Regression analysis of phosphorus concentration in Big Green Lake, Green Lake Co., Wisconsin

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Introduction

The water quality of lakes, streams, wetlands, rivers, and other bodies of water has been officially monitored and regulated since 1972 when the Clean Water Act (CWA) was passed. The CWA attempts to protect water quality by establishing a list of pollutants that are detrimental and limits on the discharge of those pollutants into bodies of water (e.g., lakes, streams, rivers). The CWA defines water quality as the "physical, chemical, and biological characteristics of bodies of water" (Anon. 1972). Three main parameters that are used to characterize a body of water's water quality are total phosphorus concentration (as PO_4^{-3}), Secchi depth, and amount of chlorophyll (Anon. 1988).

Phosphorus is an essential nutrient for plant life and thus, is a limiting nutrient (i.e., prevents growth in its absence). As a limiting nutrient, phosphorus is responsible for the productivity (organismal activity) in BGL. When phosphorus concentration is high, the productivity of the lake is accelerated higher than normally observed (Anon. 1997). While it is important to have a certain level of nutrients in the lake to sustain a healthy ecosystem, pollution sources elevate nutrient levels in the lake (e.g., wastewater, agricultural runoff, residential fertilizers) to concentrations that exceed typical lake levels. Due to these anthropogenic sources of nutrients, the nutrient levels need to be monitored to prevent an increase to a level that can become detrimental to the lake's water quality. Trophic status in lakes is a characterization of the amount of nutrients within the lake. Eutrophication is an increase in nutrient levels in a lake to the highest trophic status (eutrophic) (Anon. 1981; Anon. 1997). Increases in nutrient levels, like phosphorus, can result in algal blooms and excessive weed growth (Anon. 1988; Anon. 1997). Algal blooms can form a solid sheet across the surface of the water blocking sunlight from underwater plants causing them to die (R.L. Wallace, pers. comm.). The decay process uses oxygen, which decreases the dissolved oxygen concentration, and can cause the death of other organisms, such as fish (W. B. Ainslie pers. comm.).

Background

Big Green Lake (BLG), located in Green Lake County, is Wisconsin's deepest natural lake with a maximum depth of 236 feet. The lake's inlet is Silver Creek and its outlet is the Puchyan River (Panuska 1999; Anon.). Due to the configuration of the lake with the inlet and outlet close together, the lake has an unusually long retention time of twenty-one years (T. Waldinger, pers. comm.). BGL is a recreational lake that is used for swimming, fishing, boating, and other activities (Anon. 1981; Anon 2011). It is important to maintain the water quality of BGL and prevent eutrophication so the lake can continue to be used as a recreational lake.

BGL drains the Green Lake Watershed. Most of the land within the watershed is used for agricultural purposes; however, two cities, Green Lake and Ripon, are also within the watershed (Anon. 1981). In 1981, the Green Lake Priority Watershed Project was implemented to maintain the water quality within BGL. The project established the goal of reducing nonpoint source runoff to decrease nutrient levels in the lake (Anon. 1981; Anon. 1988). Nonpoint sources were found to be the major source of pollution into BGL. Nonpoint pollution sources of water are diffuse discharges of pollutants that cannot be readily identified as a point. Point pollution sources are concentrated discharges of wastewater from discrete, specific sites (W.B. Ainslie, pers. comm.; Anon. 1981). The only point source in the Green Lake Watershed is the Ripon Wastewater Treatment Plant (Anon. 1988).

Phosphorous enters the lake by a number of nonpoint sources, including overland runoff (such as water from agricultural fields), ground water, waterfowl defecation, and precipitation (Anon. 1981). The watershed project implemented management practices, such as grassed waterways, diversions, and spillways to decrease phosphorus laden runoff from entering the lake. Once phosphorous enters the lake it is termed a pollutant load, which is measured as a rate (lbs/day). This is called the pollutant loading, and is used as a measurement to determine how much phosphorus is entering the lake from runoff (W.B. Ainslie, pers. comm.; D. Robertson, pers. comm.). Here I analyze the trends in lake phosphorus concentrations since the implementation of the watershed plan to determine whether the watershed project is succeeding in maintaining the water quality of BGL.

Methods

Data Collection and Organization

The total phosphorus concentration data used in this analysis was compiled by the Department of Natural Resources (DNR) from multiple sources including the DNR, the

U.S. Geological Survey (USGS), the Green Lake Sanitary District, and private monitors. The phosphorus data was collected every year from 1988 to 2010 (DNR). The months of data collection varied by year, but primarily data was collected during the spring and summer. The months that were most often omitted were the winter months. The phosphorus data was collected at various locations around the lake including the Green Lake Inlet, West Basin, East Basin, Mid Lake, and at Silver Creek, both where the creek meets the lake and further upstream along the creek. The phosphorus data was then isolated from the larger data set of many parameters, and organized in chronological order.

The loading data was obtained from USGS and was calculated from concentration measurements over time. Data was collected every month of the year from 1988 to 2010. Loading data was collected at Green Lake Inlet, Silver Creek, and White Creek. The data obtained from Silver Creek and White Creek was incomplete, thus was not included in this analysis.

Phosphorus Concentration Analysis

Using a generalized linear model in the statistical program R (Auckland, NZ), I regressed phosphorus concentration over time. The generalized linear model I utilized within R was a preprogrammed test. Phosphorus concentration was my outcome variable with both year and month as factors and location as a covariate. After performing the generalized linear model I performed an ANOVA, also a preprogrammed test, on the models generated by the generalized linear model.

Phosphorus Loading Analysis

Similar to the phosphorus concentration analysis, I used a generalized linear model in R to regress phosphorus concentration against time and amount of loading. Phosphorus concentration was again my outcome variable with year, month, and amount of phosphorus loading as factors. I then ran an ANOVA on the generated models.

Results

Phosphorus Concentration Analysis

After regressing phosphorus concentration (DNR) against time I found that phosphorus has decreased over the years. This was evident by the negative coefficient (-0.0041) observed in the linear model. When an ANOVA was performed, year was found to be a significant predictor of phosphorus concentration (p=2.059E-09). A plot of phosphorus concentration residuals (Figure 1) also shows a slight negative trend, further indicating that phosphorus concentrations have decreased over time. I also included each month in my analysis as its own factor because I suspected that phosphorus concentration changes over the course of the year. Upon analysis by linear regression and an ANOVA on the resulting coefficients I found that month is also a significant predictor of phosphorus concentration. Phosphorus concentrations are highest in the spring and summer months and lowest in the fall and winter months (Figure 2). When the coefficients of the months are compared relative to one another (Figure 3) it is clear that phosphorus concentrations in the spring and summer are higher. The higher concentrations during the spring and summer are most likely the result of increased runoff due to snow melt, the rainy season, and crop planting. The differing concentrations of phosphorus over the different months of the year indicate that there is a seasonality effect in which concentrations change as a result of the season.

Phosphorus Loading Analysis

After regressing phosphorus concentration (DNR) against both time and loading (USGS) I found that loading has a very slight negative trend due to its small negative coefficient; however, upon analysis by ANOVA, loading was determined to not be a predictor of phosphorus concentration. A plot of loading residuals (Figure 4) shows relatively steady and constant loading levels with only a partially discernable negative trend. The constant loading levels with a slight negative trend indicate that as a result of the watershed project loading has not increased. Thus, the watershed project is succeeding in maintaining certain aspects of water quality. When loading from Green Lake Inlet was analyzed for each location that phosphorus concentration was measured (Silver Creek at Green Lake Inlet, Silver Creek at Spaulding Road, West Basin, Mid Lake, and East Basin – Deep Hole) loading was found to only be a predictor for phosphorus concentration in East Basin – Deep Hole.

Discussion

The results of this study indicate phosphorus concentration in BGL has been decreasing over the past two decades. The decrease in phosphorus concentration is small, but a negative trend can be seen in a plot of phosphorus concentration residuals (Figure 1). This negative trend in phosphorus concentration indicates that the watershed project implemented in 1981 has been successful in at least maintaining water quality in the lake.

Other water quality parameters, such as Secchi depth, chlorophyll a, and dissolved oxygen, should be assessed in future analyses to better characterize the overall water quality of the lake and how it has changed over time. Also, a longer period of data collection should be used. I found data for 23 years, but due to the unusually long retention time (21 years) of BGL, my data only corresponds to about one cycle, which prevents detection of trends that occur over more than one cycle.

Month of the year was included in the analysis and was found to be a predictor for phosphorus concentration within the lake. Phosphorus concentration was found to be lowest in the winter, increase to its highest in the late spring/early summer, and then decrease again in the fall (Figures 2 and 3). The pattern of phosphorus concentration throughout the year is most likely due to the fact that in the spring there are snow melts, the rainy season, the return of waterfowl, and crop planting. This pattern is also indicative of, and lends evidence to, a seasonality effect in which phosphorus concentration is a function of the season. Further analysis on other parameters such as rainfall, could better characterize the seasonality effect.

Phosphorus loading was found to be decreasing slightly over time, but only very slightly as can be seen in Figure 4. The lack of increasing phosphorus loading together with decreasing phosphorus concentrations indicate that the watershed project, whose goal was to maintain the water quality of BGL, is succeeding. Loading was not found to be a predictor of phosphorus concentration, except in East Basin – Deep Hole. These results were somewhat surprising in that I expected loading from Green Lake Inlet to at least be a predictor for phosphorus concentration within the inlet, but possibly not further away. These contradictory results could be due to the flow pathways within the lake basin that might cause loading from the inlet to run into the East Basin. However, a test of this hypothesis will require additional study. Also, due to the long retention time of BGL, it might take a very long time for loading from the inlet to have any effect on phosphorus concentration elsewhere in the lake. Unfortunately, loading data was only obtainable from Green Lake Inlet, but in future studies loading data should be collected at other points around the lake to develop a more accurate model of total loading versus total phosphorus concentration within the lake.

Acknowledgements

I would first and foremost like to thank Dr. Tim Hess for his consistent help and troubleshooting with this project. I would like to thank my father, Bill Ainslie, for tirelessly explaining aspects of water quality and the possible implications of my analyses, as well as brainstorming with me on various aspects of the project. I would like to thank Dave Melgaard at the EPA and Dale Robertson at USGS for willingly answering my questions and offering their help. I would like to thank Jen Kaiser at the Green Lake Association and John Nelson at the University of Wisconsin – Madison for giving me this project. Finally, I would like to thank Professor Diane Beres for being my mentor for this project.

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Phosphorous Concentration Residuals

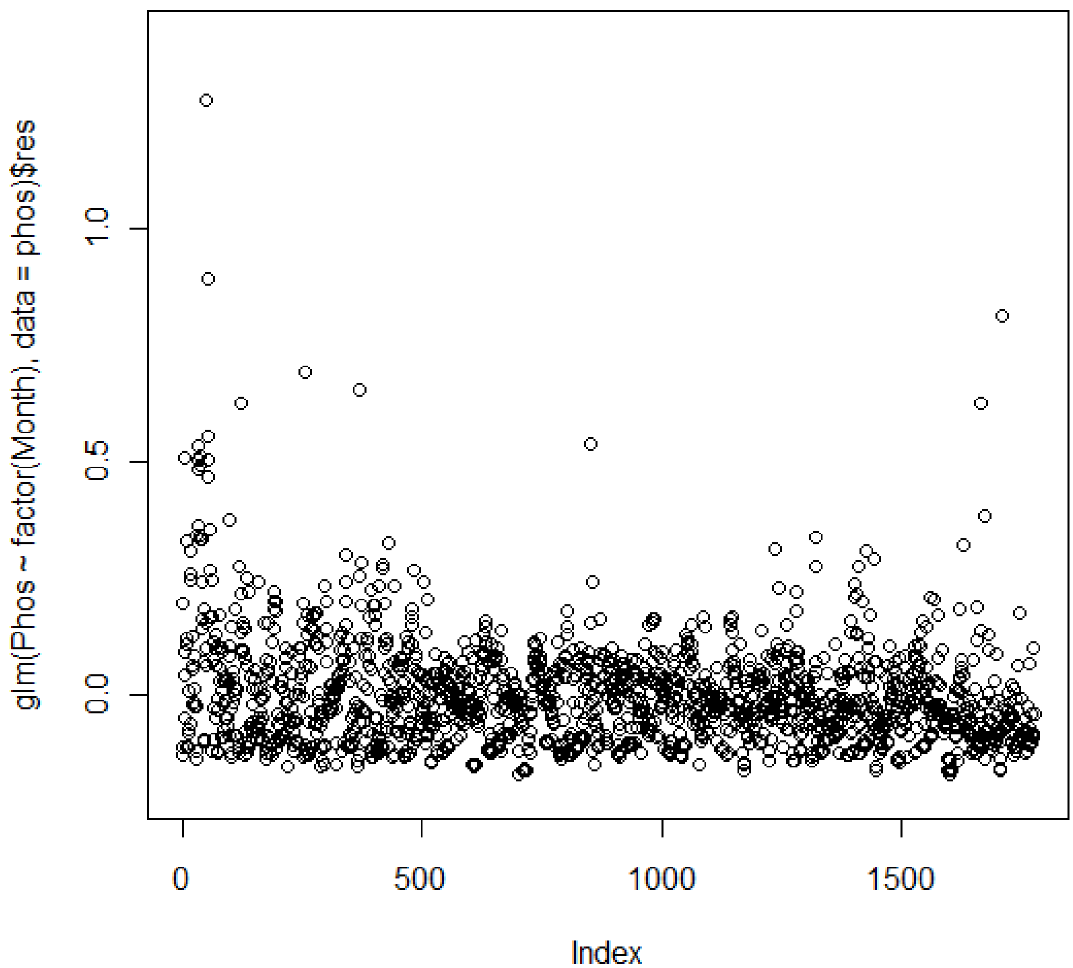

Figure 1. Scatter plot of phosphorus concentration residues. A decreasing trend can be seen indicating that phosphorus concentration has been decreasing over time.

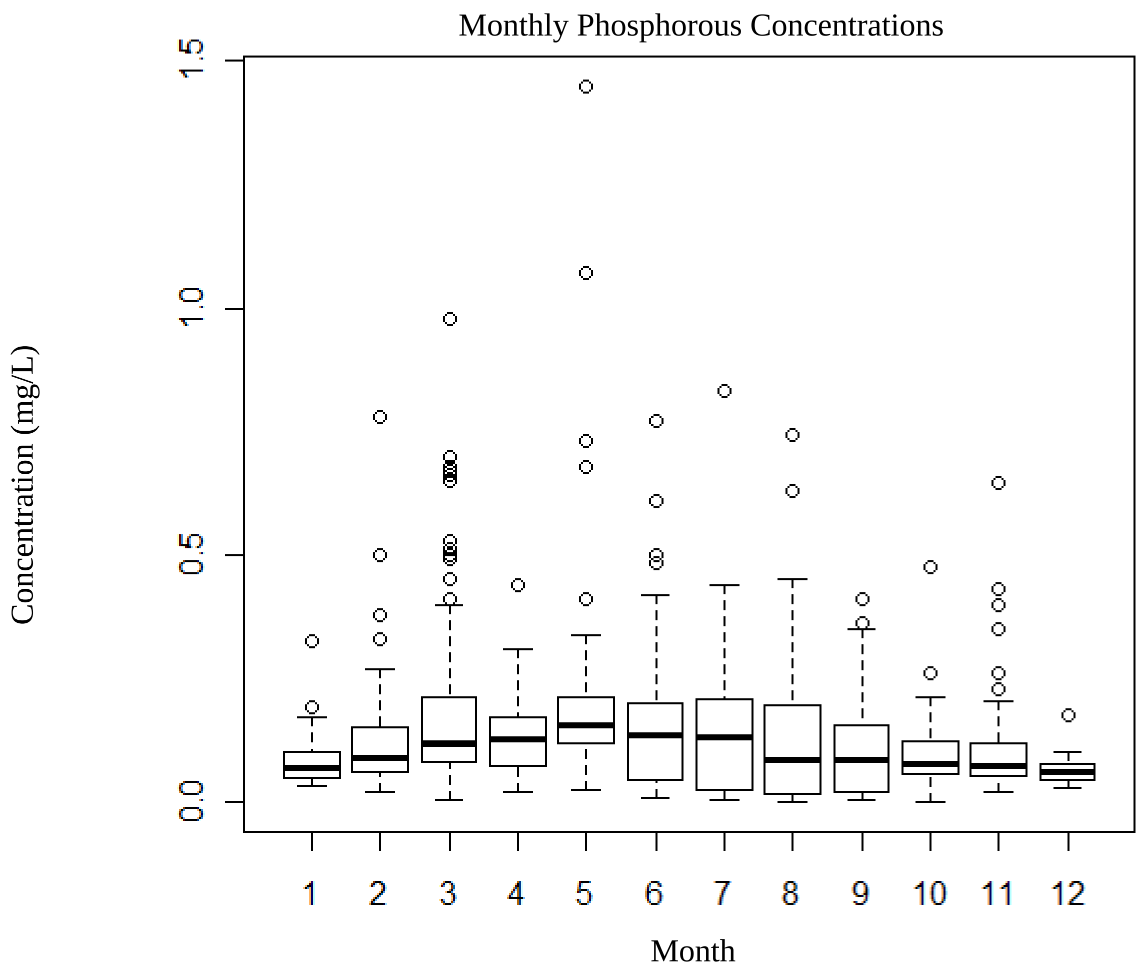

Figure 2. Boxplot of phosphorus concentration by month. The increase in phosphorus during the spring and summer and the decrease in phosphorus in the fall and winter indicate a seasonality effect.

Monthly Coefficients

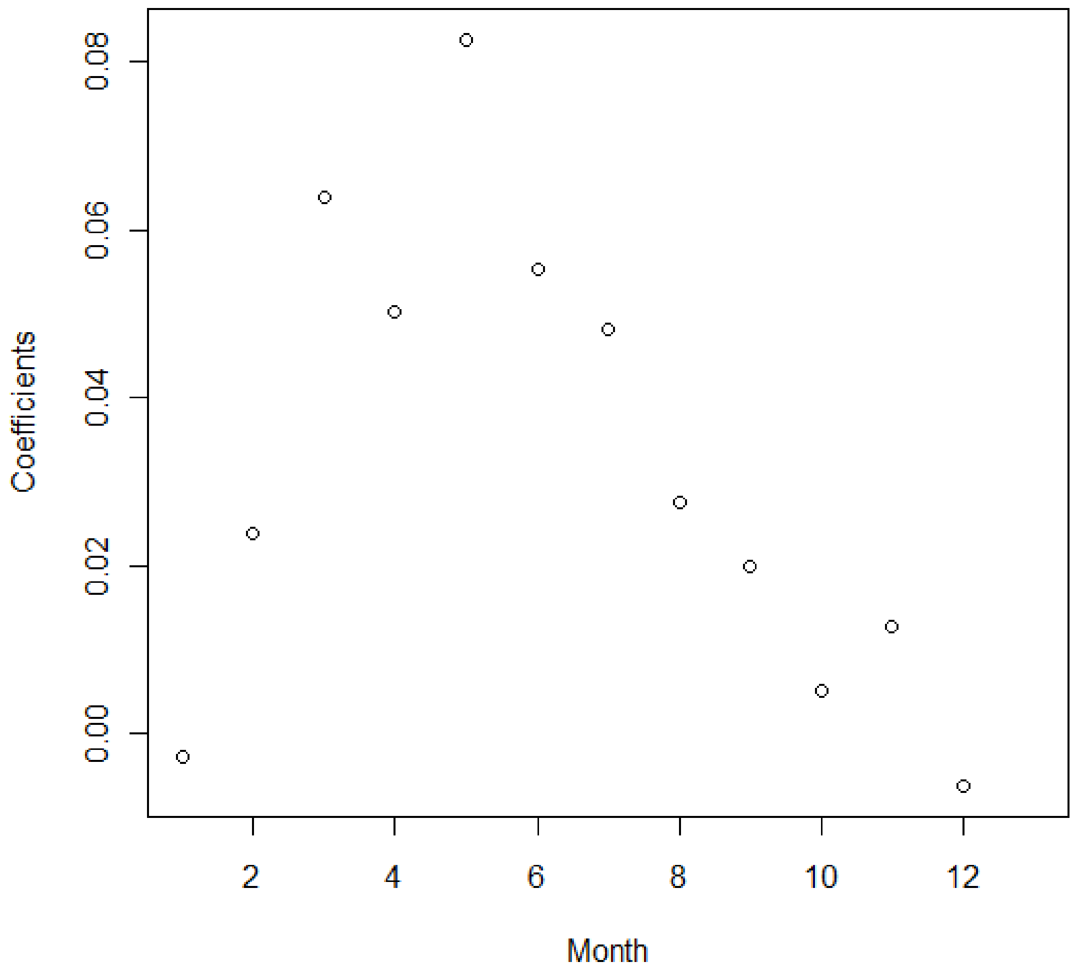

Figure 3. Plot of monthly coefficients. The increase in the spring and summer and decrease in the fall and winter is indicative of a seasonality effect.

Phosphorous Loading Residuals

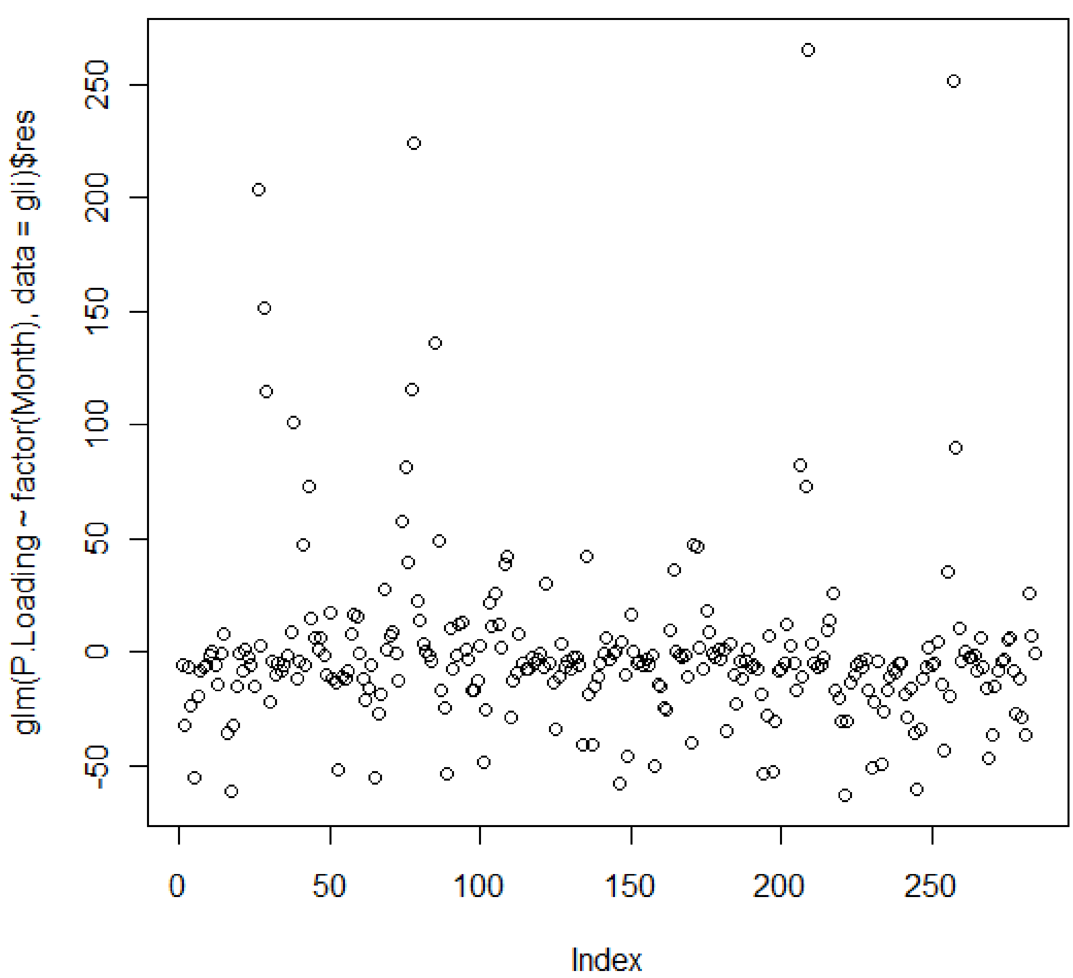

Figure 4. Scatter plot of phosphorus loading residuals. A very slight negative trend might be discernable, but the loading seems fairly constant. This indicates that the watershed project is succeeding in at least maintaining the amount of phosphorus laden runoff entering the lake.