balsam Lakes.

Finally, a linear model was created using four significant variables, from the above-mentioned analyses, that demonstrated the highest r^2 value for the model. The degrees of freedom limited the model to four predictors, as there were only nine observations (lakes) with appropriate datum. Raw data incorporated in analyses can be found in appendix C.

Table 4.1 Watersheds employed in land class/lake morphology correlations with phosphorus. See Figure 2.1 for watershed locations.

Lake Name	Contributing Watershed IDs	Total # of Contributing Watersheds
Big Bald	10	1
Upper Stony	8, 14	2
Balsam	1, 2, 3, 7, 13, 16	6
Cameron	1, 2, 3, 4, 5, 6, 7, 11, 13, 16, 19	11
Sturgeon	1, 2, 3, 4, 5, 6, 7, 11, 13, 16, 17, 19 23, 24, 25, 26, 28, 30, 31	19
Pigeon	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 16, 17, 18, 19, 23, 24, 25, 26, 28, 29, 30, 31	23
Upper Buckhorn	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 16, 17 18, 19, 23, 24, 25, 26, 28, 29, 30, 31	24
Lovesick	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 16 17, 18, 19, 23, 24, 25, 26, 28, 29, 30, 31	25
Katchewanooka	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 23, 24, 25, 26, 28,29,30,31	27

Results – Watershed Accumulation

Interestingly, seven out of twenty-eight land classes demonstrated significant linear relationships ($p < 0.05$) with phosphorus concentration (freshwater marsh $r^2 = 0.87$, coniferous swamp $r^2 = 0.62$, open fen $r^2 = 0.54$, coniferous plantation $r^2 = 0.78$, mixed forest mostly deciduous $r^2 = 0.59$, pasture/abandoned field $r^2 = 0.82$, and cropland $r^2 =0.86$) (Figure 4.1, a-g). Freshwater marsh, coniferous swamp, open fen, coniferous plantation, pasture/abandoned fields, and cropland all demonstrated positive relationships with phosphorus concentrations. Only mixed forest-mostly deciduous proved to have a significant negative relationship with phosphorus concentration. Surprisingly, settlement/developed land did not demonstrate a relationship with phosphorus concentrations (Figure 4.1, i).

Results - Buffer

No significant results were found between land use within 200m of a lake and phosphorus concentrations. Individual linear regressions can be found in appendix C.

Results - Lake Morphology

Linear regression of phosphorus concentration and lake morphology descriptors (maximum depth, mean depth, lake area, shoreline perimeter, island perimeter, total perimeter) resulted in only one significant relationship. Mean depth was negatively correlated ($p = 0.013$, $r^2 = 0.61$) with phosphorus concentration (Figure 4.1, h).

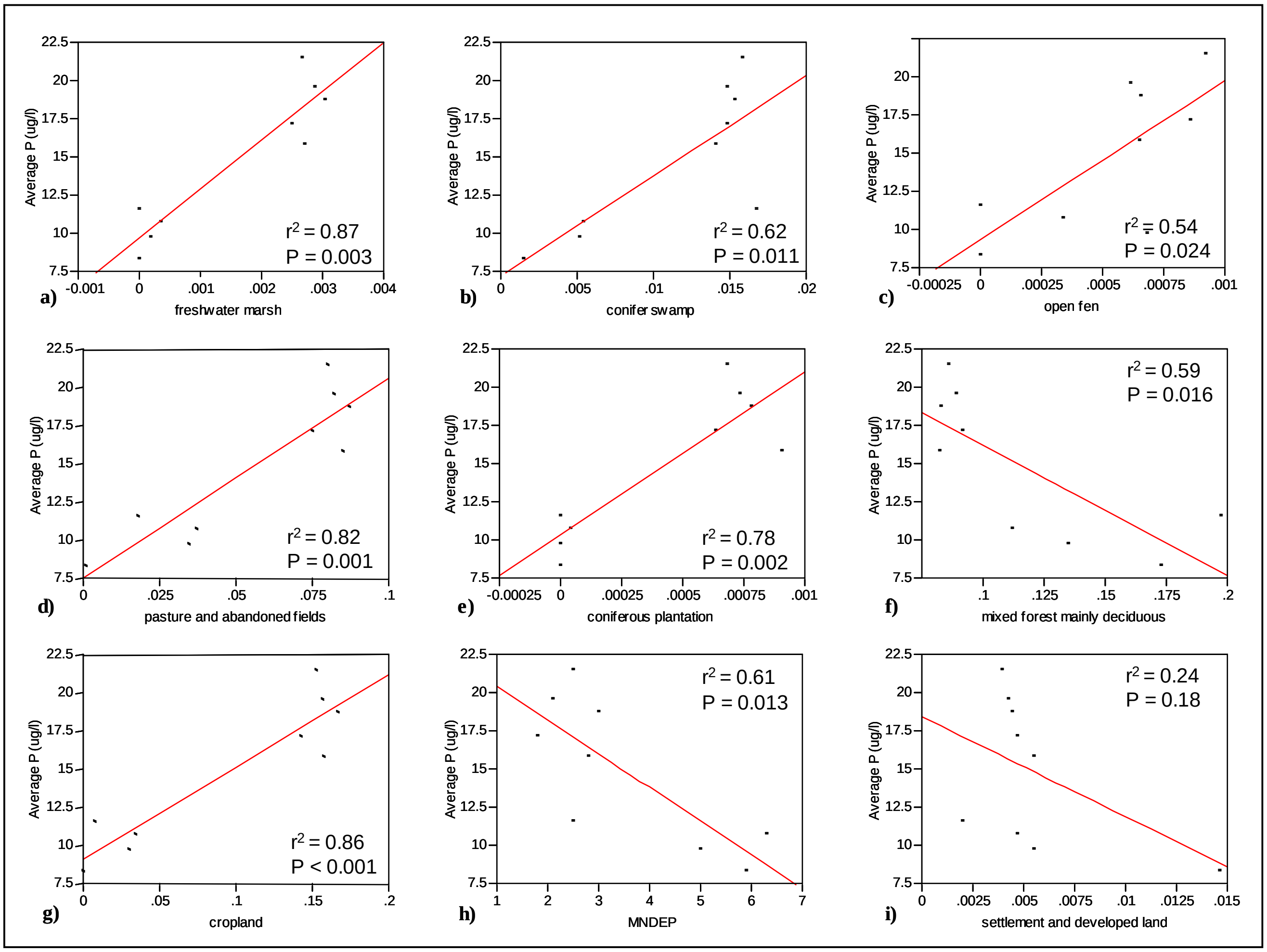

Figure 4.1 Linear regression of total phosphorus with proportion of watershed land classifications for; a) freshwater marsh, b) coniferous swamp, c) open fen, d) pasture and abandoned fields, e) coniferous plantation, f) mixed forest mostly deciduous, g) cropland, h) mean lake depth, i) settlement and developed land. Phosphorus concentrations are calculated from mean August 2005 values (N = 9).

Results - Multiple Regression Model

The four variables resulting in the highest significant r^2 value ($p = 0.026$, $r^2 = 0.90$) using a standard least squares multiple regression model were; mean depth, freshwater marsh, pasture/abandoned fields, and cropland (Figure 4.2). See appendix C for full description of statistical output.

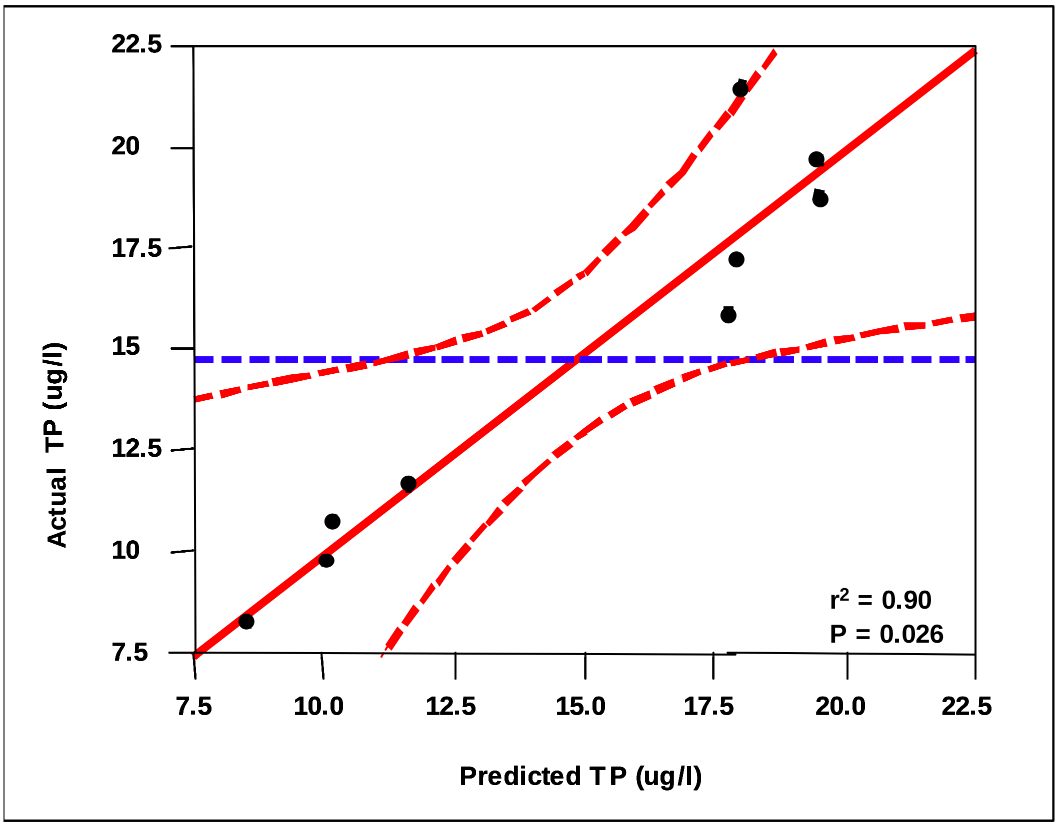

Figure 4.2 Multiple regression predictive model of phosphorus concentrations constructed using the following four environmental predictors; mean depth, freshwater marsh, pasture/abandoned fields, and cropland. Dashed lines delineate 95% confidence intervals.

Conclusion

Phosphorus concentrations in the Kawartha Lakes watershed are highly correlated with land cover; in particular, wetlands, fens, bogs and marshes are good predictors of phosphorus in the Kawartha Lakes. Phosphorus concentrations increased in lakes as the percentage of arable land (cropland/pasture/abandoned fields) contributing to its hydrologic input increased. Congruently, lakes decreased in phosphorus concentration as the percent forest cover increased among its contributing watersheds. Wetlands clearly play a role in elevating a lakes phosphorus concentration; however, the shallower a lake is the more likely it will have an abundance of wetlands making it difficult to say whether it is increased wetlands that elevate phosphorus, or shifts in a lakes nutrient cycling capacity as a result of having a shallower lake basin. It is likely that a combination of the two factors is influencing lake phosphorus concentrations in the Kawartha Lakes watershed.

Although settlement and developed land did not demonstrate a significant relationship with phosphorus concentration they should still be investigated as possible areas of concern during various times of the year.

Take Home Message

Cultivated Land + Shallow Lakes = Elevated Phosphorus

Clearly other sources of phosphorus need to be explored including, urban storm water runoff, waste treatment facilities, golf courses, faulty septic systems, biofouling (Zebra mussels, Canadian Geese), and atmospheric deposition before it is possible to assess the particular mechanisms behind phosphorus concentrations in the Kawartha Lakes watershed. The take home message from this chapter is simply that the lakes belonging to the TSW, and south of the system, are subject to having higher phosphorus concentrations because they are artificially shallow systems in an agricultural area. It is also important to remember that regression analysis is an excellent tool for determining relationships between environmental variables but it does not prove causality.

5.0 Past and Present Phosphorus levels in the Kawartha Lakes

Introduction

This is the final chapter to present new datum and concentrates on elucidating patterns in phosphorus concentrations across both time, and the lake continuum (Balsam to Katchewanooka Lake).

Methodology

Appropriate historical datum was found from two sources (Hutchinson et al., 1994; MOE, 1976). Datum from 1972, 1976 (MOE, 1976) 2003, 2004, and 2005 (KLSA, 2006) were compared using two techniques; analysis of variance (ANOVA) with Tukey's tests for significance, and interpretation of spline curve scatter plot. Similarly, consistently sampled phosphorus concentrations for Sturgeon Lake 1971-1991 (Hutchinson et al., 1994) were analysed using linear regression. A second linear regression was performed using the 1971-1991 data along with KLSA's data from 2003-2005. Finally, non-linear regression was employed to determine if any patterns exist in phosphorous concentration along the lake continuum (Balsam-Katchewanooka). ANOVA analyses could only be conducted to compare three different years of datum, 1972, 1976 and 2005. Other years could not be utilized, as the datum was incomplete for a legitimate analysis. Similarly, the following ten lakes were utilized in the ANOVA analysis as no suitable data was found for other lakes; Balsam, Big Bald, Upper Buckhorn, Cameron, Clear, Katchewanooka, Pigeon, Upper Stony, Lower Stony and Sturgeon.

Results

ANOVA analysis demonstrated a significant response in phosphorus concentration across years. A Tukey's post-hoc test revealed that 2005 total phosphorus concentrations had decreased significantly ($p < 0.05$) from 1972 levels (Figure 5.1).

Linear regression demonstrated a marginally significant ($p = 0.069$, $r^2 = 0.17$) negative trend in phosphorus concentrations across years (1971-1991) and a significant ($p = 0.02$, $r^2 = 0.22$) negative trend across years when the KLSA (2003-2005) datum was included (Figure 5.2).

The spline curve scatter plot is not a test of significance but demonstrates that Figures 5.1 and 5.2 should be interpreted cautiously. Figure 5.3 obscures the decreasing trend in phosphorus concentrations: had appropriate 2003 datum been available, ANOVA analysis may have revealed that phosphorus concentrations had reverted back to 1972 levels.

Finally, Figure 5.4 shows a significant non-linear (logistic 3-parameter) ($p < 0.001$, $r^2 = 0.80$) positive relationship of lake accumulation with phosphorus concentration. This demonstrates that lakes phosphorus concentration increase along the lake continuum.

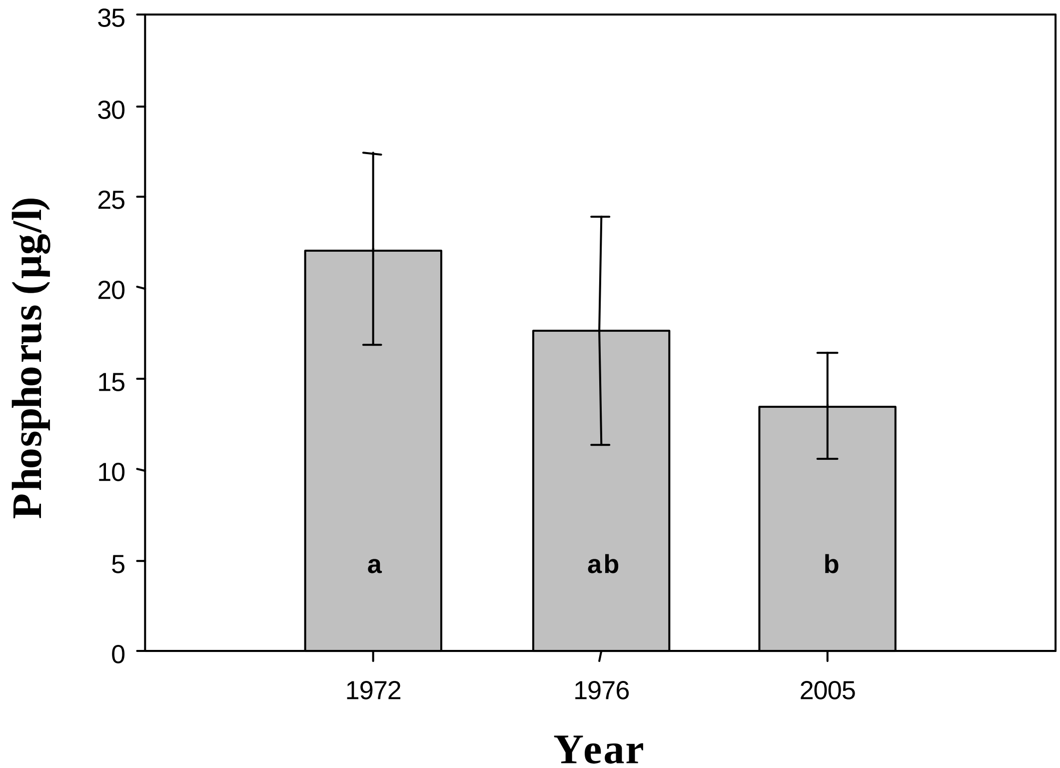

Figure 5.1 Bar graph showing mean August total phosphorus concentrations and standard deviations for ten Kawartha lakes (Balsam, Big Bald, Upper Buckhorn, Cameron, Clear, Katchewanooka, Pigeon, Sturgeon, Upper and Lower Stony) for 1972, 1976 and 2005. Different letters denote significant differences between means following ANOVA procedure and Tukey's test (p = 0.001)(N=10).

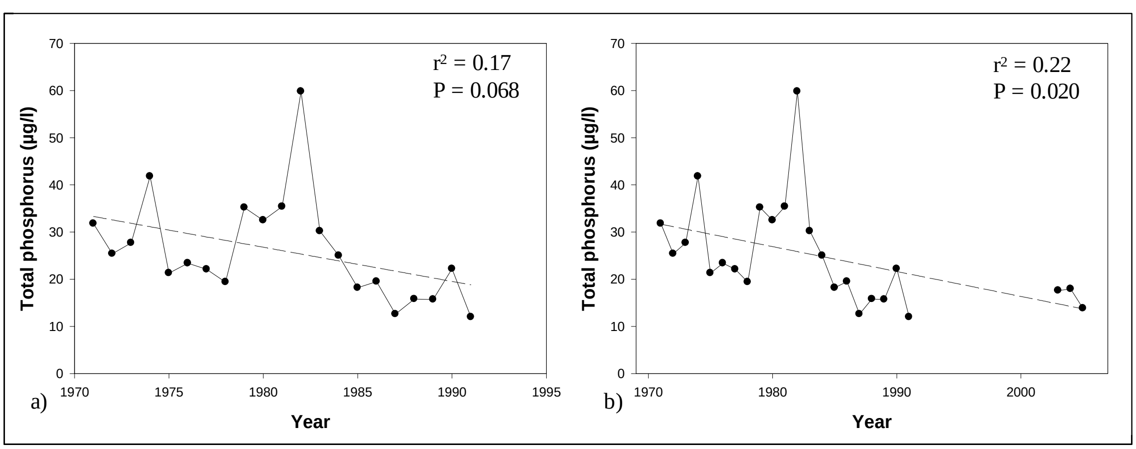

Figure 5.2 Linear regression of August total phosphorus concentrations across years for Sturgeon lake from a) 1971-1991, N = 21, b) 1971-2005, N = 24. Note, it appears phosphorus concentrations have remained relatively constant since 1988.

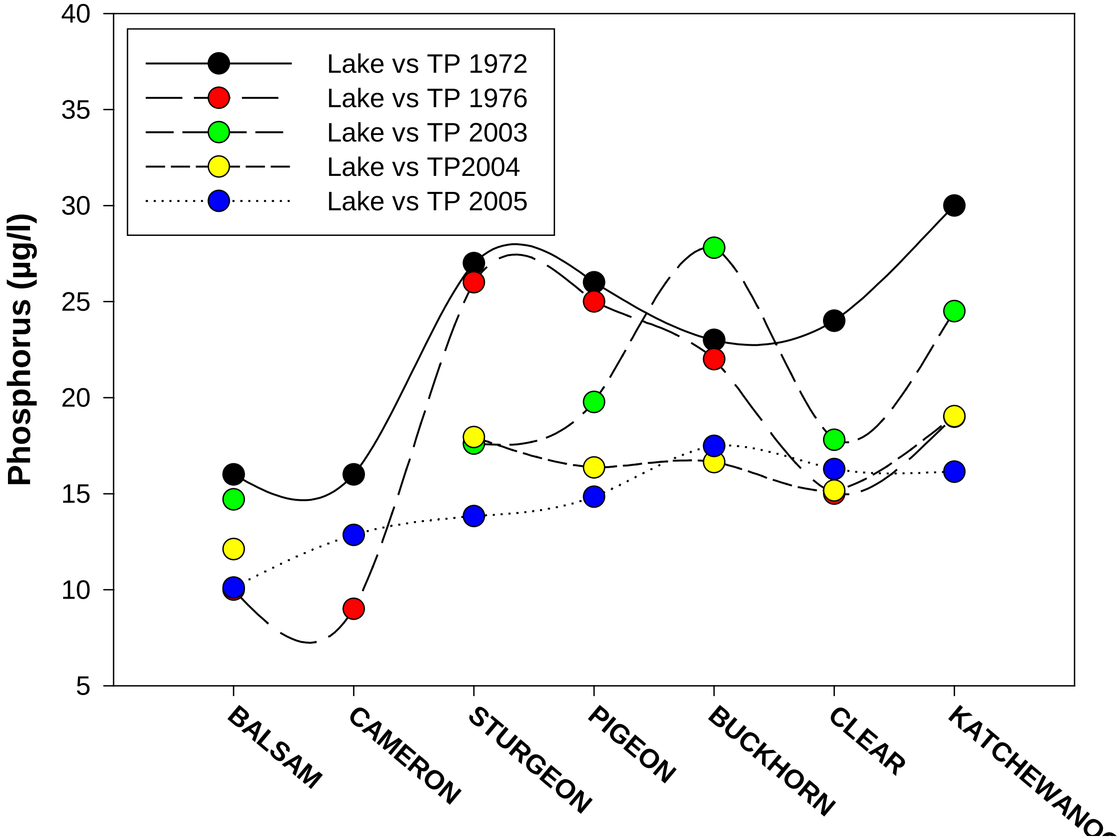

Figure 5.3 Spline curve of seven Kawartha Lakes along a down stream/lake gradient from Balsam Lake to Katchewanooka Lake. Phosphorus levels are pooled August concentrations and patterns should be interpreted cautiously as sample intensity varies greatly between years and lakes.

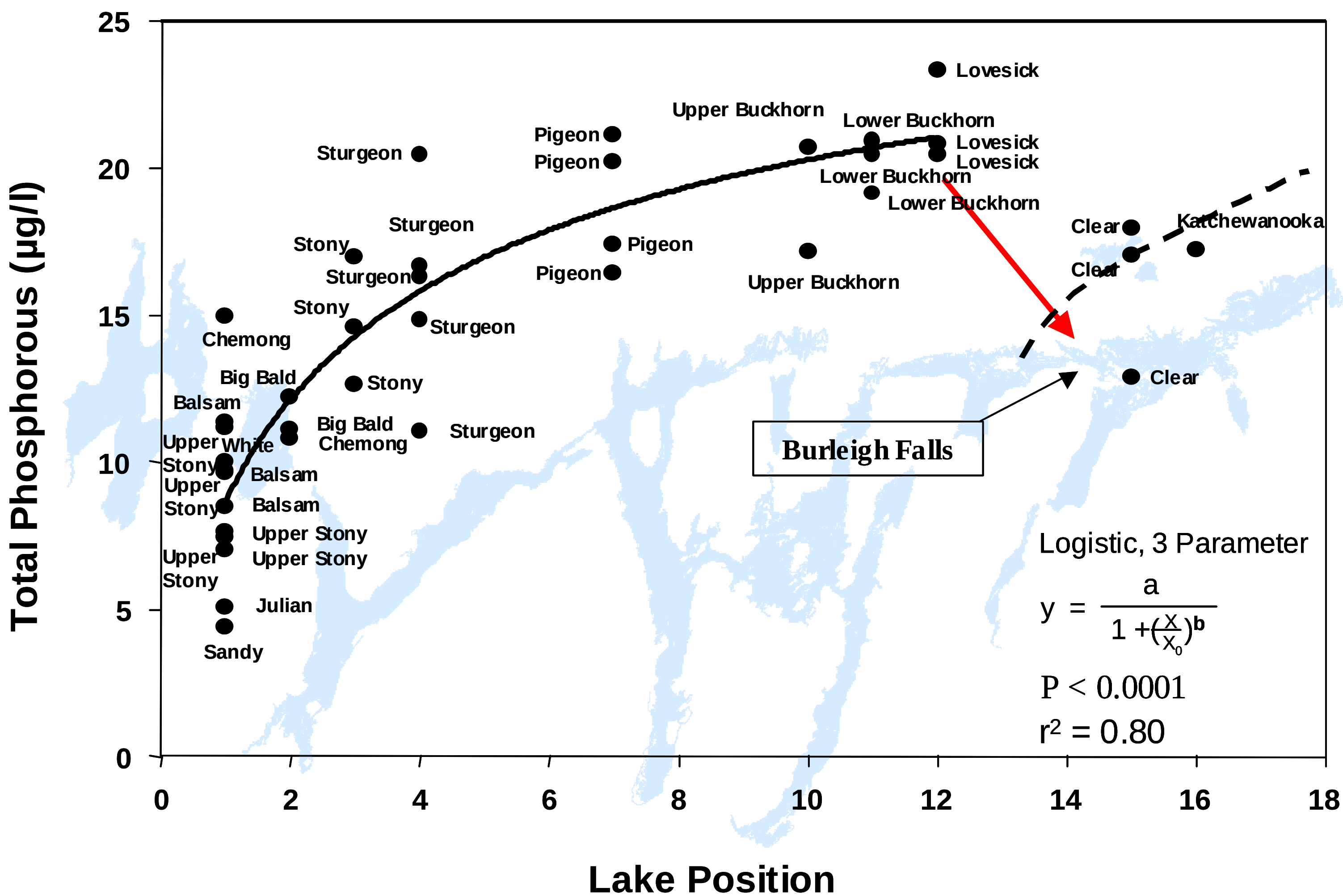

Figure 5.4 Lake chain outline overlaid by a non-linear regression (logistic, 3 parameter, solid black line) of mean August 2005 phosphorus concentrations with lake position. Lake position is defined as 1 plus the number of lakes that eventually feed into it. Lakes used in analyses are either part of the Trent Severn Waterway or contribute to it. Water flows form Balsam Lake (left) through to Katchewanooka Lake (right). Dotted line represents a plausible repetition of the logistic pattern after the dilution and resultant decrease in phosphorus concentration has occurred from the confluence of Upper Stony Lake and Lovesick Lake at Burleigh Falls.

Conclusion

The majority of the archived data and subsequent analyses used in this chapter suggest that phosphorus levels have declined in the Kawartha Lakes watershed, which is congruent with the finding of Robillard and Fox (2006); however, the results should be interpreted cautiously. There is evidence that phosphorus levels are closely linked with precipitation patterns, where wet years have higher phosphorus concentrations than dry years (Novotny and Olem, 1994). According to Environment Canada the Kawartha Lakes area had a much higher average rainfall in 1972 than it did in either 1976 or 2005. Similarly, 1976 had a higher average rainfall in 1976 than it did in 2005; however, it is ostensible that phosphorus levels have been decreasing over time. Fortunately, the datum from Sturgeon Lake was collected annually and demonstrates a clear decreasing trend in phosphorus concentrations over time (Figure 5.3). It would appear that phosphorus concentrations have remained relatively stable in Sturgeon Lake from 1988 through to 2005 at approximately 17 µg/l.

Finally, the results authenticate that lake phosphorus concentrations increase as water flows East through the lake continuum from Balsam Lake to Lovesick Lake. The increasing logistic pattern is then disrupted as phosphorus poor water enters the system from Upper Stony Lake and dilutes the phosphorus rich water of Lovesick Lake below Burleigh Falls in Lower Stony Lake. The lakes' phosphorus concentrations continue to increase after dilution at Lower Stony Lake as demonstrated by the successively higher phosphorus concentrations in Clear and Katchewanooka Lakes.

Take Home Message

Phosphorus levels have declined approximately 7 µg/l over the past 20 years and are currently around 14 µg/l. Phosphorus concentrations are known to increase in wet years and decrease in dry years: 2005 was a dry year. Phosphorus concentrations increase as water flows from Balsam Lake along the Trent Severn Waterway to Rice Lake. There is a slight dilution and resultant reduction in phosphorus concentration as phosphorus poor water enters the system from Upper Stony Lake via Lower Stony Lake (Figure 5.4).

6.0 Conclusions

The Kawartha Lakes watershed is a unique chain of lakes unlike any that have been extensively studied. Many lake models have been developed; however, to this author's knowledge none have been developed to fully incorporate the diverse array of characteristics particular to the Kawartha Lakes:

- "Unnaturally" Shallow basin. Mean depth between 1.8 and 6.3 m.
- Regulated water level due to canal traffic between Georgian Bay and Lake Ontario.
- North shore of lakes exposed to bedrock, south shores exposed to glacial till.
- Southern half of watershed used mainly for Agriculture, northern half mostly forested (Figure 2.1).
- Highly inhabited and intensively used for recreational purposes. (Close proximity to major urban centres)

The findings of this report deal predominantly with land use and lake morphology relationships with phosphorus concentrations. It is evident that lake phosphorus concentrations increase when the proportion of cropland contributing to its hydrological budget increases (Figures 3.2, 4.1, 4.2).

Congruent with land use, phosphorus concentrations also increase with decreasing mean lake depth. These findings are analogous to those outlined in chapter 1 (Genkai-Kato and Carpenter, 2005; Jeppesen et al., 2005; Søndergaard et al., 2005).

Phosphorus concentrations of the Kawartha Lakes exhibit a decreasing trend across years (Figure 5.1, 5.2). The longevity of this trend is questionable and should be investigated in more detail; however, phosphorus concentrations have decreased province wide with the introduction of phosphate regulation in the late 70's and early 80's.

Finally, phosphorus concentrations increase as water flows through the TSW (Figure 5.4). The dilution effect at Stony Lake is convincing evidence that landscape controls (i.e. land use) dictate elevated phosphorus concentrations.

This report is a summation of available information and should not be considered a final resolution regarding phosphorus concentrations in the Kawartha Lakes watershed. Many other avenues should be explored as the potential for unconsidered/untested major sources of phosphorus are anticipated. The findings of this report resolve the importance of lake depth and land use with phosphorus concentrations in lentic systems within the Kawartha Lakes watershed.

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Appendices

Appendix A Watershed Land classification

Percent land classification for each of the 31 watersheds draining into the Kawartha Lakes. See Figure 2.1 for watershed locations.

Land Class / Watershed ID	1	2	3	4	5	6	7	8
Water	15.00%	18.49%	15.12%	13.61%	10.77%	6.75%	13.08%	7.46%
Coastal mudflats	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Intertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Supertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshwater marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.03%	0.00%
Deciduous swamp	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%	0.51%	0.38%
Conifer swamp	0.00%	0.00%	0.00%	0.00%	0.00%	0.45%	0.68%	0.18%
Open fen	0.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Treed fen	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open bog	0.00%	0.02%	0.00%	0.08%	0.00%	0.06%	0.00%	0.00%
Treed bog	0.76%	1.88%	1.23%	2.10%	1.97%	1.66%	0.90%	2.20%
Tundra heath	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Dense deciduous	30.54%	17.13%	28.36%	14.49%	12.81%	7.74%	7.84%	11.31%
Dense coniferous	2.48%	2.21%	1.64%	2.18%	3.37%	9.11%	3.71%	6.94%
Coniferous plantation	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%
Mixed forest mainly deciduous	18.41%	16.51%	16.38%	14.82%	17.72%	12.57%	7.08%	18.47%
Mixed forest mainly coniferous	18.72%	22.88%	20.13%	23.58%	31.30%	33.17%	24.56%	34.40%
Sparse coniferous	1.39%	1.67%	2.41%	3.20%	3.81%	4.31%	2.61%	4.02%
Sparse deciduous	10.90%	15.23%	11.44%	21.27%	15.21%	13.18%	32.85%	10.88%
Recent cutovers	1.25%	0.65%	0.80%	2.27%	0.39%	0.42%	0.24%	0.45%
Recent burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Old cutover and burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bedrock/sand/minetailings	0.00%	0.00%	0.00%	0.00%	0.66%	1.02%	1.12%	1.62%
Settlement and developed land	0.00%	1.07%	0.00%	1.18%	0.86%	0.41%	1.13%	1.54%
Pasture and abandoned fields	0.07%	2.25%	2.50%	1.24%	1.14%	4.82%	1.60%	0.08%
Cropland	0.00%	0.00%	0.00%	0.00%	0.00%	3.87%	2.05%	0.06%
Alvar	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Unclassified	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total area (m^2)	235694375	568402500	274629375	303890000	521921250	511340625	262040625	333803125

Land Class / Watershed ID	9	10	11	12	13	14	15	16
Water	13.56%	4.80%	2.64%	8.30%	12.10%	12.04%	14.64%	21.90%
Coastal mudflats	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Intertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Supertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshwater marsh	0.00%	0.00%	0.00%	0.00%	0.04%	0.00%	0.00%	0.10%
Deciduous swamp	1.29%	1.85%	2.39%	0.86%	1.89%	0.17%	3.55%	2.20%
Conifer swamp	0.78%	1.68%	0.46%	0.63%	1.07%	0.08%	2.87%	2.71%
Open fen	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.50%	0.00%
Treed fen	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open bog	0.11%	0.00%	0.11%	0.00%	0.00%	0.00%	0.00%	0.00%
Treed bog	1.39%	4.77%	1.73%	2.07%	0.00%	3.27%	0.59%	0.00%
Tundra heath	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Dense deciduous	5.70%	7.92%	3.93%	6.88%	11.85%	4.50%	10.70%	9.89%
Dense coniferous	3.98%	5.06%	10.59%	12.45%	20.72%	9.89%	9.65%	13.00%
Coniferous plantation	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed forest mainly deciduous	19.46%	19.76%	15.46%	17.17%	9.68%	14.68%	3.95%	5.70%
Mixed forest mainly coniferous	31.87%	40.99%	45.06%	43.82%	24.34%	37.39%	13.52%	4.97%
Sparse coniferous	7.00%	3.17%	2.28%	0.69%	0.00%	3.98%	3.98%	0.00%
Sparse deciduous	11.09%	7.11%	7.80%	5.64%	2.85%	10.16%	12.43%	2.25%
Recent cutovers	0.03%	0.00%	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%
Recent burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Old cutover and burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bedrock/sand/minetailings	3.22%	0.10%	0.00%	0.10%	0.00%	2.18%	8.53%	0.05%
Settlement and developed land	0.09%	0.20%	0.08%	0.00%	0.00%	1.29%	0.00%	0.00%
Pasture and abandoned fields	0.20%	1.81%	5.60%	0.62%	5.85%	0.21%	5.67%	12.98%
Cropland	0.22%	0.78%	1.65%	0.76%	9.63%	0.02%	9.41%	16.93%
Alvar	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	7.32%
Unclassified	0.00%	0.00%	0.22%	0.00%	0.00%	0.00%	0.00%	0.00%
Total area (m^2)	370907500	204029375	145009375	184938125	68408125	148426250	474902500	221445625

Land Class / Watershed ID	17	18	19	20	21	22	23	24
Water	11.78%	22.11%	11.61%	0.34%	1.85%	1.04%	2.26%	0.25%
Coastal mudflats	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Intertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Supertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshwater marsh	0.81%	0.97%	0.50%	0.00%	0.69%	0.18%	0.13%	0.01%
Deciduous swamp	1.21%	2.24%	2.01%	3.26%	3.83%	5.37%	3.54%	1.78%
Conifer swamp	2.53%	2.25%	4.68%	12.76%	6.88%	3.15%	5.75%	1.87%
Open fen	0.00%	0.13%	0.00%	1.03%	0.22%	0.14%	1.01%	0.00%
Treed fen	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open bog	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Treed bog	0.00%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tundra heath	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Dense deciduous	5.63%	10.47%	7.73%	11.08%	8.93%	9.36%	8.91%	10.57%
Dense coniferous	12.91%	8.65%	11.79%	17.11%	14.39%	7.06%	9.73%	3.40%
Coniferous plantation	0.00%	0.00%	0.00%	0.00%	0.00%	0.24%	0.00%	0.00%
Mixed forest mainly deciduous	2.21%	3.21%	2.32%	1.65%	1.91%	1.49%	2.25%	1.17%
Mixed forest mainly coniferous	4.33%	5.82%	4.15%	6.03%	6.41%	4.87%	4.40%	2.57%
Sparse coniferous	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sparse deciduous	2.28%	6.86%	2.20%	3.82%	3.23%	3.83%	2.10%	2.48%
Recent cutovers	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Recent burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Old cutover and burns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bedrock/sand/minetailings	0.00%	0.00%	0.33%	0.17%	0.10%	0.07%	0.00%	0.10%
Settlement and developed land	2.05%	0.00%	0.00%	0.00%	0.00%	3.59%	0.00%	0.00%
Pasture and abandoned fields	20.77%	12.43%	20.95%	16.72%	22.28%	17.00%	28.04%	20.28%
Cropland	33.49%	24.78%	31.73%	26.02%	29.28%	42.61%	31.88%	55.53%
Alvar	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Unclassified	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total area (m^2)	400200625	533998750	130961250	280700625	213991250	803167500	161599375	228590625

Land Class / Watershed ID	27	28	29	30	31
Water	25.19%	0.37%	0.80%	0.35%	19.65%
Coastal mudflats	0.00%	0.00%	0.00%	0.00%	0.00%
Intertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%
Supertidal marsh	0.00%	0.00%	0.00%	0.00%	0.00%
Freshwater marsh	1.43%	0.11%	0.02%	0.10%	2.30%
Deciduous swamp	2.72%	2.00%	1.79%	1.94%	2.73%
Conifer swamp	2.80%	4.30%	2.91%	3.59%	2.91%
Open fen	0.00%	0.06%	0.03%	0.08%	0.05%
Treed fen	0.00%	0.00%	0.00%	0.00%	0.00%
Open bog	0.00%	0.00%	0.00%	0.00%	0.00%
Treed bog	0.00%	0.00%	0.00%	0.00%	0.00%
Tundra heath	0.00%	0.00%	0.00%	0.00%	0.00%
Dense deciduous	8.20%	12.74%	11.84%	9.38%	6.46%
Dense coniferous	4.23%	14.20%	12.91%	8.06%	6.11%
Coniferous plantation	0.18%	0.00%	0.12%	1.44%	0.43%
Mixed forest mainly deciduous	1.46%	5.34%	4.39%	2.46%	1.45%
Mixed forest mainly coniferous	3.67%	4.58%	5.46%	5.29%	2.85%
Sparse coniferous	0.00%	0.00%	0.00%	0.00%	0.00%
Sparse deciduous	2.16%	1.60%	3.16%	2.04%	1.67%
Recent cutovers	0.00%	0.00%	0.00%	0.00%	0.00%
Recent burns	0.00%	0.00%	0.00%	0.00%	0.00%
Old cutover and burns	0.00%	0.00%	0.00%	0.00%	0.00%
Bedrock/sand/minetailings	0.33%	0.83%	0.54%	0.22%	0.01%
Settlement and developed land	0.22%	0.00%	0.00%	0.00%	0.90%
Pasture and abandoned fields	14.10%	12.66%	15.94%	14.87%	13.85%
Cropland	33.30%	41.21%	40.08%	50.20%	38.63%
Alvar	0.00%	0.00%	0.00%	0.00%	0.00%
Unclassified	0.00%	0.00%	0.00%	0.00%	0.00%
Total area (m^2)	373797500	130019375	257659375	191311250	342918125

Appendix B Land classification buffer (200 meters)

Two hundred meter buffer percent land classification for eleven Kawartha Lakes

Lake Name	Upper Stony	Upper Buckhorn	Sturgeon	Pigeon	Lovesick	Lower Stony	Katchanoka	Chemong	Cameron	Big Bald	Balsam
Water	25.63%	7.46%	6.90%	4.99%	13.14%	11.93%	4.51%	4.30%	9.54%	6.68%	6.28%
Freshwater marsh	0.00%	1.57%	6.75%	16.79%	0.00%	0.00%	0.00%	0.00%	7.63%	0.00%	0.86%
Deciduous swamp	8.59%	8.87%	2.96%	3.63%	19.65%	8.15%	9.89%	5.03%	3.66%	8.85%	2.12%
Conifer swamp	7.95%	2.06%	4.14%	2.04%	11.33%	4.84%	4.67%	1.39%	2.18%	7.99%	2.96%
Dense deciduous	6.52%	12.29%	6.58%	14.55%	9.54%	10.93%	5.29%	7.64%	16.66%	16.84%	16.43%
Dense coniferous	13.60%	6.90%	15.82%	9.38%	8.95%	23.09%	17.49%	9.72%	7.63%	11.18%	19.58%
Mixed forest mainly deciduous	3.56%	1.70%	2.95%	4.79%	7.63%	5.34%	0.74%	1.71%	5.06%	2.56%	8.99%
Mixed forest mainly coniferous	15.76%	5.96%	6.00%	3.61%	8.29%	15.87%	6.54%	3.86%	5.11%	8.61%	9.42%
Sparse deciduous	13.39%	18.76%	1.36%	6.91%	16.28%	14.21%	4.99%	7.88%	0.83%	33.63%	1.88%
Bedrock/sand/minetailings	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.23%	0.00%	0.00%
Pasture and abandoned fields	2.02%	5.61%	11.92%	5.27%	0.52%	0.57%	4.01%	11.26%	15.21%	0.00%	12.40%
Cropland	2.98%	28.81%	34.62%	28.04%	4.66%	5.06%	41.86%	47.21%	26.25%	3.67%	15.93%
Alvar	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.15%

Appendix C Statistical output

Stats for Figure 2.2

```
********* PRINCIPAL COMPONENTS ANALYSIS -- Sites    in Variable space **********
PC-ORD, Version 4.36
25 Sep 2006, 20:08


PCA Kawartha
```

VARIANCE EXTRACTED, FIRST 10 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	8.143	38.777	38.777	3.645
2	2.101	10.006	48.782	2.645
3	1.991	9.483	58.265	2.145
4	1.580	7.522	65.787	1.812
5	1.307	6.225	72.012	1.562
6	1.021	4.864	76.876	1.362
7	0.959	4.566	81.442	1.195
8	0.715	3.405	84.847	1.053
9	0.644	3.065	87.912	0.928
10	0.550	2.617	90.529	0.816

FIRST 6 EIGENVECTORS

	Eigenvector					
Variable	1	2	3	4	5	6
water	0.2974	0.1919	-0.1313	-0.0032	0.0572	0.0287
freshwat	-0.1540	-0.1773	-0.3693	-0.1286	-0.0351	0.0361

deciduou	-0.2521	-0.1579	0.0578	0.2214	0.1660	-0.1238
conifer	-0.2670	0.0775	0.1870	0.1724	0.2350	0.1442
open fen	-0.1061	0.2552	0.2201	0.2178	0.5145	0.2486
open bog	0.1684	-0.2973	0.1274	-0.1882	0.3698	-0.3419
treed bo	0.2819	-0.1480	0.0274	-0.0226	-0.0462	0.2957
dense de	0.0793	0.5641	-0.0721	-0.0196	0.0498	-0.3005
dense co	-0.1390	0.0828	0.4576	-0.1301	-0.2271	0.1925
conifero	-0.1012	-0.1270	-0.2834	-0.0933	-0.0387	-0.2697
mixed fo	0.3175	0.0418	0.1066	-0.1941	-0.0533	0.0820
mixed fo	0.3057	-0.1953	0.1612	-0.0830	-0.0141	0.1959
sparse c	0.2718	-0.2089	-0.0105	0.3770	-0.0406	-0.0972
sparse d	0.2616	0.0770	-0.1149	0.2185	0.1159	-0.0370
recent c	0.2038	0.2948	-0.2168	-0.1433	0.2639	-0.2107
bedrock/	0.0909	-0.1756	0.0084	0.6571	-0.1711	-0.2215
settleme	0.0216	-0.1502	-0.4222	-0.0945	0.0208	0.4097
pasture	-0.3215	-0.0472	-0.0544	-0.0400	0.0842	0.0086
cropland	-0.3192	-0.0721	-0.1979	-0.0403	0.0156	-0.1066
alvar	-0.0528	0.1092	0.2355	-0.1383	-0.4767	-0.3116
unclassi	0.0572	-0.3674	0.2720	-0.2779	0.3186	-0.2641

COORDINATES (SCORES) OF Sites

	Axis (Component)					
Sites	1	2	3	4	5	6
1 1n	3.3818	3.8900	-0.7607	-0.5074	1.1317	-0.9656
2 2n	3.8389	1.2780	-1.1791	-0.6652	0.2404	0.1723
3 3n	3.4528	2.7657	-0.9519	-0.4530	0.0746	-0.9778
4 4n	5.0861	1.1369	-1.7101	-1.0756	1.9813	-1.2162
5 5n	3.6788	0.2985	-0.6070	0.0096	-0.4576	0.6859
6 6n	2.9838	-0.9461	0.2877	-0.1168	0.0723	0.0334
7 7n	3.0816	0.1622	-1.1661	0.9703	-0.0143	0.5649
8 8n	3.4525	-0.2164	-0.4338	-0.0107	-0.6817	1.1612
9 9n	4.2061	-2.0957	0.6645	0.6673	0.6235	-0.8903
10 10n	3.1512	-1.1601	0.7402	-0.1120	-0.7447	1.8185
11 11n	2.7549	-4.5676	3.2048	-2.5971	2.4643	-1.5962

12	12n	2.3713	-0.4134	1.1374	-0.8083	-1.0289	1.4625
13	13n	0.4209	0.7011	1.1287	-0.7299	-0.9064	0.4998
14	14n	3.5804	-1.0842	0.0096	0.1992	-1.0733	1.9239
15	20n	-3.3582	1.3663	2.2749	1.4251	2.2814	1.3206
16	21n	-2.8833	-0.0325	0.5431	0.3362	0.4968	0.3621
17	22n	-2.5185	-0.9625	-1.9023	0.0885	0.4889	0.9169
18	23n	-3.0357	0.7579	1.0182	0.9315	1.9599	0.7848
19	24n	-2.0942	-0.0138	-0.6374	-0.0979	-0.1305	-0.6098
20	25n	-2.8053	-0.0358	-0.1611	0.6377	0.4981	-0.8599
21	26n	-2.5254	-0.4517	-0.8549	0.2633	0.2485	-0.6129
22	28n	-1.8978	0.4495	0.5466	-0.0422	-0.3128	-0.1285
23	29n	-1.7584	0.2835	0.2128	-0.1874	-0.4127	-0.3122
24	30n	-2.6244	-0.6793	-1.5537	-0.5239	-0.2921	-1.6370
25	15A	2.8532	-1.7260	-0.0101	5.9425	-1.2677	-1.5887
26	15B	-2.0230	1.6330	1.8349	1.3185	1.9236	0.8630
27	16A	-0.8120	1.5995	2.6266	-1.4448	-3.1158	-0.9098
28	16B	-2.6371	0.3633	1.3189	-0.4154	-2.0876	-1.6769
29	17A	-2.0181	0.0030	1.4828	-0.5869	-0.9733	0.6165
30	17B	-2.4230	-1.3527	-3.0704	-0.8737	-0.1250	1.7024
31	18A	0.0500	1.7202	0.5784	-0.0144	-0.2281	-0.2763
32	18B	-2.3090	-0.2616	-0.4665	0.0022	0.2203	0.0391
33	19A	-2.1121	-0.1717	-0.0764	-0.6628	-0.6196	0.2484
34	19B	-2.5686	-0.0687	0.4672	0.1292	-0.0292	0.0635
35	27NoRice	-2.5735	-0.5643	-1.4544	-0.1600	-0.0304	-0.6847
36	31NoScug	-3.3667	-1.6045	-3.0815	-0.8359	-0.1738	-0.2968

Writing weighted average scores on 6 axes for   21 Variable
   into file for graphing.

********************************** End of PCA **********************************

************************** Output from Graph **************************

PC-ORD Version 4.36
9/25/2006, 8:10 PM

PCA Kawartha

Pearson and Kendall Correlations with Ordination Axes N= 36

Axis:	1			2			3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
water	.849	.720	.603	.278	.077	.086	-.185	.034	-.121
freshwater marsh	-.439	.193	-.522	-.257	.066	-.194	-.521	.272	-.229
deciduous swamp	-.719	.518	-.605	-.229	.052	-.147	.082	.007	.125
conifer swamp	-.762	.580	-.736	.112	.013	.035	.264	.070	.166
open fen	-.303	.092	-.377	.370	.137	.229	.311	.096	.078
open bog	.480	.231	.388	-.431	.186	-.152	.180	.032	.022
treed bog	.804	.647	.645	-.214	.046	-.105	.039	.001	-.008
dense deciduous	.226	.051	.083	.818	.669	.600	-.102	.010	-.057
dense coniferous	-.397	.157	-.286	.120	.014	.111	.646	.417	.502
coniferous plantation	-.289	.083	-.260	-.184	.034	-.271	-.400	.160	-.340
mixed forest mainly deciduous	.906	.821	.663	.061	.004	.102	.150	.023	.156
mixed forest mainly coniferous	.872	.761	.565	-.283	.080	-.041	.228	.052	.203
sparse coniferous	.775	.601	.657	-.303	.092	-.132	-.015	.000	-.027
sparse deciduous	.746	.557	.492	.112	.012	.044	-.162	.026	-.073
recent cutovers	.582	.338	.586	.427	.183	.180	-.306	.094	-.290
bedrock/sand/minetailings	.259	.067	.170	-.255	.065	-.197	.012	.000	.070
settlement and developed land	.061	.004	.327	-.218	.047	-.338	-.596	.355	-.377
pasture and abandoned fields	-.917	.841	-.660	-.068	.005	.010	-.077	.006	.013
cropland	-.911	.830	-.662	-.105	.011	-.192	-.279	.078	-.125
alvar	-.151	.023	-.110	.158	.025	.187	.332	.110	.273
unclassified	.163	.027	.074	-.533	.284	-.236	.384	.147	.236

************************* Output from Graph *************************
PC-ORD Version 4.36
9/25/2006, 8:11 PM

PCA Kawartha

Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space:

	R Squared	
Axis	Increment	Cumulative
1	.878	.878
2	-.048	.829
3	-.073	.756

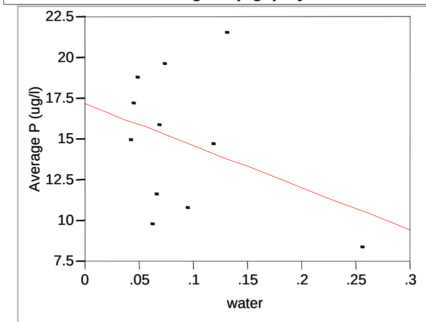
Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes.

Axis pair	r	Orthogonality,% = 100(1-r^2)
1 vs 2	0.000	100.0
1 vs 3	0.000	100.0
2 vs 3	0.000	100.0

Number of entities = 36
Number of entity pairs used in correlation = 630
Distance measure for ORIGINAL distance: Sorensen (Bray-Curtis)

Chapter 4 Regressions
Buffer

Bivariate Fit of Average P (ug/l) By water



Linear Fit

Linear Fit

Average P (ug/l) = 17.218686 - 25.859637 water

Summary of Fit

RSquare	0.138184
RSquare Adj	0.042427
Root Mean Square Error	4.196578
Mean of Response	14.83559
Observations (or Sum Wgts)	11

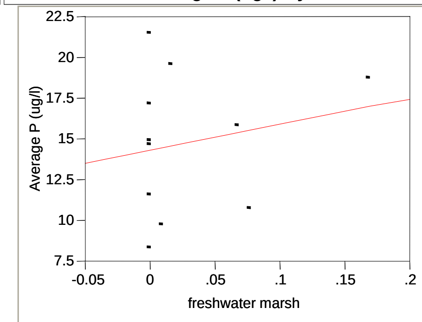
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	25.41420	25.4142	1.4431
Error	9	158.50138	17.6113	Prob > F
C. Total	10	183.91558		0.2603

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.218686	2.352976	7.32	<.0001
water	-25.85964	21.5268	-1.20	0.2603

Bivariate Fit of Average P (ug/l) By freshwater marsh



Linear Fit

Linear Fit

Average P (ug/l) = 14.356731 + 15.674806 freshwater marsh

Summary of Fit

RSquare	0.038239
RSquare Adj	-0.06862
Root Mean Square Error	4.433244
Mean of Response	14.83559
Observations (or Sum Wgts)	11

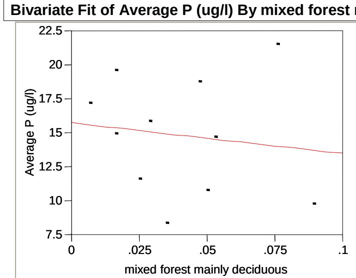
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	7.03267	7.0327	0.3578
Error	9	176.88291	19.6537	Prob > F
C. Total	10	183.91558		0.5645

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.356731	1.55805	9.21	<.0001
freshwater marsh	15.674806	26.20376	0.60	0.5645

Bivariate Fit of Average P (ug/l) By mixed forest mainly deciduous



Linear Fit

Linear Fit

Average P (ug/l) = 15.760883 - 22.608142 mixed forest mainly deciduous

Summary of Fit

RSquare	0.018385
RSquare Adj	-0.09068
Root Mean Square Error	4.478768
Mean of Response	14.83559
Observations (or Sum Wgts)	11

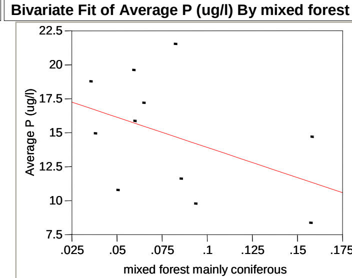
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.38130	3.3813	0.1686
Error	9	180.53427	20.0594	Prob > F
C. Total	10	183.91558		0.6910

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.760883	2.627305	6.00	0.0002
mixed forest mainly deciduous	-22.60814	55.06574	-0.41	0.6910

Bivariate Fit of Average P (ug/l) By mixed forest mainly coniferous



Linear Fit

Linear Fit

Average P (ug/l) = 18.429601 - 44.414975 mixed forest mainly coniferous

Summary of Fit

RSquare	0.192555
RSquare Adj	0.102839
Root Mean Square Error	4.062043
Mean of Response	14.83559
Observations (or Sum Wgts)	11

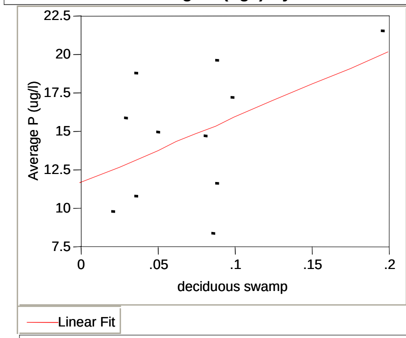
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	35.41382	35.4138	2.1463
Error	9	148.50176	16.5002	Prob > F
C. Total	10	183.91558		0.1770

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	18.429601	2.741958	6.72	<.0001
mixed forest mainly coniferous	-44.41497	30.3171	-1.47	0.1770

Bivariate Fit of Average P (ug/l) By deciduous swamp



Linear Fit

Average P (ug/l) = 11.670415 + 42.782368 deciduous swamp

Summary of Fit

RSquare	0.242761
RSquare Adj	0.158624
Root Mean Square Error	3.933728
Mean of Response	14.83559
Observations (or Sum Wgts)	11

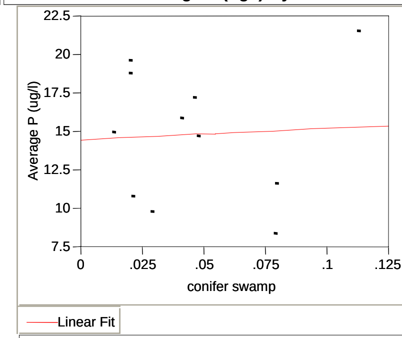
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	44.64761	44.6476	2.8853
Error	9	139.26797	15.4742	Prob > F
C. Total	10	183.91558		0.1236

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.670415	2.208837	5.28	0.0005
deciduous swamp	42.782368	25.18663	1.70	0.1236

Bivariate Fit of Average P (ug/l) By conifer swamp



Linear Fit

Average P (ug/l) = 14.487393 + 7.4314625 conifer swamp

Summary of Fit

RSquare	0.003005
RSquare Adj	-0.10777
Root Mean Square Error	4.513719
Mean of Response	14.83559
Observations (or Sum Wgts)	11

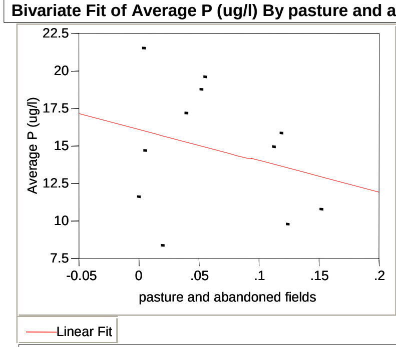
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.55268	0.5527	0.0271
Error	9	183.36289	20.3737	Prob > F
C. Total	10	183.91558		0.8728

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.487393	2.514261	5.76	0.0003
conifer swamp	7.4314625	45.12016	0.16	0.8728

Bivariate Fit of Average P (ug/l) By pasture and abandoned fields



Linear Fit

Average P (ug/l) = 16.141106 - 20.871048 pasture and abandoned fields

Summary of Fit

RSquare	0.071938
RSquare Adj	-0.03118
Root Mean Square Error	4.354884
Mean of Response	14.83559
Observations (or Sum Wgts)	11

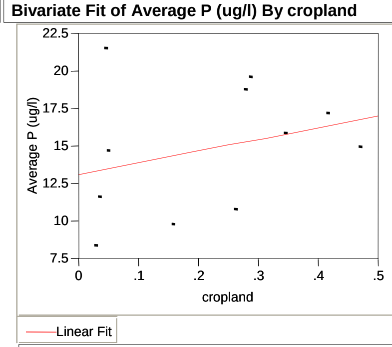
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13.23048	13.2305	0.6976
Error	9	170.68510	18.9650	Prob > F
C. Total	10	183.91558		0.4252

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.141106	2.04137	7.91	<.0001
pasture and abandoned fields	-20.87105	24.98809	-0.84	0.4252

Bivariate Fit of Average P (ug/l) By cropland



Linear Fit

Average P (ug/l) = 13.161968 + 7.6991396 cropland

Summary of Fit

RSquare	0.084174
RSquare Adj	-0.01758
Root Mean Square Error	4.326079
Mean of Response	14.83559
Observations (or Sum Wgts)	11

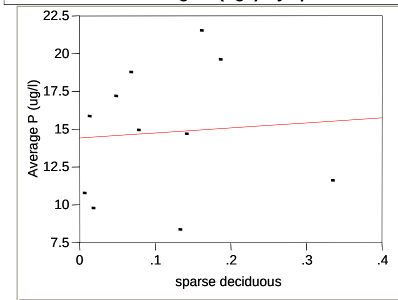
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	15.48094	15.4809	0.8272
Error	9	168.43463	18.7150	Prob > F
C. Total	10	183.91558		0.3868

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	13.161968	2.255551	5.84	0.0002
cropland	7.6991396	8.465214	0.91	0.3868

Bivariate Fit of Average P (ug/l) By sparse deciduous



Linear Fit

Linear Fit

Average P (ug/l) = 14.479182 + 3.2632672 sparse deciduous

Summary of Fit

RSquare	0.00555
RSquare Adj	-0.10494
Root Mean Square Error	4.507954
Mean of Response	14.83559
Observations (or Sum Wgts)	11

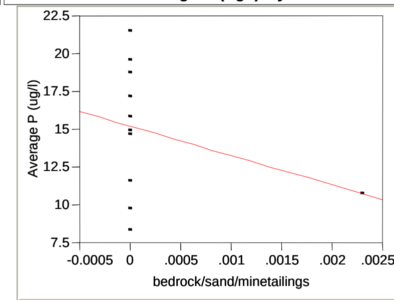
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.02074	1.0207	0.0502
Error	9	182.89484	20.3216	Prob > F
C. Total	10	183.91558		0.8277

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.479182	2.091977	6.92	<.0001
sparse deciduous	3.2632672	14.56044	0.22	0.8277

Bivariate Fit of Average P (ug/l) By bedrock/sand/minetailings



Linear Fit

Linear Fit

Average P (ug/l) = 15.24365 - 1947.326 bedrock/sand/minetailings

Summary of Fit

RSquare	0.099591
RSquare Adj	-0.00045
Root Mean Square Error	4.289512
Mean of Response	14.83559
Observations (or Sum Wgts)	11

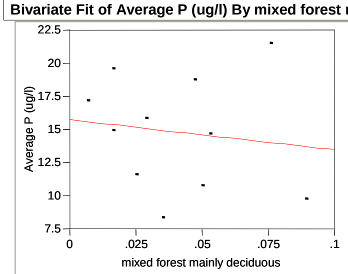
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	18.31634	18.3163	0.9955
Error	9	165.59923	18.3999	Prob > F
C. Total	10	183.91558		0.3445

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.24365	1.356463	11.24	<.0001
bedrock/sand/minetailings	-1947.326	1951.763	-1.00	0.3445

Bivariate Fit of Average P (ug/l) By mixed forest mainly deciduous



Linear Fit

Linear Fit

Average P (ug/l) = 15.760883 - 22.608142 mixed forest mainly deciduous

Summary of Fit

RSquare	0.018385
RSquare Adj	-0.09068
Root Mean Square Error	4.478768
Mean of Response	14.83559
Observations (or Sum Wgts)	11

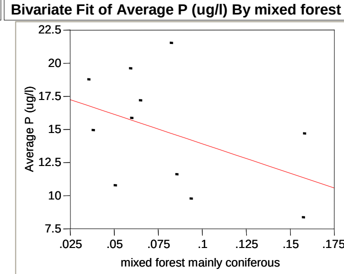
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.38130	3.3813	0.1686
Error	9	180.53427	20.0594	Prob > F
C. Total	10	183.91558		0.6910

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.760883	2.627305	6.00	0.0002
mixed forest mainly deciduous	-22.60814	55.06574	-0.41	0.6910

Bivariate Fit of Average P (ug/l) By mixed forest mainly coniferous



Linear Fit

Linear Fit

Average P (ug/l) = 18.429601 - 44.414975 mixed forest mainly coniferous

Summary of Fit

RSquare	0.192555
RSquare Adj	0.102839
Root Mean Square Error	4.062043
Mean of Response	14.83559
Observations (or Sum Wgts)	11

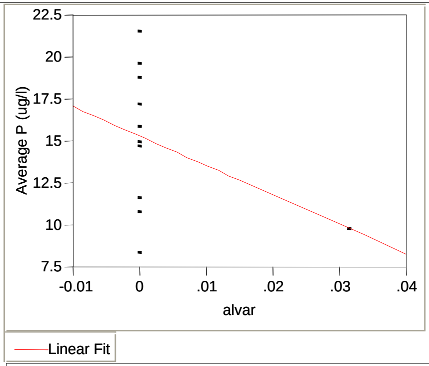
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	35.41382	35.4138	2.1463
Error	9	148.50176	16.5002	Prob > F
C. Total	10	183.91558		0.1770

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	18.429601	2.741958	6.72	<.0001
mixed forest mainly coniferous	-44.41497	30.3171	-1.47	0.1770

Bivariate Fit of Average P (ug/l) By alvar



Linear Fit

Average P (ug/l) = 15.337817 - 175.26991 alvar

Summary of Fit

RSquare	0.150859
RSquare Adj	0.05651
Root Mean Square Error	4.165603
Mean of Response	14.83559
Observations (or Sum Wgts)	11

Analysis of Variance

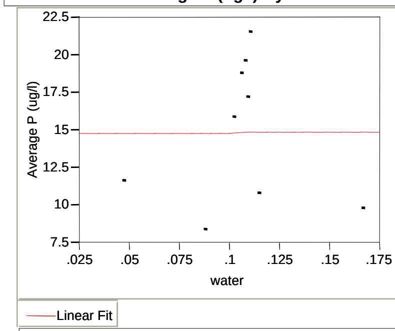
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	27.74538	27.7454	1.5990
Error	9	156.17020	17.3522	Prob > F
C. Total	10	183.91558		0.2378

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.337817	1.317279	11.64	<.0001
alvar	-175.2699	138.6085	-1.26	0.2378

Watershed Accumulation

Bivariate Fit of Average P (ug/l) By water



Linear Fit

Average P (ug/l) = 14.738243 + 0.9188172 water

Summary of Fit

RSquare	0.000035
RSquare Adj	-0.14282
Root Mean Square Error	5.125247
Mean of Response	14.83609
Observations (or Sum Wgts)	9

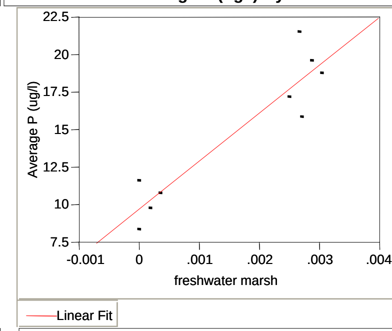
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00639	0.0064	0.0002
Error	7	183.87708	26.2682	Prob > F
C. Total	8	183.88348		0.9880

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.738243	6.501551	2.27	0.0577
water	0.9188172	58.90455	0.02	0.9880

Bivariate Fit of Average P (ug/l) By freshwater marsh



Linear Fit

Average P (ug/l) = 9.7157181 + 3201.3264 freshwater marsh

Summary of Fit

RSquare	0.868804
RSquare Adj	0.850061
Root Mean Square Error	1.856449
Mean of Response	14.83609
Observations (or Sum Wgts)	9

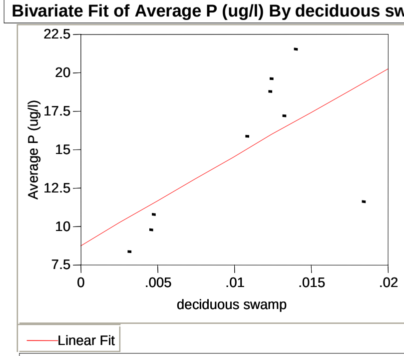
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	159.75866	159.759	46.3552
Error	7	24.12481	3.446	Prob > F
C. Total	8	183.88348		0.0003

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.7157181	0.973924	9.98	<.0001
freshwater marsh	3201.3264	470.1979	6.81	0.0003

Bivariate Fit of Average P (ug/l) By deciduous swamp



Linear Fit

Average P (ug/l) = 8.8238495 + 574.77419 deciduous swamp

Summary of Fit

RSquare	0.381514
RSquare Adj	0.293159
Root Mean Square Error	4.030763
Mean of Response	14.83609
Observations (or Sum Wgts)	9

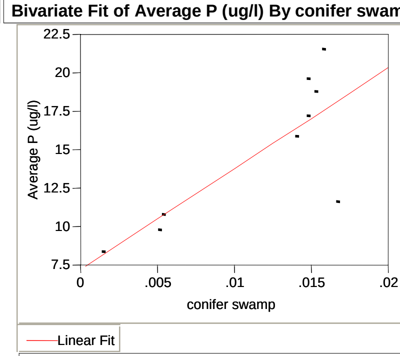
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	70.15412	70.1541	4.3180
Error	7	113.72936	16.2471	Prob > F
C. Total	8	183.88348		0.0763

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.8238495	3.190072	2.77	0.0279
deciduous swamp	574.77419	276.6037	2.08	0.0763

Bivariate Fit of Average P (ug/l) By conifer swamp



Linear Fit

Average P (ug/l) = 7.2661014 + 654.1477 conifer swamp

Summary of Fit

RSquare	0.623845
RSquare Adj	0.570109
Root Mean Square Error	3.143444
Mean of Response	14.83609
Observations (or Sum Wgts)	9

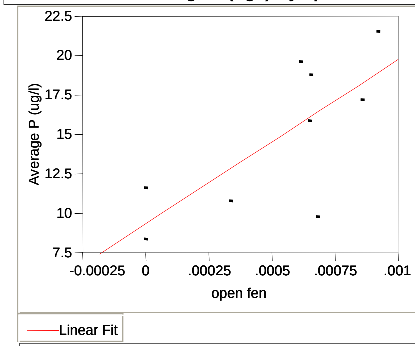
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	114.71478	114.715	11.6093
Error	7	69.16869	9.881	Prob > F
C. Total	8	183.88348		0.0113

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.2661014	2.456421	2.96	0.0212
conifer swamp	654.1477	191.987	3.41	0.0113

Bivariate Fit of Average P (ug/l) By open fen



Linear Fit

Average P (ug/l) = 9.3741122 + 10376.81 open fen

Summary of Fit

RSquare	0.540183
RSquare Adj	0.474495
Root Mean Square Error	3.475481
Mean of Response	14.83609
Observations (or Sum Wgts)	9

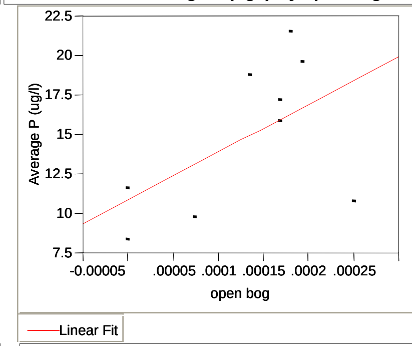
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	99.33068	99.3307	8.2234
Error	7	84.55279	12.0790	Prob > F
C. Total	8	183.88348		0.0241

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.3741122	2.229335	4.20	0.0040
open fen	10376.81	3618.571	2.87	0.0241

Bivariate Fit of Average P (ug/l) By open bog



Linear Fit

Average P (ug/l) = 10.911021 + 30058.133 open bog

Summary of Fit

RSquare	0.302308
RSquare Adj	0.202637
Root Mean Square Error	4.281089
Mean of Response	14.83609
Observations (or Sum Wgts)	9

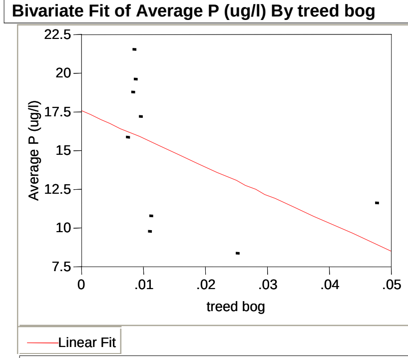
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	55.58941	55.5894	3.0331
Error	7	128.29407	18.3277	Prob > F
C. Total	8	183.88348		0.1251

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	10.911021	2.667547	4.09	0.0046
open bog	30058.133	17259.18	1.74	0.1251

Bivariate Fit of Average P (ug/l) By treed bog



Linear Fit

Average P (ug/l) = 17.630565 - 181.43462 treed bog

Summary of Fit

RSquare	0.252812
RSquare Adj	0.146071
Root Mean Square Error	4.430342
Mean of Response	14.83609
Observations (or Sum Wgts)	9

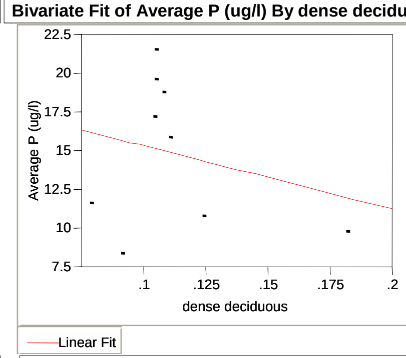
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	46.48796	46.4880	2.3685
Error	7	137.39551	19.6279	Prob > F
C. Total	8	183.88348		0.1677

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.630565	2.340511	7.53	0.0001
treed bog	-181.4346	117.8928	-1.54	0.1677

Bivariate Fit of Average P (ug/l) By dense deciduous



Linear Fit

Average P (ug/l) = 19.451575 - 40.950688 dense deciduous

Summary of Fit

RSquare	0.061601
RSquare Adj	-0.07246
Root Mean Square Error	4.964963
Mean of Response	14.83609
Observations (or Sum Wgts)	9

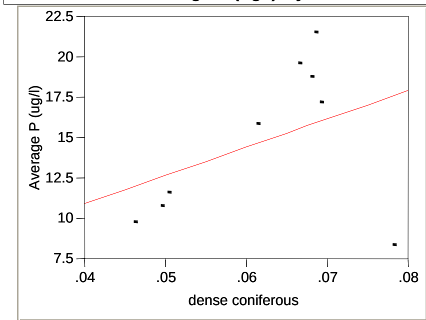
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11.32747	11.3275	0.4595
Error	7	172.55600	24.6509	Prob > F
C. Total	8	183.88348		0.5196

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	19.451575	7.00699	2.78	0.0275
dense deciduous	-40.95069	60.41026	-0.68	0.5196

Bivariate Fit of Average P (ug/l) By dense coniferous



Linear Fit

Linear Fit

Average P (ug/l) = 3.9279776 + 175.33659 dense coniferous

Summary of Fit

RSquare	0.159879
RSquare Adj	0.039862
Root Mean Square Error	4.697786
Mean of Response	14.83609
Observations (or Sum Wgts)	9

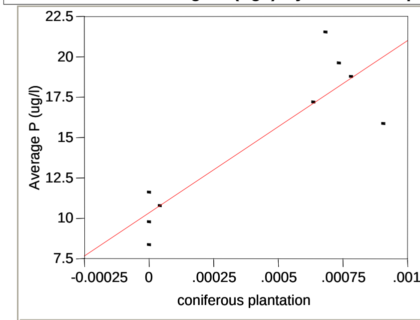
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	29.39910	29.3991	1.3321
Error	7	154.48438	22.0692	Prob > F
C. Total	8	183.88348		0.2863

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.9279776	9.579812	0.41	0.6940
dense coniferous	175.33659	151.9144	1.15	0.2863

Bivariate Fit of Average P (ug/l) By coniferous plantation



Linear Fit

Linear Fit

Average P (ug/l) = 10.340018 + 10665.557 coniferous plantation

Summary of Fit

RSquare	0.779799
RSquare Adj	0.748341
Root Mean Square Error	2.405096
Mean of Response	14.83609
Observations (or Sum Wgts)	9

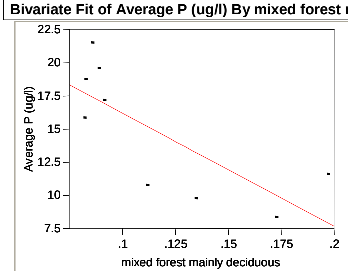
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	143.39207	143.392	24.7891
Error	7	40.49141	5.784	Prob > F
C. Total	8	183.88348		0.0016

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	10.340018	1.207555	8.56	<.0001
coniferous plantation	10665.557	2142.167	4.98	0.0016

Bivariate Fit of Average P (ug/l) By mixed forest mainly deciduous



Linear Fit

Linear Fit

Average P (ug/l) = 24.844971 - 85.743168 mixed forest mainly deciduous

Summary of Fit

RSquare	0.586715
RSquare Adj	0.527674
Root Mean Square Error	3.294939
Mean of Response	14.83609
Observations (or Sum Wgts)	9

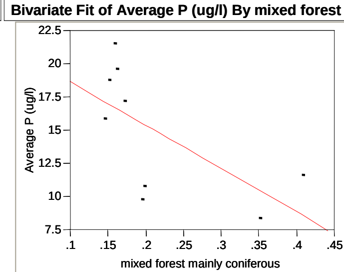
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	107.88711	107.887	9.9374
Error	7	75.99636	10.857	Prob > F
C. Total	8	183.88348		0.0161

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	24.844971	3.35963	7.40	0.0002
mixed forest mainly deciduous	-85.74317	27.19958	-3.15	0.0161

Bivariate Fit of Average P (ug/l) By mixed forest mainly coniferous



Linear Fit

Linear Fit

Average P (ug/l) = 21.932442 - 32.600416 mixed forest mainly coniferous

Summary of Fit

RSquare	0.423388
RSquare Adj	0.341015
Root Mean Square Error	3.891922
Mean of Response	14.83609
Observations (or Sum Wgts)	9

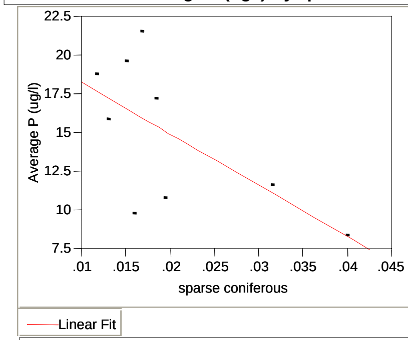
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	77.85409	77.8541	5.1399
Error	7	106.02939	15.1471	Prob > F
C. Total	8	183.88348		0.0577

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	21.932442	3.388295	6.47	0.0003
mixed forest mainly coniferous	-32.60042	14.37959	-2.27	0.0577

Bivariate Fit of Average P (ug/l) By sparse coniferous



Linear Fit

Average P (ug/l) = 21.553394 - 330.33751 sparse coniferous

Summary of Fit

RSquare	0.41572
RSquare Adj	0.332251
Root Mean Square Error	3.917716
Mean of Response	14.83609
Observations (or Sum Wgts)	9

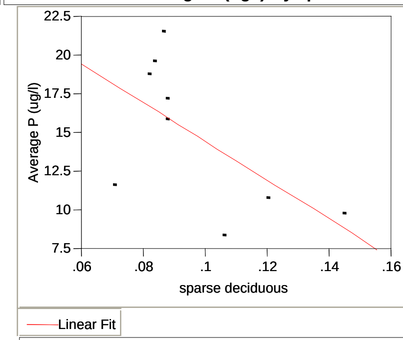
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	76.44401	76.4440	4.9806
Error	7	107.43946	15.3485	Prob > F
C. Total	8	183.88348		0.0608

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	21.553394	3.281013	6.57	0.0003
sparse coniferous	-330.3375	148.0195	-2.23	0.0608

Bivariate Fit of Average P (ug/l) By sparse deciduous



Linear Fit

Average P (ug/l) = 26.958711 - 124.99147 sparse deciduous

Summary of Fit

RSquare	0.363069
RSquare Adj	0.272079
Root Mean Square Error	4.090427
Mean of Response	14.83609
Observations (or Sum Wgts)	9

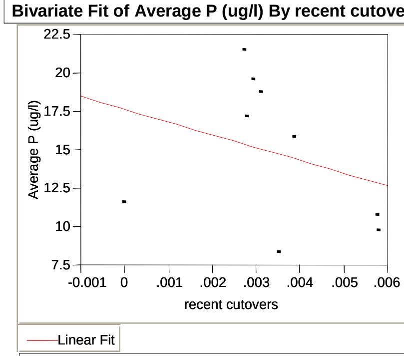
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	66.76234	66.7623	3.9902
Error	7	117.12113	16.7316	Prob > F
C. Total	8	183.88348		0.0859

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	26.958711	6.220032	4.33	0.0034
sparse deciduous	-124.9915	62.57246	-2.00	0.0859

Bivariate Fit of Average P (ug/l) By recent cutovers



Linear Fit

Average P (ug/l) = 17.671976 - 831.40482 recent cutovers

Summary of Fit

RSquare	0.091645
RSquare Adj	-0.03812
Root Mean Square Error	4.884837
Mean of Response	14.83609
Observations (or Sum Wgts)	9

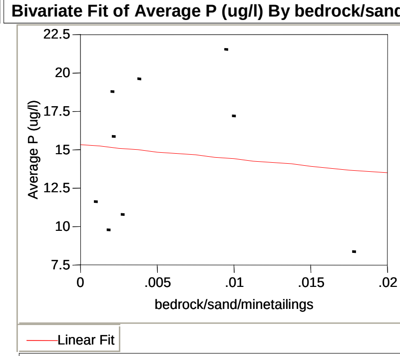
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	16.85207	16.8521	0.7062
Error	7	167.03140	23.8616	Prob > F
C. Total	8	183.88348		0.4285

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.671976	3.746821	4.72	0.0022
recent cutovers	-831.4048	989.318	-0.84	0.4285

Bivariate Fit of Average P (ug/l) By bedrock/sand/minetailings



Linear Fit

Average P (ug/l) = 15.366377 - 92.917106 bedrock/sand/minetailings

Summary of Fit

RSquare	0.011983
RSquare Adj	-0.12916
Root Mean Square Error	5.094534
Mean of Response	14.83609
Observations (or Sum Wgts)	9

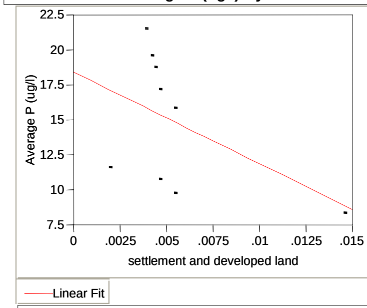
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.20354	2.2035	0.0849
Error	7	181.67993	25.9543	Prob > F
C. Total	8	183.88348		0.7792

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.366377	2.48916	6.17	0.0005
bedrock/sand/minetailings	-92.91711	318.8888	-0.29	0.7792

Bivariate Fit of Average P (ug/l) By settlement and developed land



Linear Fit

Average P (ug/l) = 18.476066 - 656.70486 settlement and developed land

Summary of Fit

RSquare	0.238728
RSquare Adj	0.129975
Root Mean Square Error	4.471902
Mean of Response	14.83609
Observations (or Sum Wgts)	9

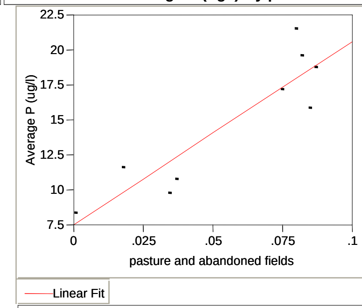
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	43.89809	43.8981	2.1951
Error	7	139.98538	19.9979	Prob > F
C. Total	8	183.88348		0.1820

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	18.476066	2.873639	6.43	0.0004
settlement and developed land	-656.7049	443.2408	-1.48	0.1820

Bivariate Fit of Average P (ug/l) By pasture and abandoned fields



Linear Fit

Average P (ug/l) = 7.503731 + 131.61737 pasture and abandoned fields

Summary of Fit

RSquare	0.818958
RSquare Adj	0.793095
Root Mean Square Error	2.180782
Mean of Response	14.83609
Observations (or Sum Wgts)	9

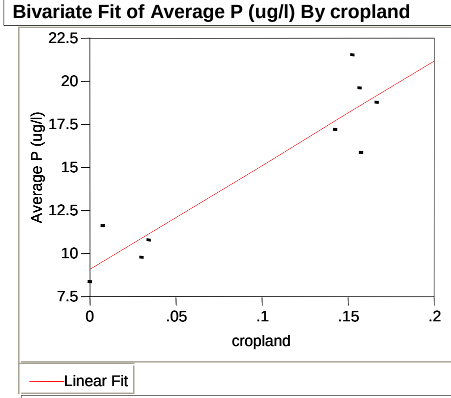
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	150.59279	150.593	31.6650
Error	7	33.29068	4.756	Prob > F
C. Total	8	183.88348		0.0008

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.503731	1.492082	5.03	0.0015
pasture and abandoned fields	131.61737	23.38964	5.63	0.0008

Bivariate Fit of Average P (ug/l) By cropland



Linear Fit

Average P (ug/l) = 9.1011535 + 60.640186 cropland

Summary of Fit

RSquare	0.859363
RSquare Adj	0.839272
Root Mean Square Error	1.922085
Mean of Response	14.83609
Observations (or Sum Wgts)	9

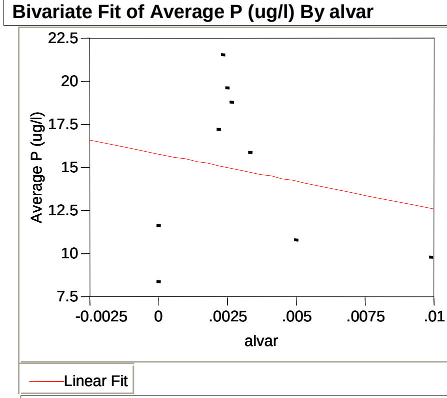
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	158.02261	158.023	42.7734
Error	7	25.86086	3.694	Prob > F
C. Total	8	183.88348		0.0003

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.1011535	1.086008	8.38	<.0001
cropland	60.640186	9.271999	6.54	0.0003

Bivariate Fit of Average P (ug/l) By alvar



Linear Fit

Average P (ug/l) = 15.84169 - 321.34603 alvar

Summary of Fit

RSquare	0.040173
RSquare Adj	-0.09695
Root Mean Square Error	5.021331
Mean of Response	14.83609
Observations (or Sum Wgts)	9

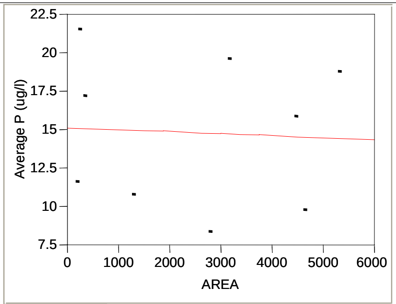
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	7.38711	7.3871	0.2930
Error	7	176.49637	25.2138	Prob > F
C. Total	8	183.88348		0.6051

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.84169	2.500612	6.34	0.0004
alvar	-321.346	593.683	-0.54	0.6051

Bivariate Fit of Average P (ug/l) By AREA



Linear Fit

Linear Fit

Average P (ug/l) = 15.160325 - 0.0001283 AREA

Summary of Fit

RSquare	0.003014
RSquare Adj	-0.13941
Root Mean Square Error	5.119146
Mean of Response	14.83778
Observations (or Sum Wgts)	9

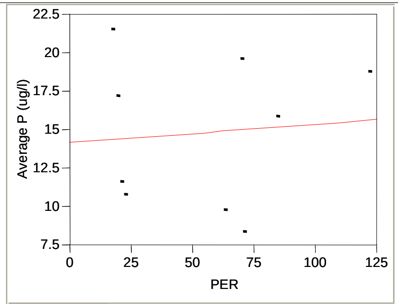
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.55456	0.5546	0.0212
Error	7	183.43960	26.2057	Prob > F
C. Total	8	183.99416		0.8884

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.160325	2.797859	5.42	0.0010
AREA	-0.000128	0.000882	-0.15	0.8884

Bivariate Fit of Average P (ug/l) By PER



Linear Fit

Linear Fit

Average P (ug/l) = 14.181552 + 0.0118953 PER

Summary of Fit

RSquare	0.008341
RSquare Adj	-0.13332
Root Mean Square Error	5.105452
Mean of Response	14.83778
Observations (or Sum Wgts)	9

Analysis of Variance

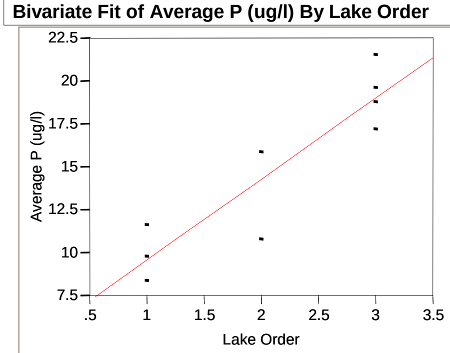
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.53465	1.5346	0.0589
Error	7	182.45951	26.0656	Prob > F
C. Total	8	183.99416		0.8152

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.181552	3.195371	4.44	0.0030
PER	0.0118953	0.049024	0.24	0.8152

Lake Morphology

Bivariate Fit of Average P (ug/l) By Lake Order



Linear Fit

Linear Fit

Average P (ug/l) = 4.8774194 + 4.7180645 Lake Order

Summary of Fit

RSquare	0.833437
RSquare Adj	0.809643
Root Mean Square Error	2.092387
Mean of Response	14.83778
Observations (or Sum Wgts)	9

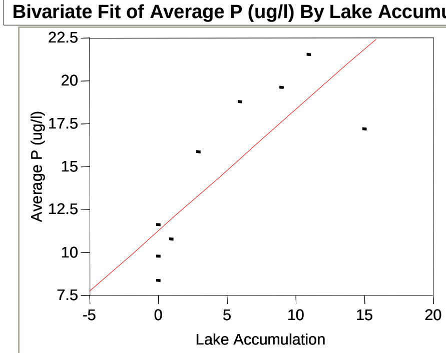
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	153.34758	153.348	35.0262
Error	7	30.64657	4.378	Prob > F
C. Total	8	183.99416		0.0006

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.8774194	1.821776	2.68	0.0317
Lake Order	4.7180645	0.7972	5.92	0.0006

Bivariate Fit of Average P (ug/l) By Lake Accumulation



Linear Fit

Linear Fit

Average P (ug/l) = 11.313383 + 0.704879 Lake Accumulation

Summary of Fit

RSquare	0.669695
RSquare Adj	0.622508
Root Mean Square Error	2.946529
Mean of Response	14.83778
Observations (or Sum Wgts)	9

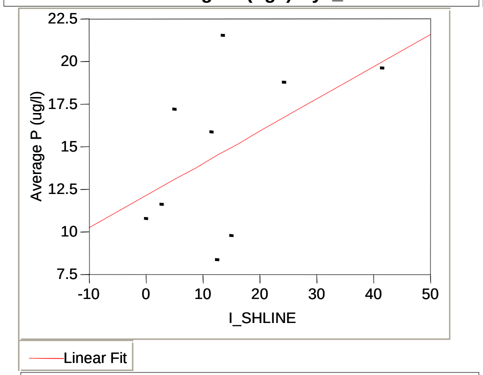
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	123.21990	123.220	14.1925
Error	7	60.77425	8.682	Prob > F
C. Total	8	183.99416		0.0070

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.313383	1.35642	8.34	<.0001
Lake Accumulation	0.704879	0.187105	3.77	0.0070

Bivariate Fit of Average P (ug/l) By I_SHLINE



Linear Fit

Average P (ug/l) = 12.172553 + 0.1893214 I_SHLINE

Summary of Fit

RSquare	0.249877
RSquare Adj	0.142716
Root Mean Square Error	4.440371
Mean of Response	14.83778
Observations (or Sum Wgts)	9

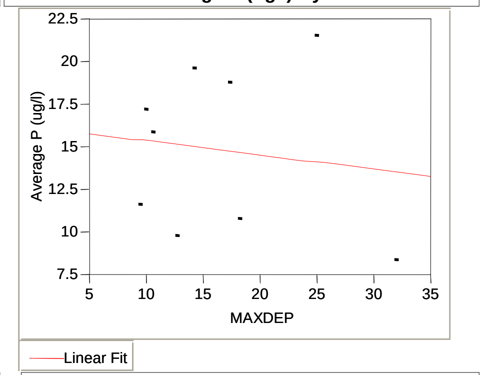
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	45.97587	45.9759	2.3318
Error	7	138.01829	19.7169	Prob > F
C. Total	8	183.99416		0.1706

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.172553	2.28847	5.32	0.0011
I_SHLINE	0.1893214	0.123981	1.53	0.1706

Bivariate Fit of Average P (ug/l) By MAXDEP



Linear Fit

Average P (ug/l) = 16.22915 - 0.0834267 MAXDEP

Summary of Fit

RSquare	0.01734
RSquare Adj	-0.12304
Root Mean Square Error	5.082234
Mean of Response	14.83778
Observations (or Sum Wgts)	9

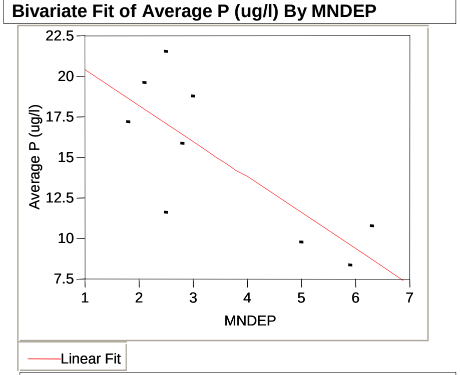
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.19044	3.1904	0.1235
Error	7	180.80371	25.8291	Prob > F
C. Total	8	183.99416		0.7356

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.22915	4.306118	3.77	0.0070
MAXDEP	-0.083427	0.237375	-0.35	0.7356

Bivariate Fit of Average P (ug/l) By MNDEP



Linear Fit

Average P (ug/l) = 22.622424 - 2.1962951 MNDEP

Summary of Fit

RSquare	0.614052
RSquare Adj	0.558917
Root Mean Square Error	3.185057
Mean of Response	14.83778
Observations (or Sum Wgts)	9

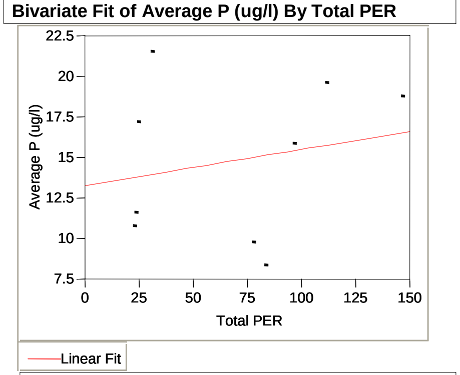
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	112.98205	112.982	11.1372
Error	7	71.01210	10.145	Prob > F
C. Total	8	183.99416		0.0125

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.622424	2.562904	8.83	<.0001
MNDEP	-2.196295	0.658117	-3.34	0.0125

Bivariate Fit of Average P (ug/l) By Total PER



Linear Fit

Average P (ug/l) = 13.278242 + 0.0225222 Total PER

Summary of Fit

RSquare	0.045518
RSquare Adj	-0.09084
Root Mean Square Error	5.008837
Mean of Response	14.83778
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	8.37505	8.3750	0.3338
Error	7	175.61911	25.0884	Prob > F
C. Total	8	183.99416		0.5815

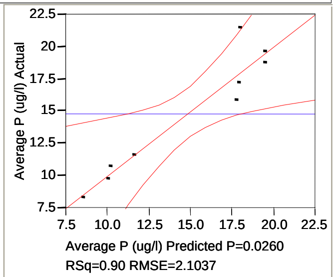
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	13.278242	3.173862	4.18	0.0041
Total PER	0.0225222	0.038981	0.58	0.5815

Regression Model

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.903793
RSquare Adj	0.807586
Root Mean Square Error	2.103658
Mean of Response	14.83778
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	166.29264	41.5732	9.3943
Error	4	17.70151	4.4254	Prob > F
C. Total	8	183.99416		0.0260

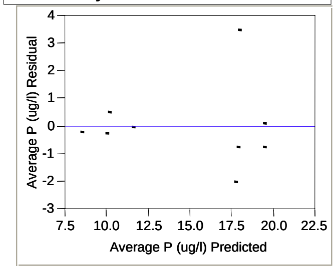
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.196116	3.719381	3.28	0.0305
Mean Depth	-0.628681	0.631071	-1.00	0.3755
freshwater marsh	9155.3314	12857.74	0.71	0.5158
pasture and abandoned fields	137.29955	238.5808	0.58	0.5958
cropland	-184.2219	337.5036	-0.55	0.6142

Effect Tests

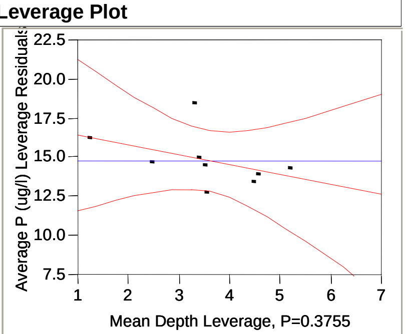
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mean Depth	1	1	4.3919304	0.9924	0.3755
freshwater marsh	1	1	2.2437244	0.5070	0.5158
pasture and abandoned fields	1	1	1.4656076	0.3312	0.5958
cropland	1	1	1.3184873	0.2979	0.6142

Residual by Predicted Plot



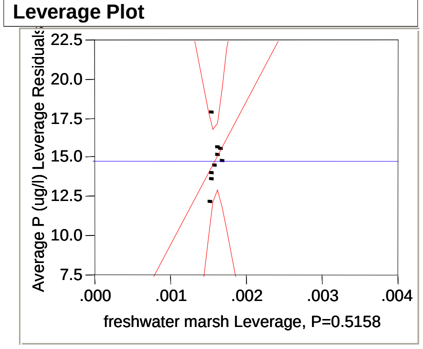
Mean Depth

Leverage Plot



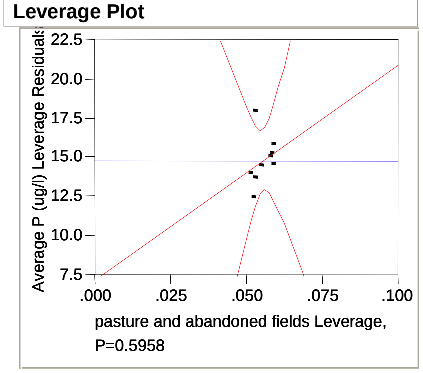
freshwater marsh

Leverage Plot



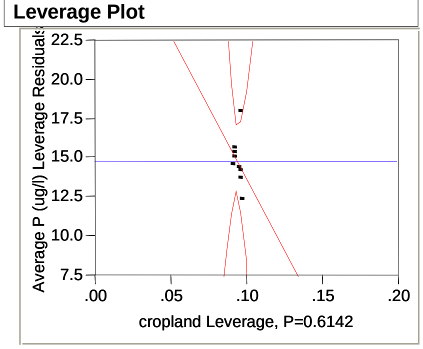
pasture and abandoned fields

Leverage Plot



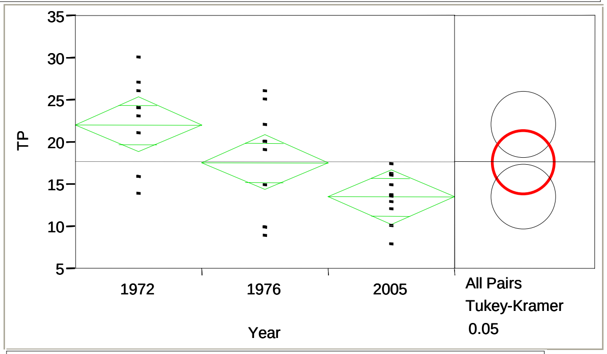
cropland

Leverage Plot



Stats for Figure 5.2

Oneway Analysis of TP By Year



Oneway Anova

Summary of Fit

Rsquare	0.351207
Adj Rsquare	0.303149
Root Mean Square Error	5.027933
Mean of Response	17.73561
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	2	369.4882	184.744	7.3079	0.0029
Error	27	682.5629	25.280		
C. Total	29	1052.0512			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1972	10	22.1000	1.5900	18.838	25.362
1976	10	17.6000	1.5900	14.338	20.862
2005	10	13.5068	1.5900	10.244	16.769

Std Error uses a pooled estimate of error variance

Means Comparisons

Dif=Mean[i]-Mean[j]

	1972	1976	2005
1972	0.0000	4.5000	8.5932
1976	-4.5000	0.0000	4.0932
2005	-8.5932	-4.0932	0.0000

Alpha= 0.05

Comparisons for all pairs using Tukey-Kramer HSD

q*
2.47942

Abs(Dif)-LSD

	1972	1976	2005
1972	-5.5751	-1.0751	3.0180
1976	-1.0751	-5.5751	-1.4820
2005	3.0180	-1.4820	-5.5751

Positive values show pairs of means that are significantly different.

Stats for Figure 5.2

Linear Regression Sturgeon Lake (1971-1991)

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.4060	0.1648	0.1208	10.3854

	Coefficient	Std. Error	t	P	VIF
y0	1461.6294	741.4219	1.9714	0.0634	107029.0375<
a	-0.7247	0.3743	-1.9363	0.0679	107029.0375<

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	2	14652.4165	7326.2082
Residual	19	2049.2835	107.8570
Total	21	16701.7000	795.3190

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	1	404.3688	404.3688	3.7491	0.0679
Total	20	2453.6524	122.6826		

Linear Regression for Sturgeon Lake (1971-2005)

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.4718	0.2226	0.1873	9.7774

	Coefficient	Std. Error	t	P	VIF
y0	1072.3474	417.3058	2.5697	0.0175	43719.0043<
a	-0.5280	0.2103	-2.5102	0.0199	43719.0043<

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	2	15421.4112	7710.7056
Residual	22	2103.1613	95.5982
Total	24	17524.5725	730.1905

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	1	602.3622	602.3622	6.3010	0.0199
Total	23	2705.5235	117.6315		

Stats for Figure 5.4

Nonlinear Regression (logistic 3-parameter) Lake Accumulation

R = 0.89691933 Rsqr = 0.80446428 Adj Rsqr = 0.79224329

Standard Error of Estimate = 2.4057

	Coefficient	**Std. Error**	**t**	**P**
a	27.9780	8.5912	3.2566	0.0027
b	-0.7417	0.2828	-2.6223	0.0133
x0	2.8435	2.6516	1.0724	0.2916

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	2	761.9472	380.9736	65.8265	<0.0001
Residual	32	185.2014	5.7875		
Total	34	947.1486	27.8573		

PRESS = 220.4209

Durbin-Watson Statistic = 2.4614

Normality Test: Passed (P = 0.5509)

Constant Variance Test: Passed (P = 0.2507)

Appendix D Raw Data

Data used in Figure 3.2

Watershed ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
% Cropland	0%	0%	0%	0%	0%	4%	2%	0%	0%	1%	2%	1%	10%	0%	9%	17%
Corrected BFI	93%	84%	88%	79%	69%	64%	67%	61%	70%	63%	64%	68%	66%	67%	68%	66%
BFI Class	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Crop Class	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Susceptibility Index	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Data used in Figure 3.2

Watershed ID	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
% Cropland	33%	25%	32%	26%	29%	43%	32%	56%	46%	52%	33%	41%	40%	50%	39%
Corrected BFI	55%	70%	53%	44%	52%	51%	46%	39%	37%	43%	75%	53%	57%	50%	66%
BFI Class	7	8	7	6	7	7	5	4	4	4	7	6	6	5	8
Crop Class	1	1	1	1	1	2	1	3	2	3	2	2	2	2	3
Susceptibility Index	2	1	2	3	2	3	4	7	6	7	3	4	4	5	3

Data used in Figure 5.1

Lake	TP 1972	TP 1976	TP 2005
BALSAM LAKE	16.00	10.00	10.11
BIG BALD LAKE	21.00	20.00	12.01
BUCKHORN LAKE (UPPER)	23.00	22.00	17.48
CAMERON LAKE	16.00	9.00	12.85
CLEAR LAKE	24.00	15.00	16.28
KATCHEWANOOKA LAKE	30.00	19.00	16.14
PIGEON LAKE	26.00	25.00	14.84
STONY LAKE	24.00	20.00	13.56
STURGEON LAKE	27.00	26.00	13.83
UPPER STONEY LAKE	14.00	10.00	7.96

Data used in Figure 5.2

Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Mean	31.8	25.4	27.7	41.8	21.3	23.4	22.1	19.4	35.2	32.5	35.4	59.8	30.2	25	18.2	19.5	12.6	15.8	15.7	22.2	12
SD	23.5	10.2	8.1	38.8	9	17.4	7.8	7.6	53.1	53.2	37.1	63.2	31.7	17.8	9.7	12.7	3.9	8	8.8	15.8	1
n	16	17	12	9	10	9	9	8	11	12	12	12	20	15	13	12	12	13	10	11	3

Data used to in Figure 5.3

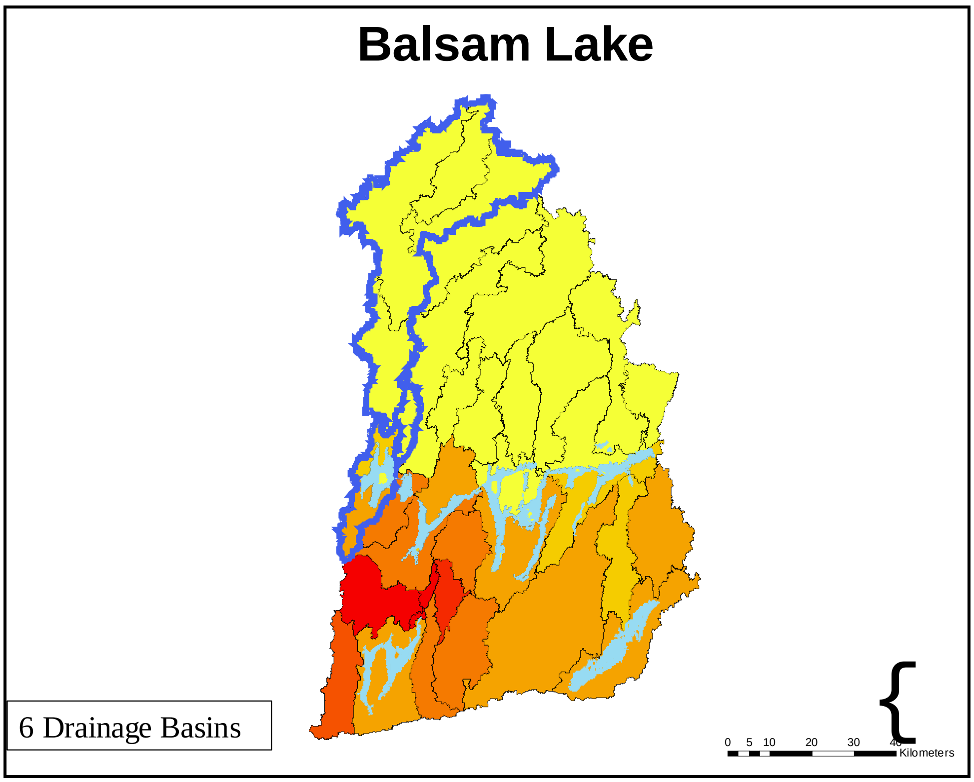
Lake	TP 1972	TP 1976	TP 2003	TP2004	TP 2005
BALSAM LAKE	16.00	10.00	14.7	12.11	10.11
CAMERON LAKE	16.00	9.00	-	-	12.85
STURGEON LAKE	27.00	26.00	17.60	17.94	13.83
PIGEON LAKE	26.00	25.00	19.77	16.36	14.84
BUCKHORN LAKE (UPPER)	23.00	22.00	27.80	16.64	17.48
CLEAR LAKE	24.00	15.00	17.80	15.16	16.28
KATCHEWANOOKA LAKE	30.00	19.00	24.50	19.03	16.14

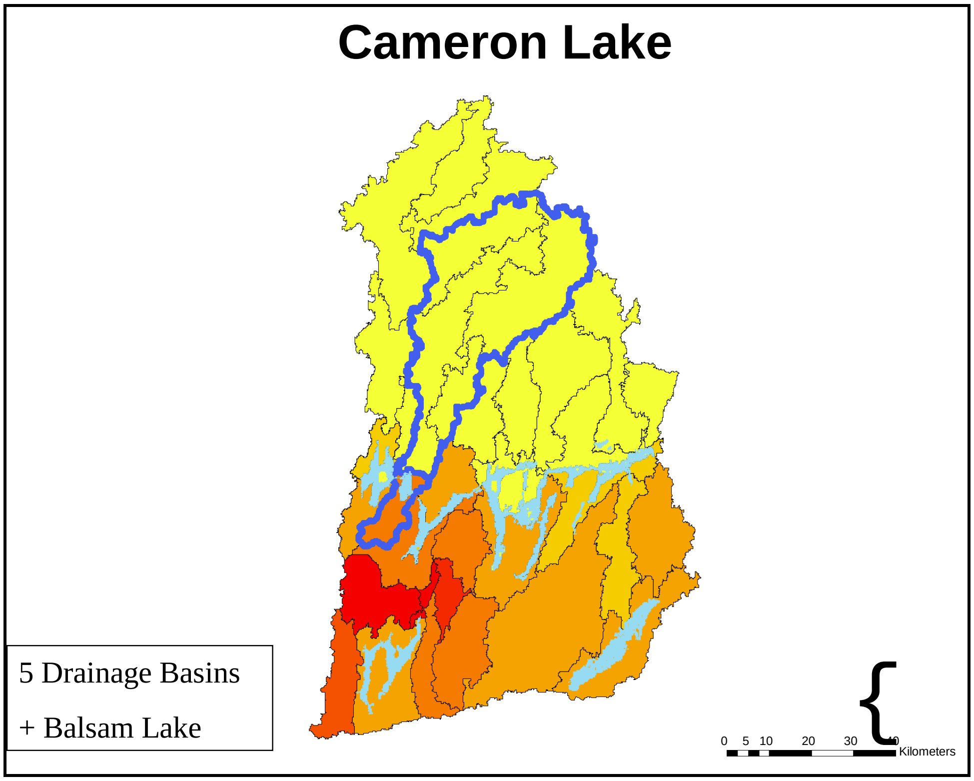
Data used in Figure 5.4

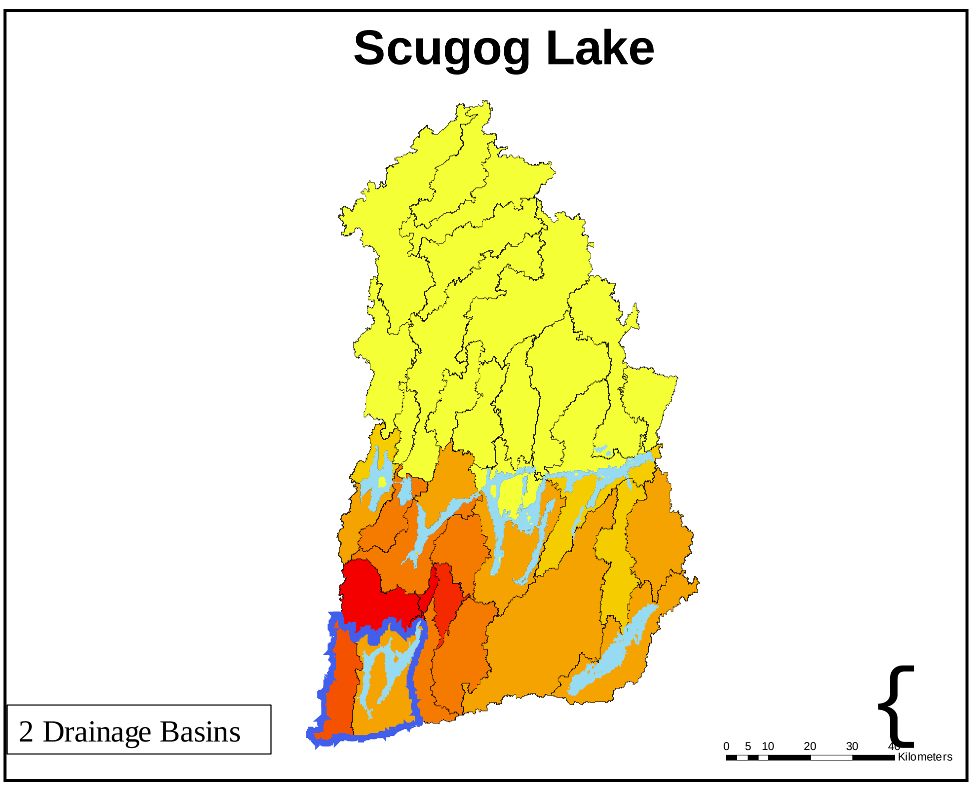
Lake Name	Lake Order	Lake Ac2	Average P (ug/l)	AREA	PER	I_SHLINE	MAX DEP	MNDEP	Total PER
BALSAM LAKE	1	1	9.813333	4664.7	63.6	15.1	12.8	5	78.7
BIG BALD LAKE	1	1	11.6425	201	21.4	2.9	9.5	2.5	24.3
BUCKHORN LAKE (UPPER)	3	10	19.648	3188.8	70.5	41.7	14.3	2.1	112.2
CAMERON LAKE	2	2	10.755	1303.2	23.2	0	18.3	6.3	23.2
CHEMONG LAKE	1	1	14.96	2277.9	76.9	6.3	6.4	2.4	83.2
CLEAR LAKE	1	15	15.93	1054.3	24.1	5.5	12.2	5.6	29.6
JULIAN LAKE	1	1	5.045	86	4.2	0.1	13.4	4.7	4.3
KATCHEWANOOKA LAKE	3	16	17.205	350.9	20.3	5	10.1	1.8	25.3
LOVESICK LAKE	3	12	21.505	257.2	17.8	13.5	25	2.5	31.3
PIGEON LAKE	3	7	18.765	5344.4	122.9	24.3	17.4	3	147.2
SANDY LAKE	1	1	4.385	370.1	10.6	0.4	12.8	4.8	11
STONY LAKE	3	3	14.70667	2824.9	71.4	12.6	32	5.9	84
STURGEON LAKE	2	4	15.844	4495.1	85.4	11.6	10.7	2.8	97
UPPER STONEY LAKE	1	1	8.347	2824.9	71.4	12.6	32	5.9	84
WHITE LAKE (DUMMER)	1	1	11.16	176.2	7.4	0.8	7	3	8.2

Appendix E Basin Contribution Diagrams

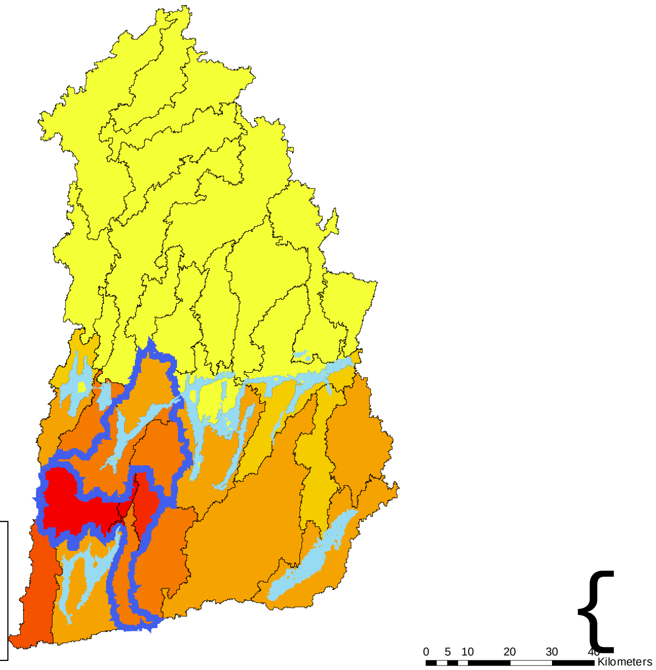
Blue basin outline defines true exact watershed contribution
Black basin outline (Bold) delineates undefined contribution of watershed.




Cameron Lake
5 Drainage Basins
+ Balsam Lake
0 5 10 20 30 40
Kilometers


Scugog Lake
2 Drainage Basins
0 5 10 20 30 40
Kilometers

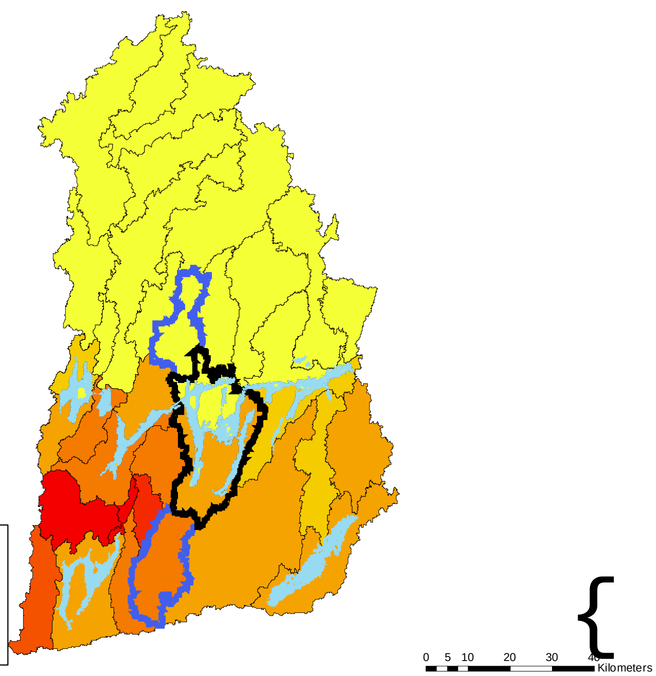
Sturgeon Lake



6 Drainage Basins

+ up canal, Scugog and Lindsay

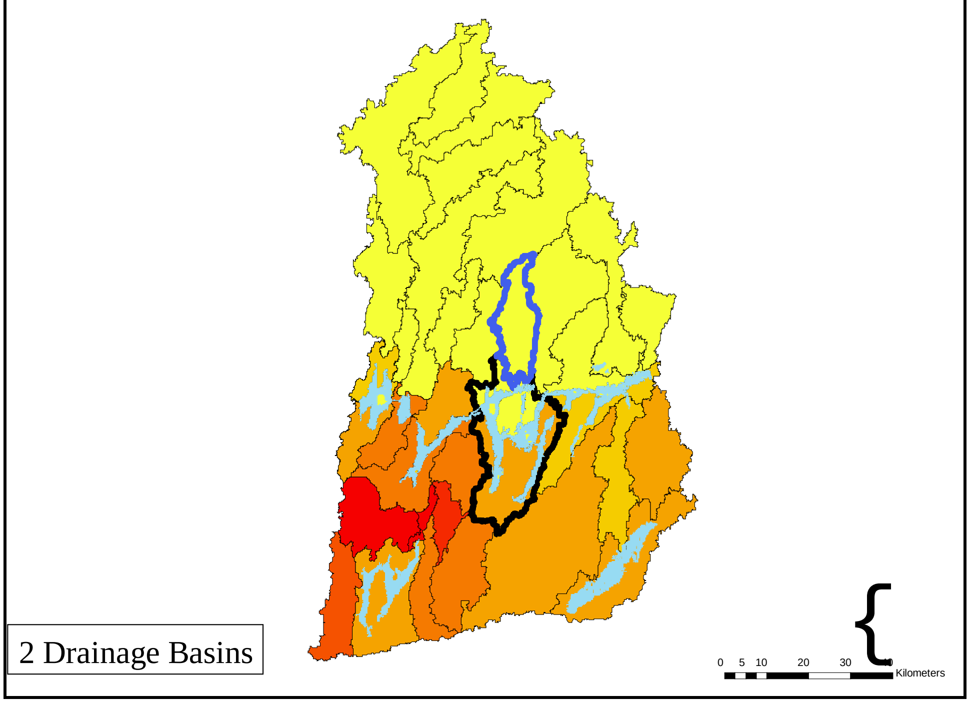
Pigeon Lake



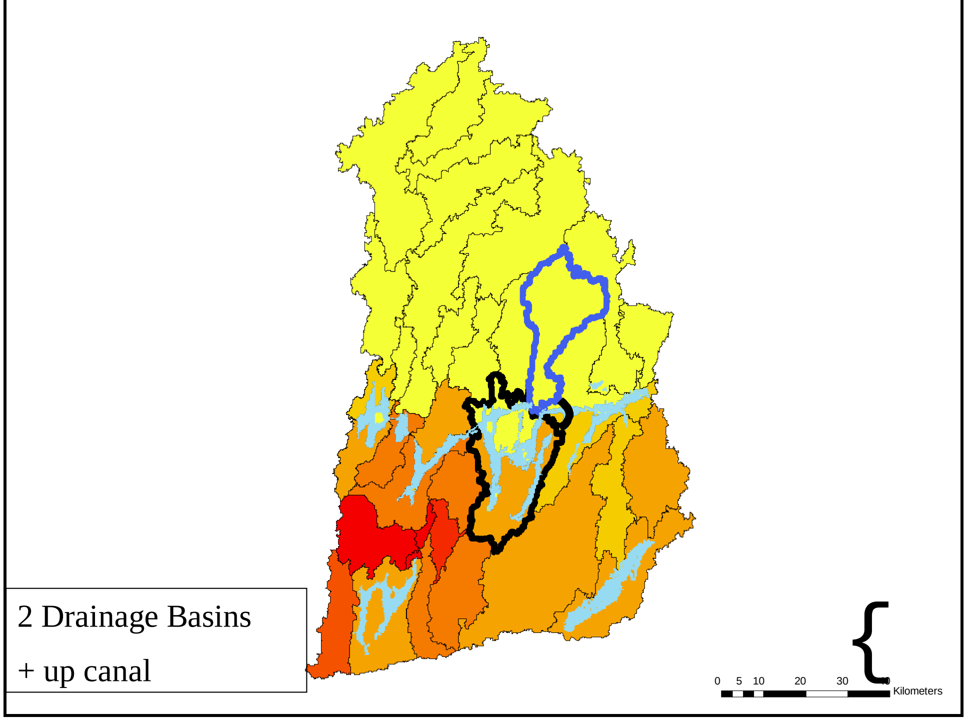
3 Drainage Basins

+ up canal and Big Bald lake

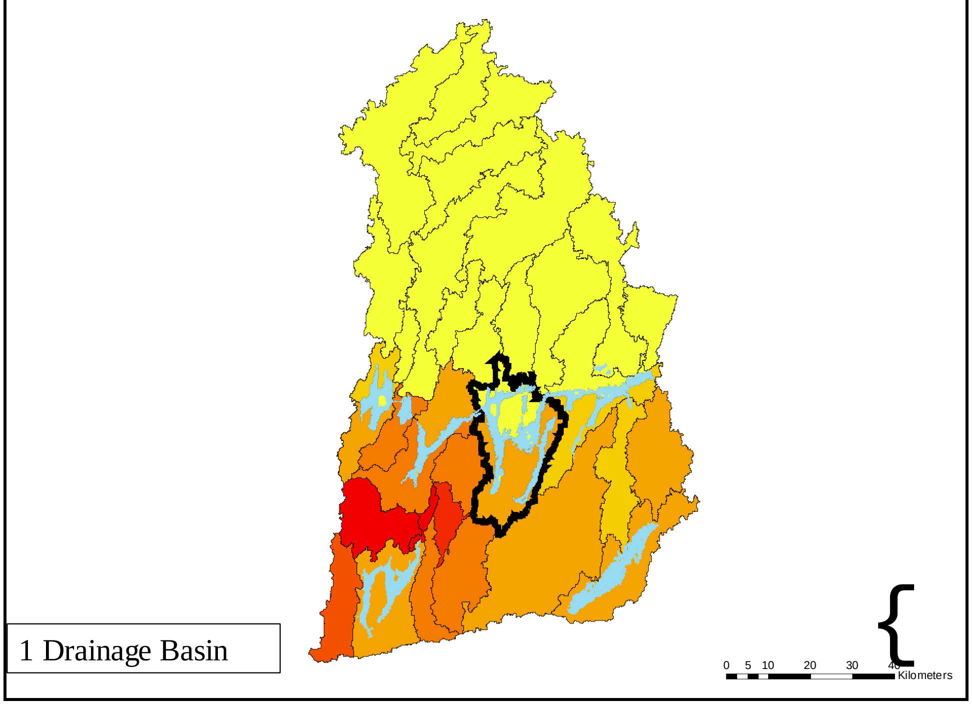
Bald Lakes



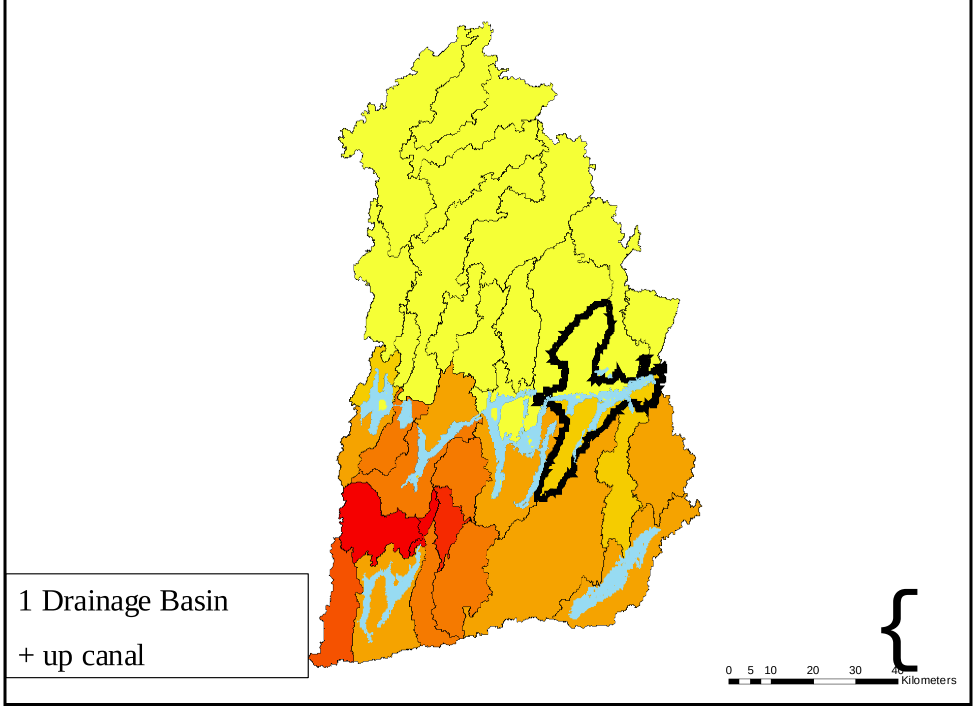
Buckhorn Lake

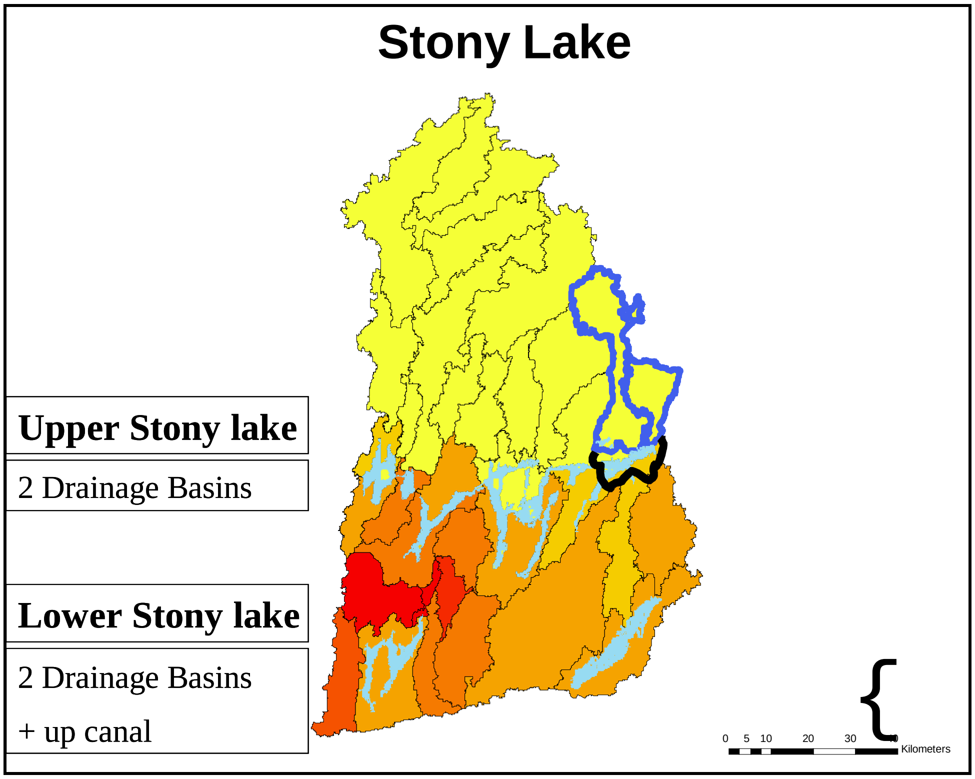


Chemong Lake

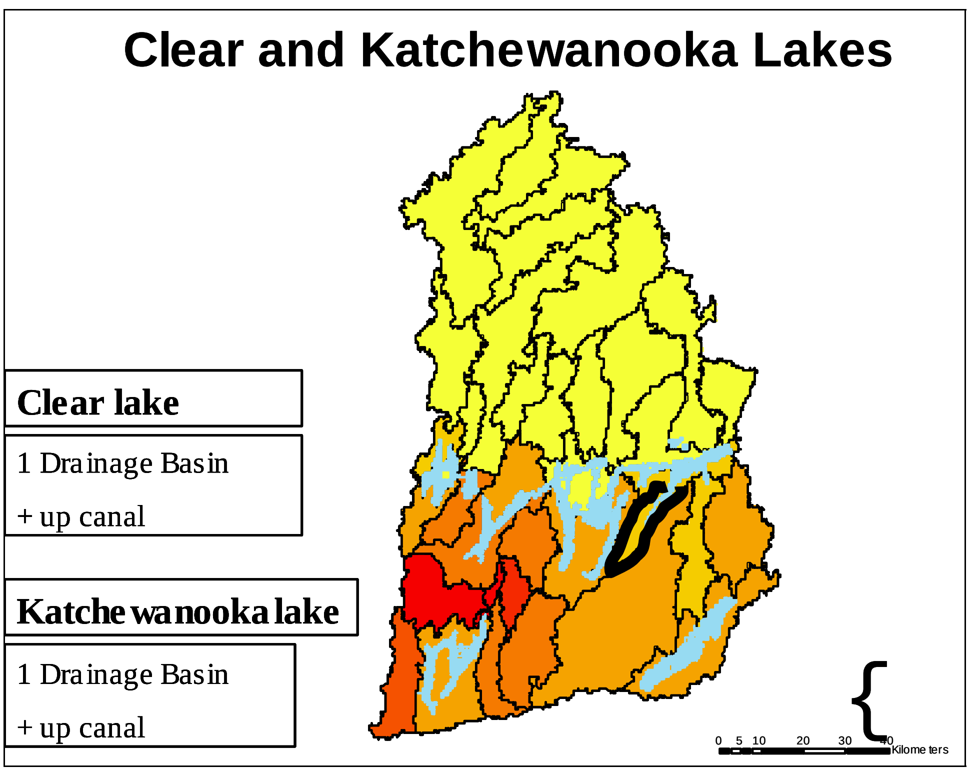


Love Sick Lake

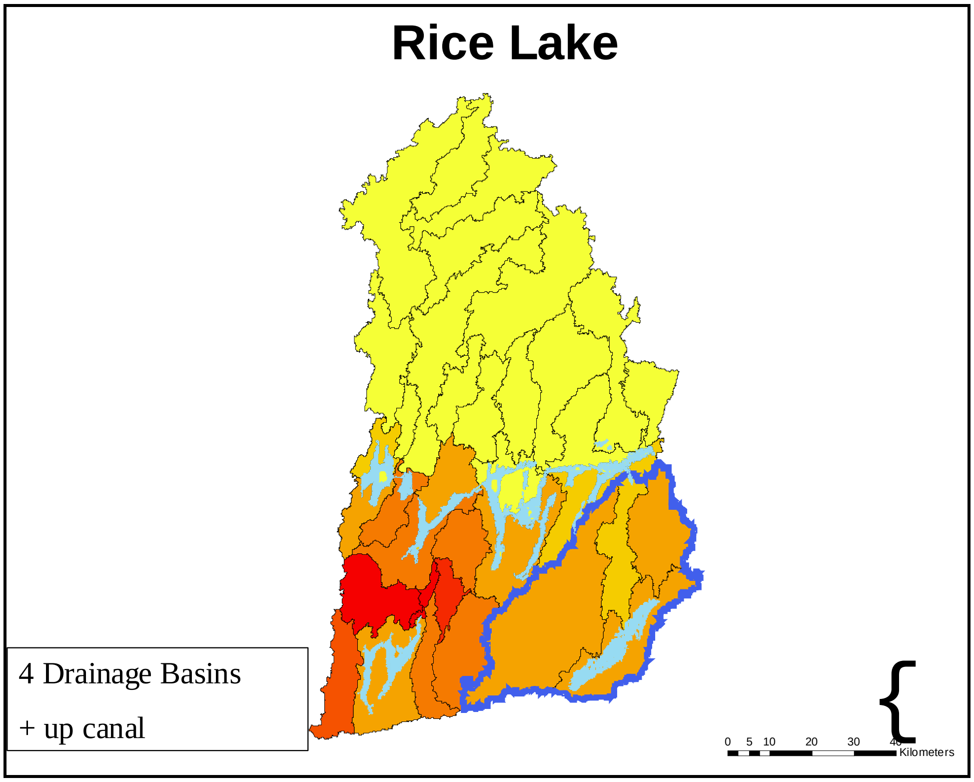




Stony Lake
Upper Stony lake
2 Drainage Basins
Lower Stony lake
2 Drainage Basins
+ up canal
0 5 10 20 30 40
Kilometers



Clear and Katchewanooka Lakes
Clear lake
1 Drainage Basin
+ up canal
Katchewanooka lake
1 Drainage Basin
+ up canal
0 5 10 20 30 40
Kilometers



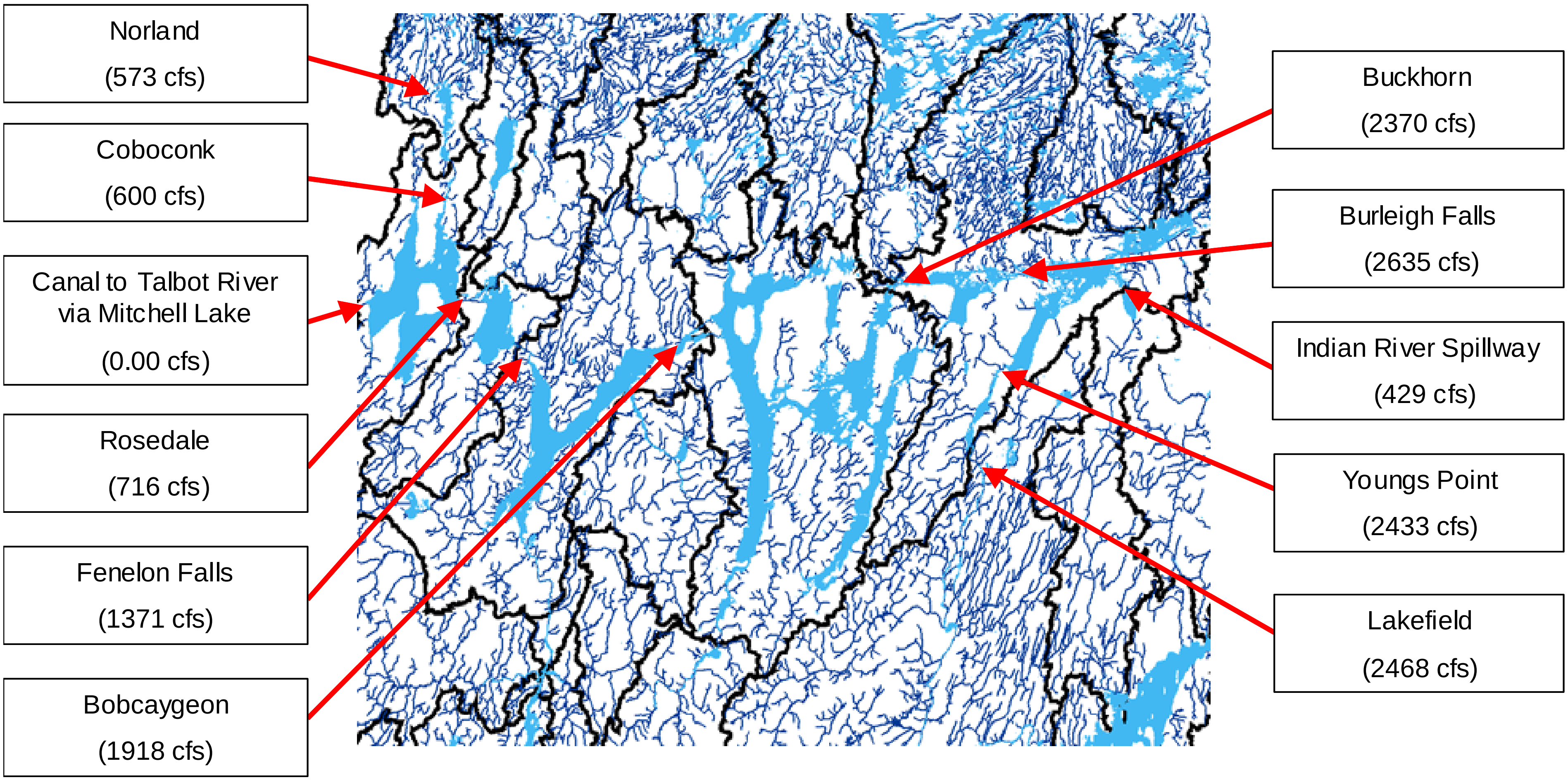
Rice Lake
4 Drainage Basins
+ up canal
0 5 10 20 30 40
Kilometers

Appendix F Stream Contribution Maps

The flow diagrams in this appendix are estimated mean annual flows. Red arrows indicate hydrological inputs, while green arrows can be either inputs or outputs depending on the lake in question. Black lines delineate watershed boundaries. The following stream flow data, provided by Kevin Walters, was used to create the preceding four flow diagrams of the Kawartha Lakes.

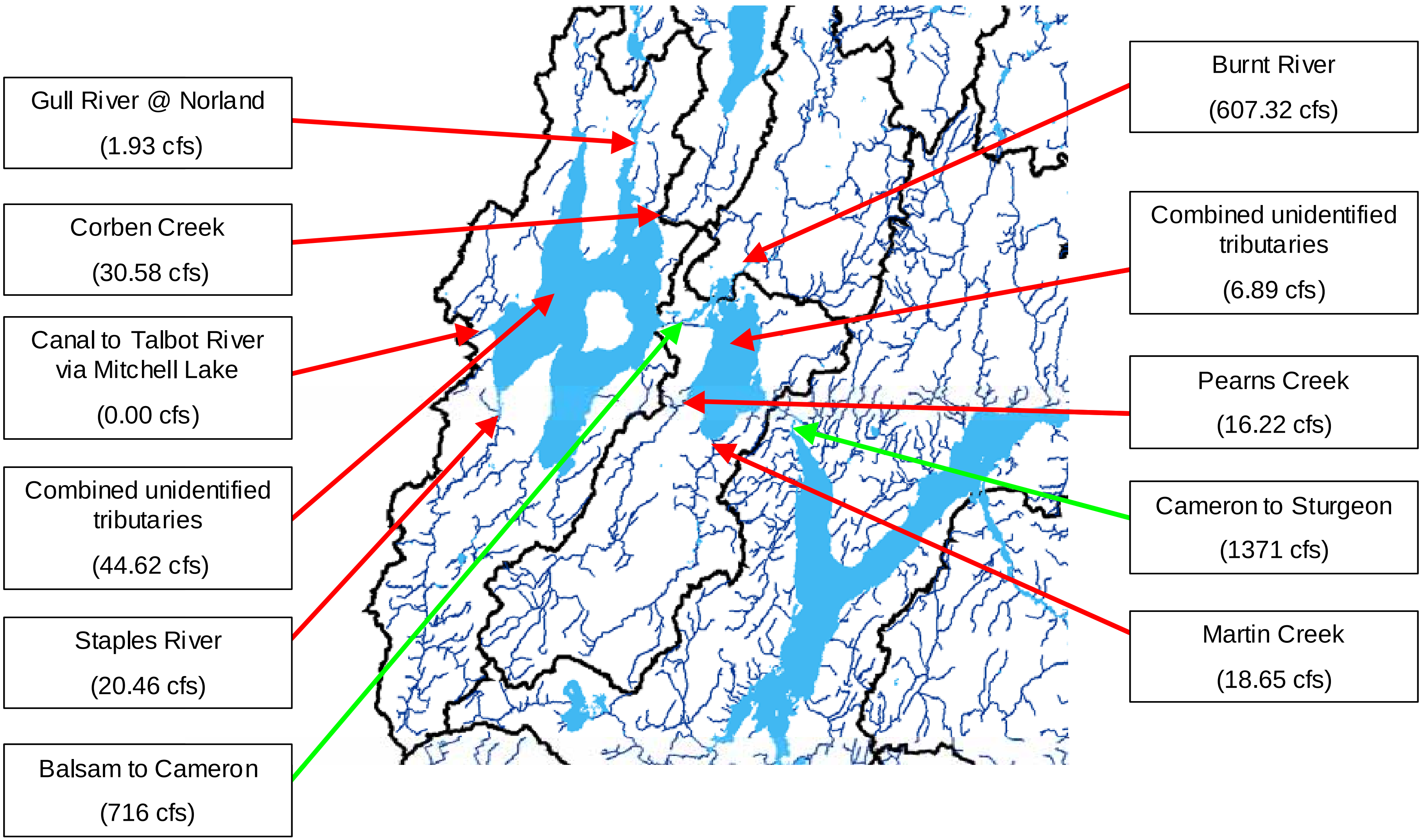
Lake Section	Inflow Source	Lake	Drainage (km^2)	Water Surplus (ft)	Mean AnnFlow (cfs)	Location
UPPER LAKES	Gull River		1280	1.16	573.28	@ Norland
	NorthernTribs		32	1.16	14.33	
	Other Tribs		24	1.16	10.75	
		Shadow/Silver	5	1.00	1.93	@Coboconk
	Staples 'River'		53	1.00	20.46	
	Corben Creek		72	1.10	30.58	
	Other Tribs		107	1.08	44.62	
	TSWCanalto Talbot				0.00	
		Balsam	52	1.00	20.08	@ Rosedale
	Burnt River		1356	1.16	607.32	
	Pearns Creek		40	1.05	16.22	
	Martin Creek		46	1.05	18.65	
	Other Tribs		17	1.05	6.89	
		Cameron	16	1.00	6.18	@ Fenelon Falls
CENTRAL	Rutherford Creek		9	1.08	3.75	
	Martin Creek		29	1.08	12.09	
	Hawkers Creek		52	1.08	21.68	
	McLarens Creek		54	0.93	19.39	
	Scugog River		1025	0.90	356.18	
	Emily Creek		162	0.93	58.17	
	Other Tribs		138	1.00	53.28	
		Sturgeon	57	1.00	22.01	@ Bobcaygeon
	Nogies Creek		192	1.10	81.54	
	Eels Creek		19	1.08	7.92	
	Miskwa Ziibi Creek		195	1.08	81.31	
	Pigeon River		246	0.90	85.48	
	Potash Creek		24	0.92	8.53	
	Chemong Tribs		37	0.90	12.86	
	Other Tribs		322	1.00	124.32	
		'Lake Kawartha'	130	1.00	50.19	@ Buckhorn
	Mississagua River		396	1.12	171.24	
	Deer Bay Creek		160	1.12	69.19	
	Moore Lake Creek		11	1.00	4.25	
	Other Tribs		34	1.06	13.92	
		The Lovesicks	16	1.00	6.18	@ Burleigh
LOWER LAKES	Eels Creek (River)		342	1.08	142.61	
	Jacks Creek		93	1.08	38.78	
	Julia Creek		6	1.00	2.32	
	Other Tribs		113	1.00	43.63	
		Stony-Clear	31	1.00	11.97	@Youngs Point,
	Miller Creek		36	0.92	12.79	
	Other Tribs - Katch		45	1.00	17.37	
	Other Tribs - White		7.5	1.00	2.90	
		Outlet Lakes	6	1.00	2.32	@Lakefield, Indian River
		sum	7074			
	Otonabee @		7360		0.00	Flow Divided 15+/- to Indian, Balance to Otonabee
	Totals				2909.46	

Trent Severn Waterway Flow Overview



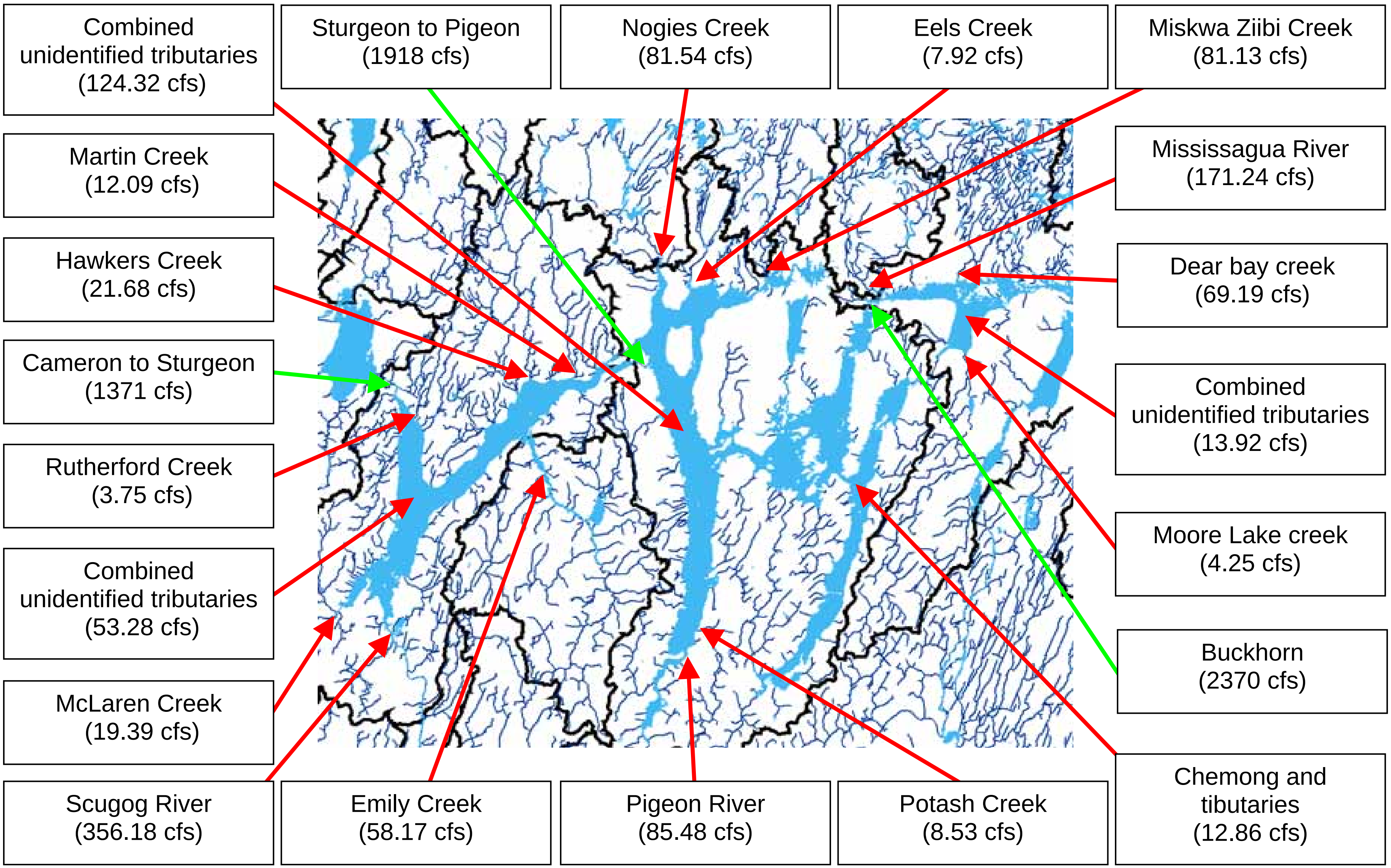
Upper Kawartha Lakes

(Balsam and Cameron Lakes)



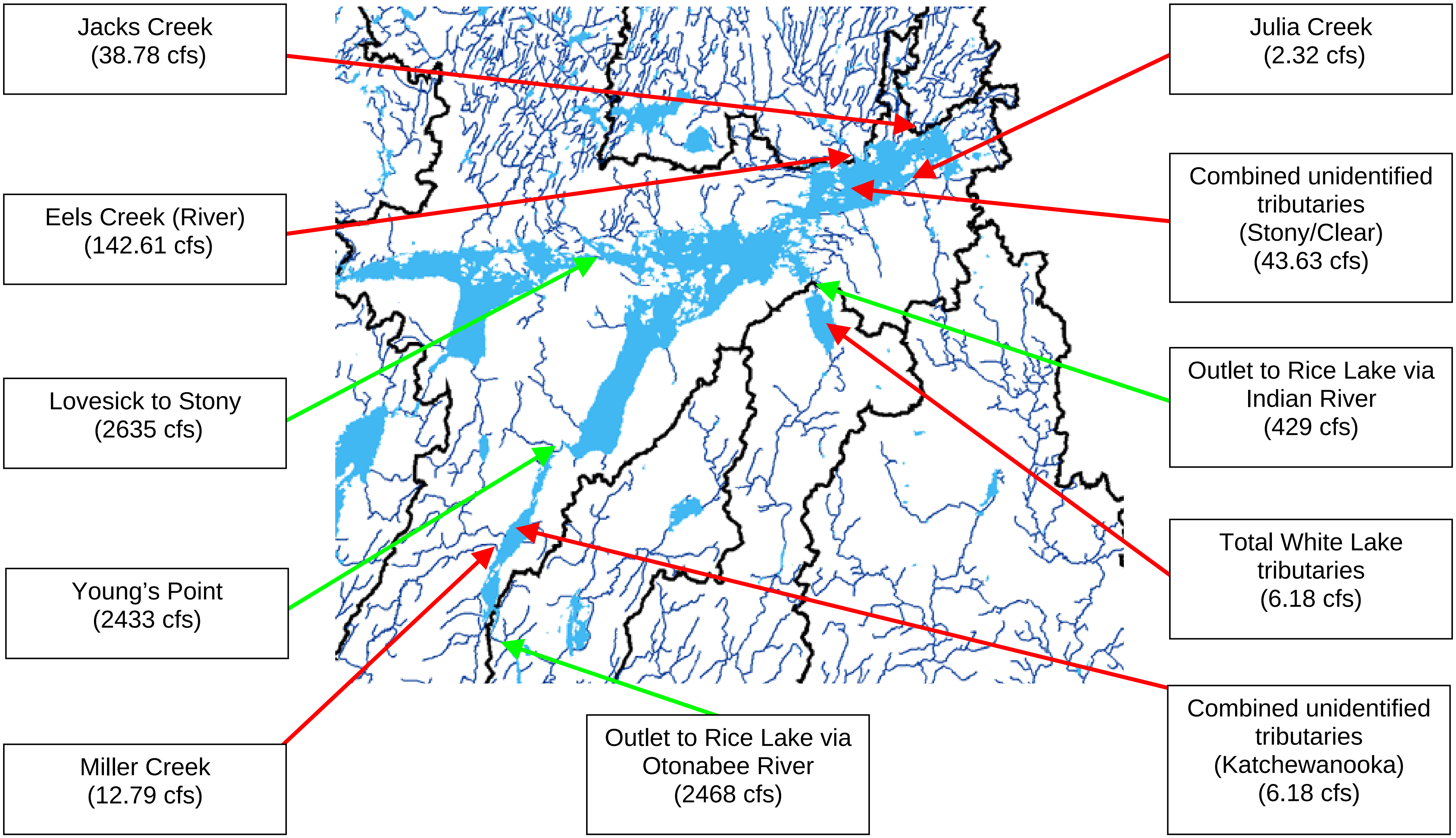
Central Kawartha Lakes

(Sturgeon, Kawartha (Pigeon, Upper Buckhorn, Chemong) Lower Buckhorn and Lovesick Lakes)



Lower Kawartha Lakes

(Stony, Clear and Katchewanooka Lakes)



Appendix G Future Considerations

The following are three areas for future study:

Empirical Modeling of Phosphorus in the Kawarthas

Building a lake model is an excellent way of establishing where information/research is needed concerning phosphorus dynamics in the Kawartha Lakes watershed. Contact a modeling professor to see if she/he has any interested students. A comprehensive model needs to incorporate the many components essential to lake nutrient cycling (i.e. residence time, settling velocity, thermocline depth, etc.).

Detailed Study of Pigeon Lake

Located approximately halfway along the lake chain, Pigeon Lake is an excellent lake to study intensively for the following reasons:
Oliver research centre is already located there. (Potential phosphorus projects for undergraduate students)
Has two distinct rivers entering the north ends for comparative study of nutrient loads from southern cropland catchments (Pigeon river) and northern forested catchments (Nogies creek).
Can test the effect of Bobcaygeon (urbanization, sewage treatment etc.).
Quantify the potential for sediments to release phosphorus
Quantify the potential for zebra mussels, fish and other invertebrates to excrete phosphorus
Quantify the P changes in Pigeon Lake through time
There is increasing evidence that Zebra Mussels are not an answer to phosphorus reductions but rather a short-term reduction in phosphorus concentrations that only compounds future challenges in phosphorus regulation (Hecky et al., 2004). Dr. Eric Sager is already working on Macrophyte relationships with phosphorus concentrations; a companion (unified) study with Zebra Mussels would be beneficial as it is highly probable that they are the key players in phosphorus cycling in the Kawartha Lakes.

Upstream/Downstream Assessments

This is a variant of a traditional control/impact experimental design and very simple to employ. Create six monitoring stations (sampling sites), two above the phosphorus source in question and four at successive intervals downstream (10, 50, 100, 200meters).