Correlating Principal Components Derived from Lake Variables with Phosphorus Levels in the Muskoka Watershed

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ENVS*4011/4012 Project in Environmental Sciences

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April 2, 2013

Judi Brouse
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Dear Ms. Brouse,

In response to your request, please find our enclosed final report entitled 'Correlating Principal Components Derived from Lake Variables with Phosphorus Levels in the Muskoka Watershed'. It has been prepared for April 2, 2013 in affiliation with the ENVS*4011/4012 Project in Environmental Sciences at the University of Guelph. Copies of this report are being submitted simultaneously to faculty advisors Shelley Hunt and Paul Sibley for further evaluation.

In recent years, the threat of phosphorus loading has been an issue of great concern. This research project was created in an attempt to answer many of the questions that still exist in this area of study. The goal of this project was to determine if a correlation exists between lakes that are over threshold for phosphorus and a number of variables in the Muskoka Watershed.

Questions relating to any aspects of the final report should be directed to Elisabeth Shapiro at eshapiro@uoguelph.ca. Your comments and feedback on this report are greatly appreciated.

Thank you for this opportunity.

Sincerely,
Rebecca Howe
Elaine Kennedy
Maureen Latam
Carrie McKinnon
Christina Ng
Elisabeth Shapiro

Acknowledgements

We would like to thank Judi Brouse, Director of Watershed Programs at the Muskoka Watershed Council for providing us with this opportunity and guiding us through this lengthy process. We would like to thank Dr. Paul Sibley, Associate Professor in the Department of Environmental Biology for acting as our faculty advisor for the duration of this project. We would like to thank Dr. Shelley Hunt, Associate Professor in the Department of Environmental Biology for guiding us through this process. Finally, we would like to thank Carmine Bernardo for his help efficiently organizing our data.

Executive Summary

Phosphorus is a naturally occurring element that is an essential component of all living organisms. Organisms can only use phosphorus when it is present in an inorganic form. This often limits growth in ecosystems, as inorganic phosphorus is not always available in the required quantities.

As humans affect and alter the natural landscape, excess phosphorus can enter ecosystems and impact the way that they function. This is particularly problematic in aquatic systems, where phosphorus is often a limiting nutrient. These systems, which previously contained just enough phosphorus to steadily support their flora and fauna, now find themselves with far too much. This phenomenon is known as phosphorus overloading and can lead to a variety of detrimental effects on water quality. Eventually, this can lead to eutrophication: a situation in which a body of water experiences increased plant growth and algal blooms, decreased available oxygen, and in worst-case scenarios, eventually a die-off of aquatic fauna.

Phosphorus loading is an issue of concern in the Muskoka Watershed. The watershed covers 7638km^2 of the Canadian Shield in Ontario, Canada and contains over 500 lakes. This watershed is integral to the region as it contains extensive wildlife habitat, provides a source of drinking water and supports a large tourism industry. For these reasons, protecting water quality is critical for both economic and environmental reasons. Computer models allow us to predict the amount of phosphorus that would be found in a lake that has no people living on it. This is called the background level, and healthy lakes exist between this level and 50% over it. When lakes have phosphorus levels that are more than 50% over the background level, they are considered to be over threshold for phosphorus. The Muskoka Watershed Council (MWC) released a watershed report card in 2010 that showed that 12 out of the regions 20 sub-watersheds contained lakes that were over threshold for phosphorus. As the number of algal blooms continues to increase annually, the MWC has become progressively more concerned for the health of the watershed.

The goal of this study was to determine the relationship between lake phosphorus levels and several physical and chemical lake variables as well as anthropogenic variables to understand this complicated phenomenon and to determine an effective way to mitigate phosphorus overloading. We evaluated several variables of interest, which included:

- Lake temperature
- Development
- Road density
- Dissolved Organic Carbon (DOC)
- Dissolved Oxygen (DO)
- Watershed Area: Surface Area (WA:SA)
- Flushing Rate
- Lake volume
- Mean depth

The aforementioned variables possess a direct or indirect relationship with lake phosphorus levels, as determined by past studies. The goal of our data analysis was to attempt to understand potentially important causative factors between each variable and phosphorus levels.

The statistics program SPSS 20 was used to run a Principal Component Analysis (PCA), which grouped variables together based on a strong positive relationship with one another.

This resulted in our nine variables being decreased into three new variables called 'principal components' (PCs). The new variables were as follows:

PC1 = Dissolved Organic Carbon, Dissolved Oxygen and Watershed Area: Surface Area

PC2 = Flushing Rate, Development and Lake Volume

PC3 = Temperature, Road Density and Depth

Our results showed that none of the PCs were significantly correlated to phosphorus levels in the Muskoka Watershed. There are some potential explanations for the negative results related to methods of data collection and the dataset itself. Only 56 lakes could be used in the analysis, which is a relatively small sample size for a PCA. The vast majority of these lakes were over-threshold for phosphorus, which meant that a strong comparison between under- and over-threshold lakes could not be made. Finally, lakes of similar phosphorus levels were distributed in a clustered pattern and were thus not independent of one another, which weakened statistical testing. This was not surprising, as lakes in close proximity of one another share environmental conditions and influences.

Although many previous studies have investigated the relationship between phosphorus and similar variables as the ones examined in our study, very few have done so with so many variables at once. They have instead studied the relationship between these variables and phosphorus individually and in a controlled setting. We were unable to find any similar studies that examined the correlation between numerous variables and phosphorus on a whole watershed scale. Isolating the effects of each of our variables in such a large-scale study was much more difficult and may have contributed to our inability to identify any significant correlations between the explanatory variables and phosphorus levels across lakes.

Despite being unable to identify causal factors, phosphorus loading is still an issue that must be dealt with in the Muskoka Watershed. Fortunately, phosphorus can be managed without targeting a single source. Anthropogenic phosphorus inputs can be managed by identifying sources and reducing their input to the Muskoka Watershed. Sewage is known to contribute a large amount of phosphorus to human developed water bodies, and can be reduced in a number of ways. Adding compounds such as aluminum, iron or calcium salts before primary treatment can remove between 70 and 90% of all phosphorus in sewage. Another way to reduce phosphorus in sewage is to apply a bacterial treatment to the waste, which can result in phosphorus reductions between 5 and 20%.

Creating riparian buffer strips around lakes is another effective way to reduce phosphorus inputs. These buffer strips are simply vegetated areas, which help protect water bodies from the impacts of nearby land uses. The plants and soil in these buffers are able to take up and retain phosphorus before it reaches the lake, acting as natural filters. These areas also provide habitat for many different organisms and increase the aesthetic value of the region.

Although we did not identify the causal factors, we believe that reducing phosphorus inputs within the Muskoka Watershed would be a valuable next step, as increased phosphorus levels are known to have detrimental effects on water quality. While working to reduce phosphorus levels, we suggest that the MWC collect additional data at regular intervals across lakes, as well as at different depths in order to facilitate understanding of internal phosphorus loading. This would enhance future data analysis capabilities while at the same time working to reduce human derived phosphorus inputs within the watershed.

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1.0 Introduction

A watershed is a collection of surface and subsurface aquatic pathways in which water from rain or snow collects and drains into a common body of water (MWC 2010). The Muskoka Watershed of Ontario covers an area of 7638 km², and contains over 500 lakes (MWC 2010).

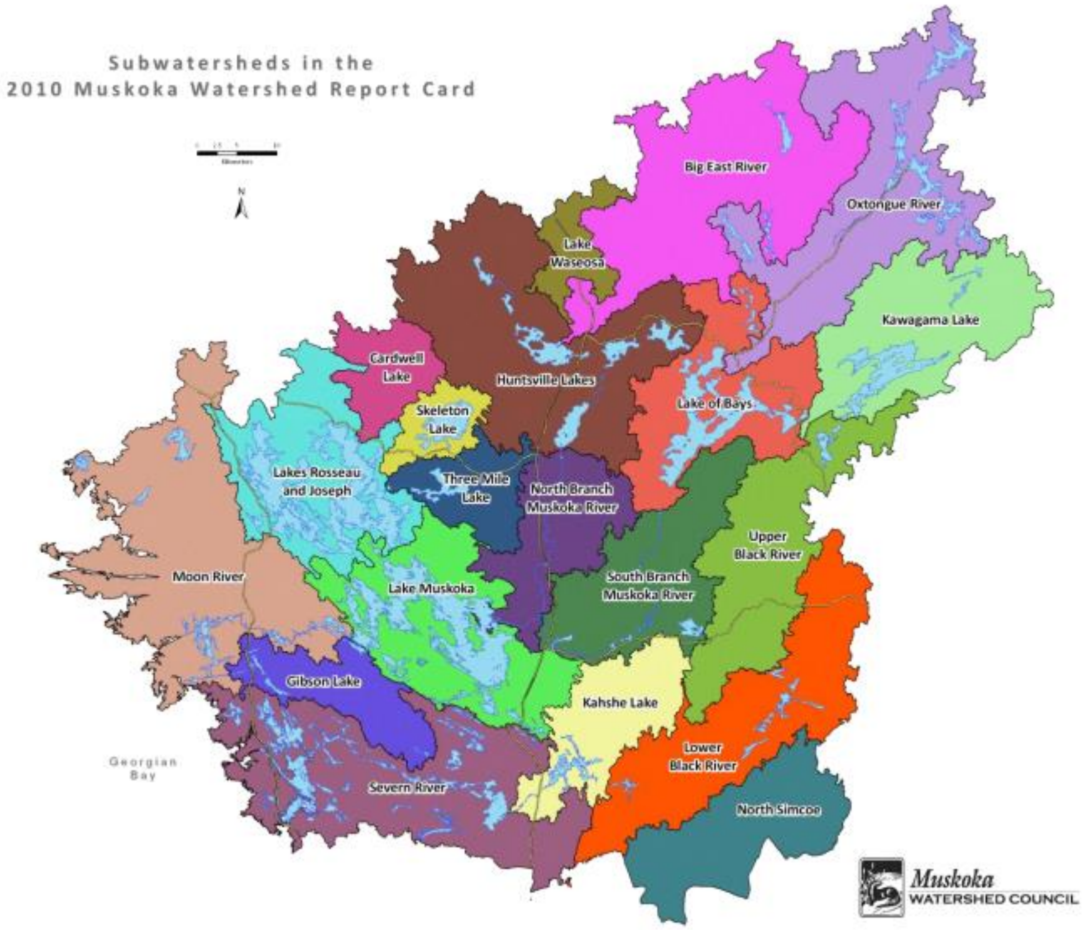

Figure 1: Muskoka sub-watersheds in the 2010 Muskoka Watershed Report Card. Adapted from MWS (2010).

This area is ecologically important, and its natural beauty draws an abundance of tourists who contribute $220 million to the local economy each year (MWC 2010). As this region is home to a large tourism industry, its economy is dependent on the continued success of these recreational activities. This watershed contains lakes and rivers that provide a source of clean drinking water for residents and habitat for wildlife. However, as this region continues to develop to meet a growing tourism demand, the health and stability of the Muskoka Watershed may become threatened. It is therefore critical that the health of this watershed be closely monitored.

The main concern for lakes in this area is eutrophication, which is caused by an increase in nutrient availability in a lake. This facilitates the growth of algae blooms. As the algae die and decompose, lakes experience hypoxic conditions, which can have detrimental effects on lake organisms and water quality (Schendel et al. 2004). If sustained, eutrophication will eventually cause shifts in aquatic plant populations and cause a decline in biodiversity (Schendel et al. 2004).

Freshwater lake productivity in Canada is often limited by phosphorus concentration (Schindler 1974). A common approach to monitoring the likelihood of eutrophication is to regularly measure lake phosphorus levels. As phosphorus is a limiting nutrient for plant growth in Canadian Shield lakes, monitoring lake phosphorus levels would provide an indication of any risks associated with fluctuating phosphorus levels caused by anthropogenic or natural inputs (Schendel et al. 2004; MOE 2010). A key indicator of overall watershed health in the Muskoka region is the identification and examination of lakes that are over-threshold for phosphorus. In order to be considered over-threshold, a lake must have phosphorus levels that are greater than 50% of their background level, a modeled baseline of phosphorus concentration in the absence of human influence (MOE 2010).

In order to develop and refine best management practices to control phosphorus loading in the Muskoka region, a better understanding of factors affecting phosphorus levels is required. In their 2010 report card, the Muskoka Watershed Council (MWC) suggested that detailed studies were required to understand changing trends in phosphorus concentrations. In this study, we examined lake phosphorus levels in the Muskoka Watershed by performing a correlational analysis to determine which lake variables were contributing significantly to phosphorus loading. The benefits and applications of this research are numerous. This information will be used in the MWC's 2014 watershed report card, which will be made available to the general public in order to facilitate future discussions pertaining to water quality in the Muskoka watershed. Scientists and government officials who seek a thorough understanding of phosphorus levels and lake dynamics may also use this report to help develop future regulations and control methods. Finally, the foundation that this study provides will create incentive and reference for further monitoring.

2.0 Literature Review

2.1 Phosphorus in the Environment

Phosphorus is a naturally occurring element that is essential to living organisms (Keyzer 2010). It is the eleventh most common element in the Earth's crust and exists primarily in rock in the form of calcium phosphate (Morton and Edward 2005). As rocks weather over time, they release phosphate, which enters soil and becomes available to organisms (Morton and Edwards 2005). When phosphate is released in this manner, it becomes dissolved in solution, making it available to plants (Bates and Lynch 1999).

2.2 Environmental Impact of Phosphorus

Water quality is fundamental to the health of any watershed, and many factors can affect water quality including nutrients, chemical pollutants, invasive species, climate change and pathogens (MOE 2010). Nutrients can play an important role in water quality, since changes in nutrient availability have the potential to change lakes dramatically and disrupt species habitat and recreational use. A nutrient that is available in small quantities in any lake system is termed a limiting nutrient, and as Schindler (1974) showed, phosphorus is the limiting nutrient for freshwater lakes. This means that additions of phosphorus can intensify plant growth and lead to lake eutrophication (Shindler 1974; Schendel et al. 2004).

Phosphorus additions stimulate the growth of aquatic plants and algae, leading to excessive plant growth and algae blooms (MWC 2010). This increased organic material eventually dies, then settles to the bottom of a lake and decomposes, which uses up the lake's oxygen supply through microbial respiration (MOE 2010). In a process known as internal loading, bottom sediments release phosphorus as oxygen is depleted, exacerbating the cycle (MOE 2010). Low levels of dissolved oxygen can also result in a build-up of toxic products such as methane, hydrogen sulphide and ammonia (Brylinsky 2004). These toxins, along with the loss of dissolved oxygen, can harm and kill aquatic organisms (Carpenter et al. 1998 Bennett et al. 2001). Additionally, algae blooms can have a negative impact, causing water discoloration, a foul taste or odour, and unpleasant algal mats that ruin beaches (MOE 2010). Ultimately, eutrophication can lead to the presence of algal and chemical toxins, loss of biodiversity, loss of drinking water, loss of recreational uses, and loss of ecosystem function.

Anthropogenic sources of phosphorus can lead to cultural eutrophication in lakes. These sources include agriculture, sewage systems, storm water runoff and atmospheric deposition from the burning of fossil fuels (MOE 2010). Historically, many severe eutrophication events caused by anthropogenic phosphorus loading have been observed, including Lake Erie in the 1950's (Schindler 1974; Dolan 1993). Government regulations have been developed to reduce the amount of phosphorus entering these systems (MOE 2010). This effort at control has focused mainly on limiting phosphorus in consumer products, promoting better agricultural practices, and reducing inputs from sewage and industry (MOE 2010). These efforts have been successful in restoring culturally eutrophied lakes to a more natural state (MOE 2010).

2.3 The Muskoka Watershed

Phosphorus loading is a concern in the Muskoka Watershed. The Muskoka Watershed Council (MWC) released a watershed report card in 2010 that showed that 12 out of the 20 sub-watersheds in the region had lakes that were over threshold for phosphorus (MWC 2010).

In 2012, the Muskoka area experienced a higher number of algae blooms than in previous years, which may be linked to increased phosphorus levels (MWC 2012). Unfortunately, this would imply a change in the trend of declining phosphorus levels in the region (MWC 2010). This will have implications for residents, tourists, and wildlife, including the 35 species at risk in the Parry Sound – Muskoka region (MH 2012). As phosphorus continues to be problematic in the Muskoka Watershed, it raises questions regarding the effectiveness of municipal legislation and what should be done in the future to improve control of anthropogenic phosphorus loading.

In order to develop effective control measures concerning phosphorus loading in the Muskoka region, a better understanding of phosphorus levels and lake dynamics is required. Only some of the lakes in the Muskoka Watershed are experiencing higher than normal levels of phosphorus, while other lakes show no signs of phosphorus loading. Evidence suggests several different variables can independently influence phosphorus levels. The major areas identified include watershed characteristics, lake characteristics, land use, and soil properties (Meynendonckx et al. 2006). Variables that impact phosphorus loading include temperature (Nicholls 1999; Soendergaard et al. 2001), soil properties (Meynendonckx et al. 2006), lake size (White and Stone 1996), flow rate (Munn et al. 2010), and dissolved organic carbon (DOC) (Lehrter 2006). The amount of development around lakes is also an important determinant of phosphorus inputs into lake systems (Wang et al. 2008). When taken individually it can be simple to understand how these factors influence phosphorus loading, but it is unclear how they interact and which factors are most important. Unfortunately, comprehensive studies examining multiple variables have not been conducted for the Muskoka Watershed. Thus, there is no information available to judge which variables are most influential to phosphorus loading in this watershed and could be used to help explain trends in phosphorus concentrations.

2.4 Study Objectives and Expected Results

In order to more effectively control phosphorus loading in the Muskoka Watershed, the relative influence of factors affecting phosphorus loading on lake phosphorus concentrations needs to be addressed. The objective of this study was to provide the MWC with a comprehensive analysis of the factors affecting phosphorus loading in the Muskoka Watershed. This study attempted to ascertain which factors have the strongest correlation to phosphorus loading in the Muskoka region, and whether any spatial or temporal patterns exist amongst the variables of study. In order to accomplish this, we determined whether or not a correlation existed between Muskoka lakes that are over-threshold for phosphorus, and between several variables as outlined by the MWC as well as additional variables that we had deemed potentially important.

Since freshwater lakes are highly complex ecosystems, we expected that many of our variables will interact with each other or with other variables that are not being addressed. Due to the complexity of this situation and the number of interactions occurring, it was difficult to predict a general trend that would be consistent in all the lakes under study. We examined previous research pertaining to our variables of study and used this to predict correlations that we believed will occur between each variable and phosphorus loading within the Muskoka region. Based on previous research, we expected the following results:

2.4.1 Temperature

Past studies have found a strong correlation between increased temperature and total phosphorus (Nicholls 1999). High temperatures cause an increase in plant biomass, which in turn leads to an increase in decaying plant matter. This is apparent in summer months when algal blooms increase in response to increases in temperature (Huang et al. 2011). As a result of these increased decomposition rates, oxygen is depleted, accelerating the release of sedimentary phosphorus (Eilola et al. 2009). Thus, we believed that there would be a positive correlation between temperature and phosphorus.

2.4.2 Lake Development

Phosphorus loading is strongly correlated to land use and land cover (Lehrter 2006). Forested areas are known to retain phosphorus better than other areas, as trees reduce phosphorus loads in runoff into watersheds (Lehrter 2006). The clearing of forests for human development will result in increased discharge of phosphorus into a body of water. Additionally, development disturbs land, increasing erosion and raising the potential for phosphorus stored in soils to enter lakes (Soranno et al. 1996). If a watershed were to become entirely urbanized, phosphorus loading to the lake could double and the consequences on water quality would be severe (Soranno et al. 1996). Therefore, we expected that higher levels of development would be associated with high concentrations of phosphorus in lakes, compared to areas with little development.

2.4.3 Dissolved Organic Carbon (DOC)

Previous research has found that elevated phosphorus levels were not observed at locations where high DOC and dissolved organic nitrogen were observed (Lehrter 2006). Not only does DOC depress primary production by limiting light availability for photosynthetic processes, but the presence of DOC also decreases the availability of phosphorus. Thus, high DOC tends to decrease the risk of eutrophication (Gergel et al. 1999). Thus, we expected high DOC to correlate poorly with phosphorus loading and predicted that lakes with high DOC levels would have lower levels of phosphorus.

2.4.4 Dissolved Oxygen

Oxygen levels in lakes are affected by several factors which also have the capacity to alter phosphorus levels within a lake (Chapra and Canale 1991). Oxic lake sediments are much more efficient at retaining phosphorus than anoxic sediments; large amounts of phosphorus are released when sediments become anoxic (Gachter et al. 2003). However, many other nutrients, such as sulfate and iron, play a role in benthic phosphorus release, making it difficult to pinpoint its source (Gachter et al. 2003). Algal blooms create a decrease in water oxygen levels and this in turn leads to greater phosphorus release from the aforementioned bottom sediments (Trojanowska and Izydorczyk 2010). We expected that lakes with low mean oxygen levels would have higher phosphorus loading compared to lakes with high mean oxygen levels.

2.4.5 Watershed Area to Lake Area

Many features of a watershed contribute to water quality, and since a lake is a reflection of its watershed a polluted watershed is more likely to result in a polluted lake (Detenbeck et al. 1993). In relatively homogenous, undeveloped lakes, trophic status can be estimated as a function of the watershed area to lake area ratio (Schindler 1971). As this ratio increases, so does external nutrient loading (Schindler 1971). Since trophic status can be determined from total phosphorus, nitrogen, or chlorophyll concentrations (Schindler 1971), we predicted that as the ratio of watershed area to lake area increases, so would total phosphorus concentration.

2.4.6 Flushing Rate

Flushing rate, the rate at which water moves out of a lake, has been shown to affect phosphorus load. It is measured in lake volume/discharge, and lower discharge rates out of a lake result in higher phosphorus levels within the lake (Lehrter 2006). Therefore, higher flushing rates cause a decreased phosphorus load when compared to lakes with lower flushing rates (Sondergaard et al. 2012, Zhu et al. 2012). If water enters a lake quickly and has a high residence time there will be increased phosphorus concentrations. If a lake has a high flushing rate and a fairly low residence time, there will be lower phosphorus concentrations. We therefore predicted that phosphorus concentrations would correlate negatively with flushing rate.

2.4.7 Lake Volume

Shallow lakes are more likely to have a high plankton biomass than deep lakes, as a large amount of sunlight and phosphorus is available to support the population (Stemberger and Miller 2003). A study by White and Stone (1996) found that shallow lakes are at a greater risk of phosphorus loading than deep lakes, and we expected the same to be true in our study.

2.4.8 Road Density

Roads can act as a conduit for surface run-off from the landscape as they are impermeable surface features. While flowing over roads, this runoff may accumulate soil and dust particles, which bind with phosphorus. Furthermore, development is known to contribute to increased phosphorus loading (Lehrter 2006) and the creation of roads is a type of development. Thus, we believed that lakes with more nearby roads would experience higher levels of phosphorus.

2.4.9 Mean Depth

Past studies have found lake depth to be an important indicator of total phosphorus (Taranu et al. 2008). In shallow lakes there is a higher percentage of water in contact with the sediment surface, enhancing the level of phosphorus entering the water through chemical reactions with the sediment (Dong and Yang 2011). Shallow lakes have increased nutrient loading, which makes them more susceptible to eutrophication than deeper lakes (O’Sullivan and Reynolds 2008). The potential for eutrophication to cause anoxic conditions, as well as the fact that deeper lakes often have an anoxic bottom layer, can increase the phosphorus levels in deep lakes due to anoxic chemical reactions with the sediment. It was difficult to predict the direction of the correlation between phosphorus and mean depth due to these opposing pieces of information.

3.0 Methods

The purpose of this study was to determine the correlation between several variables and lake phosphorus levels in the Muskoka Watershed. An extensive dataset quantifying many physical, chemical and social attributes of over 500 lakes in the watershed was provided by the MWC, including data from the 1980s to present. While the original dataset contained 520 lakes, only 59 of these had data available for every study variable, so only these 59 were included in the analysis. Based on a thorough literature review and upon recommendation of the MWC, nine different variables were selected as the most likely to have significant impacts on lake phosphorus levels, and were included in the analysis (table 1).

Variable of Study	**Data Description**
Lake Volume	Volume of each lake (m^3).
Temperature	An estimate of lake temperature was obtained by averaging temperature data collected at various measured depths between 2000 and 2012 (°C).
Dissolved Organic Carbon (DOC)	The most recent measurement provided was used for each lake (mg/L).
Dissolved Oxygen (DO)	An estimate of DO was obtained by averaging DO data collected at various measured depths between 2000 and 2012 (mg/L).
Flushing Rate	Flushing rate was defined as the number of times the lake refilled itself in one year. It was calculated for each lake by dividing volume by discharge (refills per year)
Watershed Area:Surface Area	WA:SA was found by taking the ratio of the sub-watershed area (km^2) to the surface area(km) of each of the lakes it contained (unitless).
Development	Development was represented by the ratio of developed to vacant lots within 100m of each lake's perimeter (unitless).

Road Density	ArcGIS was used to determine the density of roads within a 200m buffer around each lake's perimeter, based on shape data provided by the MWC (km road/km^2).
Lake Depth	Mean depth was used for each lake (m).
Lake Phosphorus	Phosphorus level was determined by the per cent above background level.

Table 1. Summary of the nine study variables, the phosphorus variable and the data used in calculating each.

These nine lake variables were not completely independent of each other; there was some correlation between variables. Most statistical analyses operate under the assumption that variables are independent of each other, so violating this would greatly decrease the power of statistical tests. To account for possible colinearity among the lake variables (Fekedulegn et al. 2002; Mertler and Vannatta 2005; Yu 2011), a Principal Component Analysis (PCA) was used to group similarly correlated variables together before further analysis was conducted. The goal of PCA is to reduce the dimensionality of data sets, while retaining their variation (Jolliffe 2002). PCA is able to reduce correlated variables to a smaller number of principal components (PC), which are not correlated. These uncorrelated principal components are independent of each other, allowing for further statistical analysis.

After the principal components were determined, each one was compared against lake phosphorus level in a bivariate correlation analysis. This calculated how much variability in phosphorus could be attributed to variability in each PC, as measured by Pearson's r correlation coefficient. This gave not only the strength of the correlation, but the direction as well.

All analyses were conducted using SPSS 20.0 statistical software, and significance was based on an alpha level of 0.05.

4.0 Results

In SPSS a PCA was run that included all nine independent variables. A direct oblimin rotation was chosen for the extraction of the data to adjust for the collinearity of the variables ($\delta=0$). A maximum of nine components was used and based on the scree plot shown in Figure 2 three components were chosen to reduce the variables. The PCA was run again with a maximum of three components, and factor scores obtained for the three components were used to identify and eliminate statistical outliers from the data set. A final PCA was run with the outliers removed, again using three components (n=56). Figure 3 shows the variables plotted on a component graph. The final PCs are shown in Table 2 along with the variables most strongly associated with each PC. These were determined by the matrices from the SPSS output summarized in Table 4. The cumulative variability explained by the three components was 65.6%, meaning that the components accounted for enough of the variability in the data to use them in further analyses. In each step of the PCA the KMO was >0.50 and Bartlett's test of sphericity was significant ($p<0.001$).

Three sets of factor scores were generated for each lake corresponding to the three components from the PCA. To obtain PC values these factor scores were multiplied by the square root of their corresponding eigenvalues and PC1, PC2 and PC3 values were obtained for each lake.

The bivariate correlation between each of the principal components and lake phosphorus levels revealed (n=56) that none of the correlations were significant as seen in Table 3 and Figures 4, 5, and 6 (Appendix 8.1) .

Principal Components	Variables
PC1	*DOC; Oxygen; Watershed Area:Surface Area*
PC2	*Flushing Rate; Development; Lake Volume*
PC3	*Temperature; Depth; Road Density*

Table 2. Three principal components were selected based on PCA analysis, each representing three variables most strongly correlated with each other.

Principal Component	**Correlation Coefficient (r)**	**Significance (2-tailed)**
PC1	-0.215	0.111
PC2	-0.036	0.791
PC3	0.143	0.292

Table 3. Bivariate Correlation test results for PC1/PC2/PC3 correlated against phosphorus level for Muskoka lakes. None of the PCs were significantly correlated to phosphorus level.

5.0 Discussion

5.1 PC1- Dissolved Organic Carbon (DOC), Dissolved Oxygen (DO) and watershed area:lake area (WA:LA)

PC1 was primarily composed of lake chemistry properties and their determinants. Although WA:LA is not a chemical property, it does have significant effects on DOC and DO (Hanson et al. 2006). DOC is strongly influenced by organic matter input, most often from humic and fulvic acids from soil runoff (Canham et al. 2004). The amount of runoff and its organic matter content are in turn determined by physical properties of the watershed such as surface area and the distance that runoff water travels before entering the lake. The farther the runoff water travels through soil, the more organic matter it accumulates (Hanson et al. 2006; Canham et al. 2004; Xenopouos et al. 2003). These physical properties influencing DOC content were reflected in the WA:SA variable, as it involves not only the area of the lake itself, but also the area of the watershed, which accounted for the distance travelled by runoff water. DO is likewise related to lake physical properties. DO enters lakes through gas exchange with the atmosphere at the lake's surface, and so a higher surface area is often correlated with higher DO (Hanson et al. 2006; Joyce et al. 1985). Additionally, DOC has been shown to influence DO by limiting light penetration and photosynthesis (Canham et al. 2004). Thus, DOC and DO were not only related to WA:SA, but also to each other, and could therefore be treated as a single component in PCA.

PC1 was not significantly correlated to phosphorus levels, although it exhibited a weak trend (p=0.111). This may have been because DO is highly variable through time, even in a single lake (Canham et al. 2004). The data for DO and DOC were collected on two or three occasions per year for each lake, often several years apart. This method of collection may not have accurately represented the average chemical characteristics of the lake, since they were relatively infrequent. Additionally, DOC and phosphorus are generally influenced by surrounding vegetation and soil properties, which were not included in the dataset and may have contributed to phosphorus loading (Carpenter et al. 1998; Canham et al. 2004). These potential flaws in the dataset may have contributed to the lack of correlation with P levels.

5.2 PC2- Flushing Rate, Lake Volume and Development

PC2 was grouped as flushing rate, lake volume and development. Lake volume and flushing rate were likely grouped together because they were not calculated independently; flushing rate was calculated by dividing volume by discharge. Since volume was used in the calculation for flushing rate, the two variables were mathematically correlated. Development was most likely related to lake volume. A larger lake is generally more appealing to residents and cottage-owners, as a larger lake offers more opportunity for recreational activities such as boating and fishing (Schnaiberg et al. 2002). Furthermore, larger lakes are more profitable for developers since they can build higher densities of cottages in the same region to facilitate management and decrease cost of transportation (Schnaiberg et al. 2002). This could explain the correlation between development, volume and flushing rate.

These three variables did not correlate significantly with phosphorus levels (p=0.791). Flushing rate is highly variable and does not cause an increase in phosphorus concentrations at either high or low extremes (Turner et al. 2006). At low rates, phosphorus settles out of the water and into the sediments, and at high rates phosphorus is washed out of the lake system (Turner et al. 2006). Because of this, variation in flushing rate has not been shown to have an effect on P concentrations, even when increased by a factor of three (Turner et al. 2006; Jones et al. 2008). Although development near a lake was expected to cause an increase in phosphorus concentrations due to anthropogenic inputs such as septic systems, phosphorus additions may have been diluted by the large volume of water that was associated with high development. A study by Hargan (2010) also found that shoreline development had only a small effect of phosphorus concentrations in lakes.

5.3 PC3- Lake Temperature, Road Density and Lake Depth

The final component in the PCA included average lake temperature, road density, and average lake depth. The temperature and depth of lakes are closely linked due to stratification and limnology. Deeper lakes tend to have lower average temperatures since sunlight and heat do not penetrate as far into the water body, resulting in cooler, deeper waters. A more complex relationship between temperature and depth is the process of stratification (Brylinsky 2004). Lakes of adequate depth in temperate regions stratify into thermal layers, generally a warmer upper layer and a cooler lower layer, that do not mix during summer or winter (Brylinsky 2004). In spring and autumn, these layers are mixed as atmospheric temperatures change (Brylinsky 2004). This relationship between average temperature and depth explains why they were both included in PC3. Road density was likely grouped in PC3 because of its effect on temperature. The construction of roads in the area could not have been done without some level of deforestation, and loss of tree cover has been shown to increase nearby stream temperatures. Declines in tree cover expose waterways to more heat and sunlight, allowing temperatures to rise by several degrees (Brown and Krygier 1970). These streams flow into lakes and thus raise the average lake temperature. Additionally, water flows overtop of roads instead of entering the soil, due to the impermeability of pavement (Arnold and Gibbons 1996). This exposes runoff to excessive heat and increases its temperature, whereas water entering the soil is cooled (Arnold and Gibbons 1996). Both of these increases in water temperature are a direct consequence of road construction near lakes, and help to explain why these three components were correlated.

There are several possible explanations for the lack of significance found in PC3 (p=0.292). We expected temperature to be positively correlated with phosphorus levels, as has been observed in previous studies (Huang et al. 2011). This was not the case in our analysis, possibly due to the fact that we did not consider lake stratification, which is integral to phosphorus levels. In stratified lakes, the cool bottom layer becomes anoxic in winter, and under these anoxic conditions phosphorus is released from the sediments (Sundaram and Rehm 1972). This high concentration of phosphorus is dispersed throughout the lake in spring when the layers are mixed (Sundaram and Rehm 1972). This study did not take into account stratification due to logistical and data limitations. Using average temperature data instead of stratification data may not have represented the thermochemical interactions within each lake accurately enough to detect a significant correlation with phosphorus.

Road density has also been shown to increase nutrient loading in lakes, although this was not the case with our study (Garrison and Wakeman 2000). However, information on the type of road was not included in the dataset that we analyzed, and this may have contributed to variation in the dataset. Impermeable roads made of hard pavement can cause increased nutrient loading in the overland runoff, but permeable dirt roads would not have this effect (Garrison and Wakeman 2000). The width of the road may also have had an effect on P levels, but was not included in analysis. As we did not account for road type or width, the data of PC3 may have been inadequate.

5.4 Data Limitations and Future Recommendations

None of the three principal components tested showed a significant result when compared in bivariate correlation analysis against phosphorus levels in Muskoka lakes. Thus, none of the three principal components could adequately explain the variation in phosphorus level that was included in the dataset. There are several possible reasons that could explain this insignificance. First, the sample size used in the PCA was fairly small (n=56) compared to the original dataset (n=520). This could not have been avoided, since many of the lakes were missing crucial data such as volume, temperature, and road density. This limited the dataset to the comparatively few lakes for which all the necessary data was available. Comfrey and Lee (1992), suggest that a sample size of approximately 50 is “very poor” for PCA, and Gorsuch (1983, p.332) and Hatcher (1994, p. 73) recommend a subject to item ratio of at least 5:1, although greater is more desirable. The ratio for this study was adequate at 7:1, but a larger sample size would have greatly improved the reliability of the PCA.

There were also some potential problems in the dataset and methods of data collection that may have contributed to a type II error, rejecting a hypothesis that was true. There may have been variables that significantly influenced the phosphorus levels in Muskoka lakes, but were not selected as study variables in the analysis. This unacknowledged variables included soil type, sediment type and nearby vegetation. Bias in the dataset may also have skewed the results. Although the study aimed to identify factors that separated over- from under-threshold lakes to determine which ones caused phosphorus over-loading, the vast majority of the 56 lakes with corresponding explanatory variables in the dataset were over-threshold lakes. Since there were so few under-threshold lakes for which corresponding explanatory variables were available, there could be no strong comparison between the two lake types.

The method of data collection in this study may also have contributed to a type II error. Several variables (eg. temperature, DOC, DO) were taken only twice a year, with a few years between recordings. These types of variables can fluctuate considerably over both short and long-term periods, so the frequency of recordings may not have been enough to accurately capture the data trends. More frequent recordings certainly would have improved the reliability of the dataset. Sampling should also be synoptic. When a phosphorus sample is taken, corresponding lake variables should be recorded concurrently to eliminate temporal variability between phosphorus measurements and other variables.

Finally, there was significant evidence of positive spatial autocorrelation within the dataset. Lakes of similar phosphorus level existed in a clustered pattern, and were thus not independent of each other. This was not surprising, as lakes are often connected by fluvial processes and share similar sets of environmental conditions that may have been influencing phosphorus levels. However, since the lakes were not independent of each other, important statistical assumptions were violated and the power of statistical testing was reduced. This may have also contributed to a type II error.

There is a lack of large-scale field studies that investigate phosphorus loading in lakes, making it difficult for us to compare our results. The majority of current knowledge pertaining to phosphorus loading does not examine this phenomenon in complex real world situations. These studies instead focus on the effects of one or a few variables on phosphorus levels in a controlled setting. Isolating the effects of each variable in a large-scale field study is considerably more challenging, due to the magnitude of noise and co-dependence in variables, and the time and effort required to collect the necessary data. For these reasons, there are very few comparable studies to this one.

Future data collection in the Muskoka watershed should focus on obtaining data for under-threshold lakes to improve the comparison between these lakes and the over-threshold lakes, though not at the expense of continued sampling of over-threshold lakes. Adequate data collection in both under- and over-threshold lakes is necessary for a strong statistical comparison. Water chemistry data (DOC, DO and temperature) was unavailable for most of the under-threshold lakes, as was GIS data. Obtaining this data would greatly increase the power of statistical comparisons between under- and over-threshold lakes. Additionally, more frequent monitoring of water chemistry data would be beneficial to increase the reliability of estimates, as these properties can fluctuate over short periods of time. Obtaining landscape data such as soil type, vegetation type and cover, and sediment type would also be beneficial for more a thorough analysis of factors influencing phosphorus in the watershed.

Although there were no factors that significantly influenced phosphorus levels in the analysis, there are many ways to manage phosphorus loading in lakes in a general sense, without targeting any single source. Phosphorus can be managed by controlling both external and internal loading (Cullen et al. 1988). External loading can be controlled by identifying sources of anthropogenic phosphorus and reducing the input from these sources. The most common anthropogenic sources of phosphorus are agriculture and sewage (Smil 2000, Shindler 2006). Since there is minimal agriculture in the Muskoka region, sewage is likely contributing to a rise in phosphorus, as it is the largest source of phosphorus in non-rural areas (Smil 2000). The amount of phosphorus in sewage can be reduced using a number of methods. One of the most effective methods is to add flocculating compounds (aluminum, iron or calcium salts) to the sewage before primary sedimentation (Smil 2000). This removes between 70-90% of all phosphorus in the sewage effluent, as opposed to only 5-20% from primary sedimentation alone (Smil 2000). Repeated dispensation further reduces the phosphorus concentration in sewage effluent, enabling up to a 95% reduction (Smil 2000). Another method of removing phosphorus from sewage is bacterial treatment: bacteria remove 15-40% of all phosphorus without increasing the mass of sewage sludge that is caused by the previously mentioned methods (Smil 2000; Schindler 2006).

A less direct, and potentially more economical and environmentally friendly method of phosphorus reduction is to create riparian buffer strips around the perimeter of water bodies (Pieterse et al. 2003). These strips reduce the diffuse runoff flow and increase phosphorus retention by taking it up in plants and soil before it reaches the water (Pieterse et al. 2003). Wetlands have a similar effect of phosphorus uptake and retention (Schindler 2006). The creation of riparian buffer strips and wetlands would not only reduce phosphorus levels in lakes, but also create habitat for many different types of organisms, increase aesthetic value and potentially increase tourism of the area.

Increased phosphorus from impermeable road surfaces can also be reduced by management. Replacing existing roads with permeable pavement roads would allow water to infiltrate the ground earlier, and thus reduce the potential to accumulate phosphorus compounds on the surface (Arnold and Gibbons 1996). This would also decrease its overall temperature, which has been positively correlated with phosphorus levels (Nicholls 1999; Eilola et al. 2009; Huang et al. 2011). Alternatively, simply ensuring that future roads are constructed using permeable pavement would help to reduce phosphorus levels, and would be much cheaper than replacing existing roads.

6.0 Conclusion

Phosphorus is an essential nutrient to aquatic systems, but also has the potential to cause damage to ecosystems when concentrations rise too high. The subsequent algal blooms, anoxic conditions and eventual aquatic fauna die-off are a major threat to humans, wildlife and the environment. Identifying causal factors is a key step in preventing and remediating phosphorus overloading in lakes. This study analyzed several variables suspected to influence phosphorus levels, but did not find that any of them correlated significantly with phosphorus in the Muskoka watershed. We have outlined several possible explanations for this, many of them stemming from the nature of dataset that was used.

Major recommendations for future data collection included obtaining missing data for under-threshold lakes to strength comparisons, more frequent data collection for temperature and chemical lake properties, and obtaining data on soil type and vegetation cover near the lakes in the watershed. Major recommendations for management were not based on any point source of phosphorus, since none were identified. Rather, management plans should focus on non-source-specific methods of phosphorus reduction. Riparian buffer zones are one option, as they can filter out excess phosphorus regardless of the source before it enters the lake, and also provide habitat for wildlife. Improved sewage treatment is another option, as sewage is the largest anthropogenic source of phosphorus in non-rural areas. Sewage treatment options include addition of flocculating compounds before primary sedimentation, and bacterial treatment. Overall, continued and improved water quality monitoring, broad management strategies, and further research based on an improved dataset could be adequate for the prevention and reductions of phosphorus overloading in the Muskoka Watershed.

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8.0 Appendix

8.1 Figures

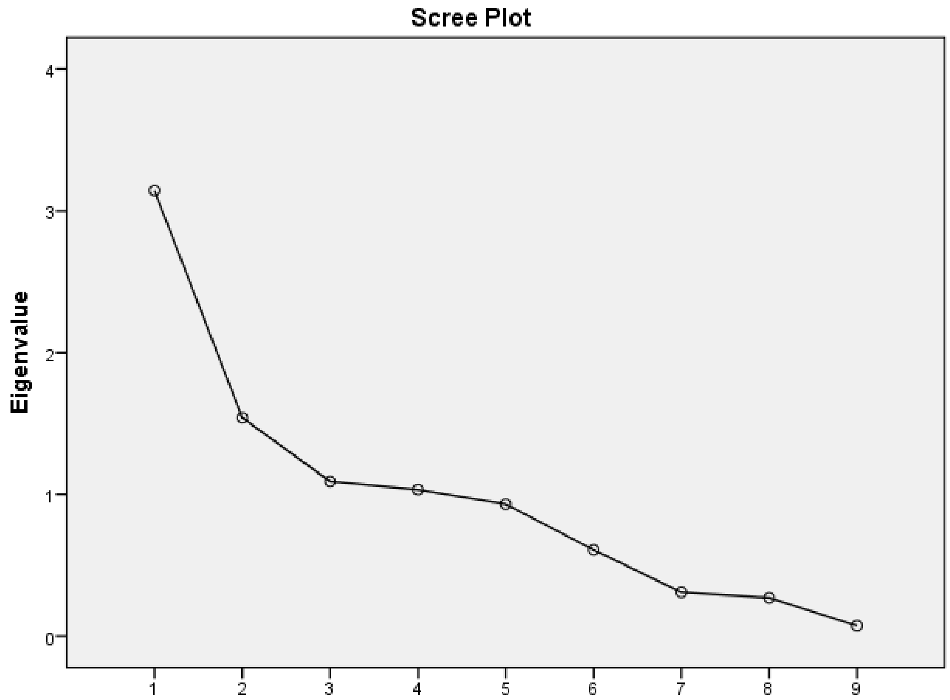

Figure 2. Scree plot from PCA first run in SPSS. Shows eigenvalues for each component. Initial leveling off at component 3 indicates that 3 components would be useful to extract from the data.

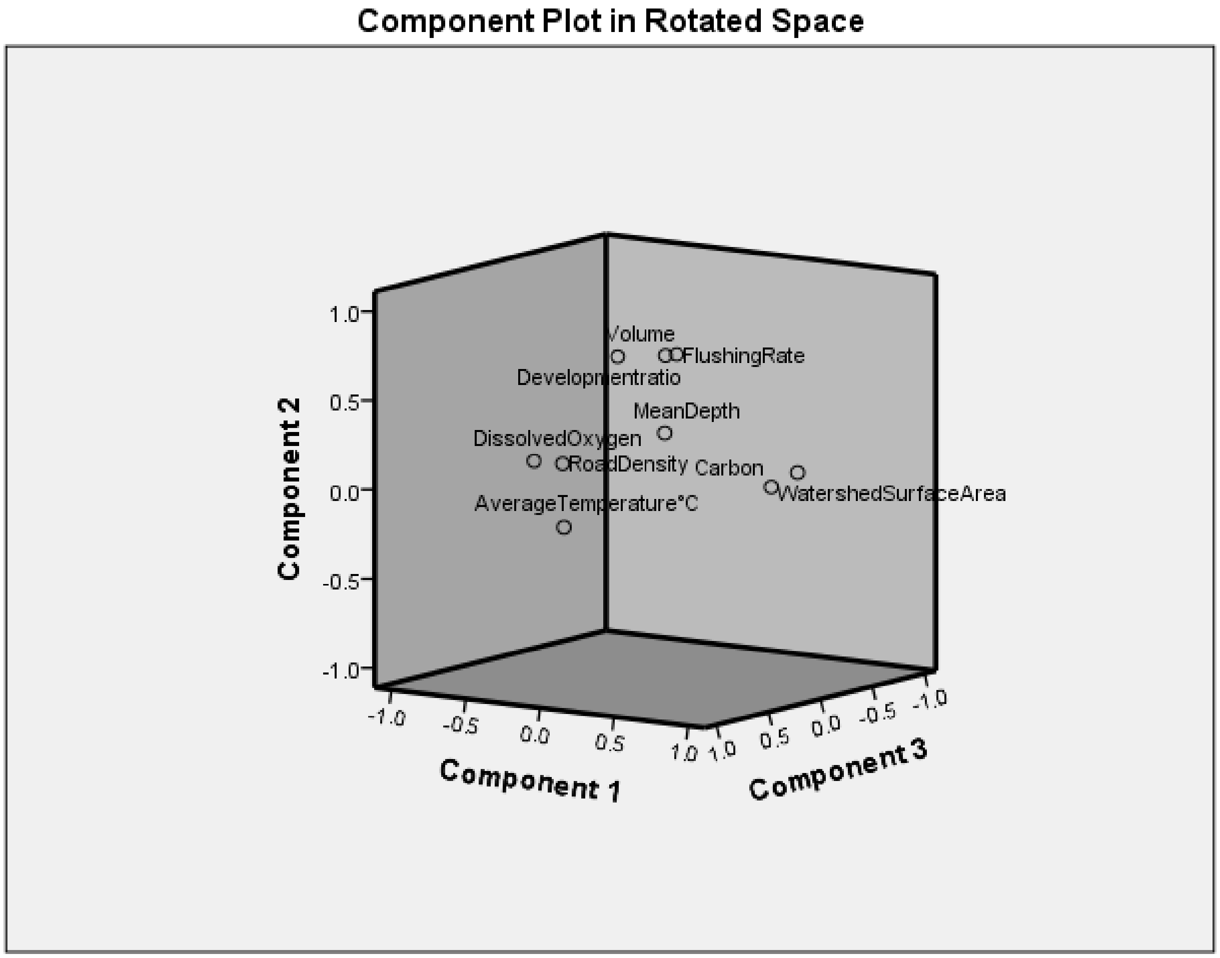

Figure 3. Component plot in rotated space. Shows where each variable falls when plotted against the 3 PCs in a three dimensional space.

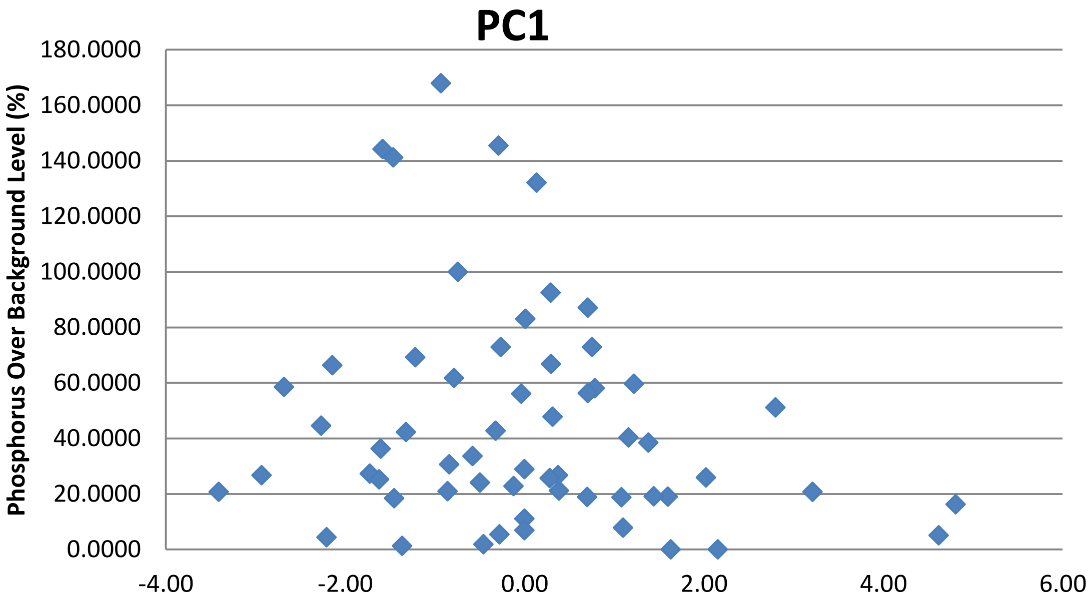

Figure 4. Correlation graph of PC1 and percent phosphorus over background level. Results were not significant with R = -0.215 and p = 0.111.

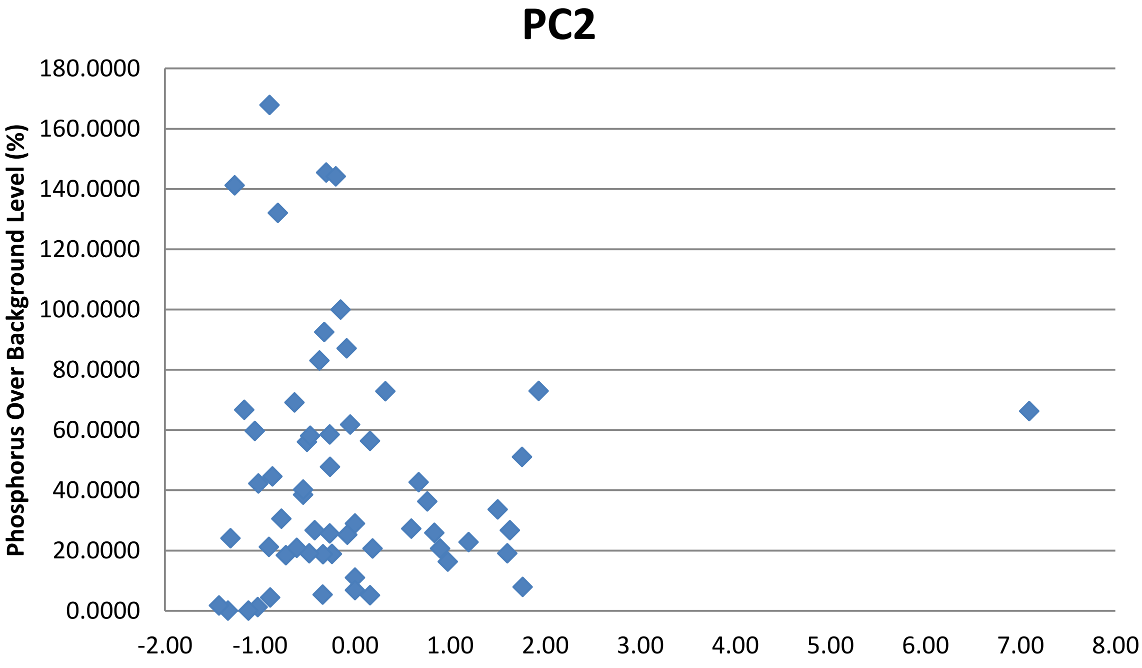

Figure 5. Correlation graph of PC2 and percent phosphorus over background level. Results were not significant with R = -0.036 and p = 0.791.

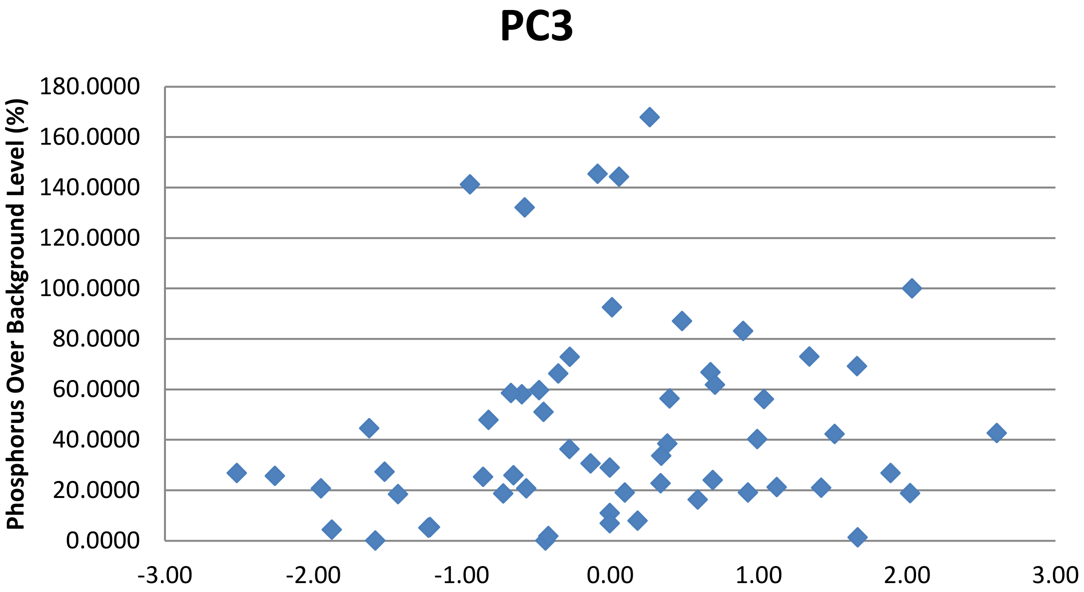

Figure 6. Correlation graph of PC3 and percent phosphorus over background level. Results were not significant with R = 0.143 and p = 0.292.

8.2 Tables

	Component Matrix[1]			**Structure Matrix**[2]		
Variable	*PC1*	*PC2*	*PC3*	*PC1*	*PC2*	*PC3*
Oxygen	-0.819	0.330	-0.268	-0.860	0.043	-0.177
Carbon	-0.799	-0.263	0.187	0.824	0.033	0.170
W:S Area	0.759	0.305	-0.126	0.783	0.093	-0.090
Flushing Rate	0.609	0.478	-0.257	0.255	0.742	0.143
Development	-0.530	0.427	0.402	0.039	0.707	-0.050
Size of Lake	0.464	-0.580	0.441	-0.422	0.654	-0.277
Temperature	0.206	0.558	0.542	0.105	-0.193	0.852
Depth	-0.053	0.546	0.451	-0.556	0.175	-0.800
Road Density	0.182	-0.294	0.565	-0.077	0.138	0.616

Table 4. Factor loadings from component and structure matrices for each variable and each component. Data indicate how strongly a variable is loading on a specific component with a maximum of 1/-1. A loading of >0.40 indicates high loading.

[1] Results without rotation

[2] Results with direct oblimin rotation