Understanding and Quantification of Phosphorus Loading into the Laurentian Great Lakes

Researching the drivers of watershed phosphorus

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Research Project

I. Introduction

In 1969, the United States established the National Environmental Policy Act (NEPA) “to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.” This action addressed the three pillars of sustainability by establishing requirements used to evaluate environmental impacts when devising policies which impact the environment, human health and welfare. The U.S. Environmental Protection Agency (EPA) complies with NEPA through the Clean Water Act, National Pollutant Discharge Elimination System (NPDES) permits, and through EPA-funded projects. EPA has become the steward of the nation’s water resources and focuses on clean water and water conservation. In 2004, the Great Lakes were declared a national treasure, and the State of the Lakes Ecosystem Conference was formed to monitor and address ecosystem health of the Great Lakes. EPA’s Great Lakes Legacy Act provides funding to clean up areas of concern (AOC) within the lakes system.

Watersheds are integrators of many anthropogenic and natural forces, including land use and climate change. Surface runoff from land impacted by human activities may contain nutrients and other contaminants that affect the quality of downstream water and impact freshwater ecosystems. A notable example is the Gulf of Mexico and late summer Lake Erie hypoxia, which have been linked to excessive nutrient loads among other factors. Furthermore, future land use change, such as that driven by emergent biofuels may exacerbate these impacts. As freshwater becomes scarce in several regions of the world, it is imperative that scientists, managers, and the public understand the relationships and feedbacks between land use change, climate change, nutrient dynamics, and water quality for sustainable management.

Specifically, diffuse sources of phosphorus (P), and the associated suspended sediments, have resulted in eutrophication of fresh water systems. In the Great Lakes, excessive phosphorus loads appear to be increasing again, creating nuisance algal blooms in nearshore areas thereby posing major environmental threats to the aquatic environment. Total phosphorus levels in Lake Erie have been steadily increasing since 1990 (Figure A.1) while Saginaw Bay total-P has remained above target levels for most of the past 25 years (Figure A.2). For over two decades, nutrients exported from agricultural, urbanized, and forested lands have directly affected water quality in the Great Lakes. In addition to phosphorus, suspended sediments loads are also increasing due to erosion and changes in land cover, i.e. increases in impervious surface. Typically, in developed countries, runoff from agriculture and urban areas are the leading cause of this non-point source pollution. Therefore it is imperative to understand the variation and sources of phosphorus and suspended sediment loading from Great Lakes watersheds into the basin. Additionally, it is not clearly understood the spatial and
temporal relationship between nutrient loads and the source. There is a need to clearly identify watershed loads to the Great Lakes and then begin to relate loads to temporal/spatial variation along with relevant sources. This additional information will provide links to land management, water use, and water quality.

Figure 0.1: Decrease in total phosphorus (P) levels through phosphorus control measures in the 1980’s, followed by rising P-levels due to unknown P-additions (Taken From Lake Erie Phosphorus, U.S. Environmental Protection Agency, 2010)
Freshwater ecosystems, including the Great Lakes, provide societal, economic and environmental benefits, but there are tradeoffs between consumption and ecosystems. Therefore, future management of freshwater resources, including the vastly important Great Lakes, which contains 1/5th of the available global freshwater, is an issue of sustainable water management. Water quality is important in maintaining the sustainability of the Great Lakes water resource, not only from an ecosystem approach, but for economics and society, so that future generations will continue to derive important ecosystem benefits. The issue of water quality inherently addresses the issue of maintaining sustainable water resources through an integrated approach by looking into not only the amount of the constituent, but other dominant factors that are driven from economics and society, as in land use and soil. Researching nutrient transport through a more holistic system approach begins to answer the question of how to manage the system for generations beyond, which is the central tenet of sustainability. Understanding the links between anthropogenic activities and nutrient loading is pivotal to managing the human and ecosystem benefits of the Great Lakes ecosystem.

II. Objectives

Daily flow and total phosphorus (P) data is incomplete for all tributaries to the Great Lakes. The typical sampling frequency for most of the gauged sites is four to five times a year, with many watersheds that
are ungauged. There is a need to develop tools that can predict loads between sampling periods and for the ungauged watersheds. Models can provide the tool to extend the loads to a continuous data set. Many models in water resources and constituent loading, relate load as a function of flow and time or basin characteristics, including land use, soil type, or slope. Therefore, the objective is to test a suite of models where load is a function of flow and time on selected watersheds to determine if these models are scalable to ungauged watersheds. The models may also be used in a predictive mode to determine loading probability functions and future climate scenarios with the determination of return flow periods through the Log Pearson Type III distribution.

Specifically, Robertson\textsuperscript{12} developed an empirical model to quantify regional sediment and phosphorus loads to Lake Michigan using regressed and extrapolated load estimates from well-monitored tributaries\textsuperscript{12}; such models have not been developed for the remaining lakes. Next to Lake Michigan, Lake Erie has the highest number of AOCs which include the Lake Erie “Dead Zone.” This late summer “Dead Zone” in the central Lake Erie basin is the result of increasing P loading, despite banning of phosphorus-containing detergents and enforcement of point source pollution control. One theory for increased P lake levels is an increase in agricultural productivity and urbanization increasing nonpoint source pollution through surface runoff into Lake Erie tributaries\textsuperscript{16}.

In order to estimate total phosphorus loading to Lake Erie and other watersheds, data from watersheds with robust measurements were used to extrapolate P-loadings from watersheds lacking sufficient data based on the assumption that similar land use and landform produces comparable stream water quality, utilizing Robertson’s extrapolation model. Data from well monitored watersheds with similar land use, gradients, and soils will provide model parameters to determine P-loads from tributaries with little-to-no data. In order to develop a model predicting total phosphorus loadings to the Great Lakes, this project proposed compiling all available data on watershed characteristics, stream flow and total phosphorus on a watershed-by-watershed basis within a target area, and using watersheds with robust data, develop constituent-transport models based on P load, stream flow, and time of year.

Watersheds chosen for model development were: Maumee River, River Raisin, Milwaukee, and Ontonagon. Maumee has the largest drainage area of any Great Lake tributary, with 8,316 square miles. The Lower Maumee is the AOC, primarily due to agricultural runoff. The River Raisin drains 1,072 square miles and also has high levels of agricultural runoff. Both the Maumee and Raisin rivers feed into the western end of Lake Erie (Figure A.3). The Milwaukee was chosen for model development because of its high degree of urban and industrial land use; most of the watersheds draining into Lake Erie are agricultural or mixed-use watersheds. The Ontonagon watershed in the Lake Superior basin is one of the only gauged and forested watersheds in the Great Lakes region. There are currently deterministic models being developed for this watershed, which would provide verification of the model developed using the Maumee, Raisin, and Milwaukee watersheds. The Ontonagon watershed also has the longest record of data.
A preliminary constituent-transport model was developed which formed the basis for a model describing nutrient inputs to the Great Lakes based on uniform land use and land form on a larger scale. The overall goal of this project was to fully quantify phosphorus loadings to the Laurentian Great Lakes system.

### III. Methodology

To accomplish the detailed objectives and overall goals for our project, the following methods were used: First, streamflow data was downloaded and stored for phosphorus loads from the Maumee, River Raisin, Detroit, Milwaukee, and Ontonagon watersheds using the USGS NWIS system and Heidelberg University’s National Center for Water Quality Research. The data was organized from 1980-01-01 to 2010-02-03, stored each data set in an Excel database format for repeated search and use. Secondly, the land use and land form was characterized by Great Lakes HUC 8 watershed via assigning classification into urban, agriculture, forested, mixed, or undeveloped land use taken from the NOAA Coastal Change Analysis Program spatial database. Next, predominant stream gradient was determined based on USDA Soil Data Mart soil survey classification and national elevation data from the national...
elevation dataset (NED). In addition, physical soil properties and digitized spatial data files were downloaded from the USDA Soil Data Mart database for each county in the selected watersheds. ArcMap was used on the spatial data to delineate a watershed area and calculate the amount of land each soil comprised in the watershed. Weighted average % clay was calculated for each watershed using topsoil percent clay for each soil and weighting by its percent of total watershed area. Then, land use was determined from the 2001 National Oceanic Atmospheric Administration (NOAA) Coastal Change Analysis Program (CCAP)\textsuperscript{18} data set, as a representative year for the matching water quality and flow data. The data sets were analyzed and formatted in ArcMap to determine the amount of land in each of the following classes: forested, water, urban/developed, and agriculture. CCAP is a high resolution standardized database of land cover and land change for the coastal regions of the United States. Third, streamflow was estimated for a 10-year, 1-day high flow for target watersheds using log-Pearson Type III statistics for each river. Lastly, constituent transport models were developed for each watershed to determine regression coefficients to understand and predict the relationships between constituent load, streamflow, time of year, land use, and soils using R statistical programming.\textsuperscript{13,17} These models were used to begin to draw conclusions on the effects of nutrient loading into the Great Lakes ecosystem.

\textbf{IV. Results}

The results are presented below, after compiling all the constituent data, it was determined that the Detroit Watershed lacked sufficient data for a statistical analysis; therefore this watershed was removed from the study.

\textbf{A. Land Use Characterization}

Using the National Oceanic and Atmospheric Administration’s Coastal Change Analysis Program (CCAP) spatial data sets, each watershed was mapped for land use classification. This program utilizes 22 standard land classes to describe the Great Lakes Basin’s watersheds\textsuperscript{18}. In the determination of major land use classes, we merged many of the CCAP’s categories into a broader class as seen in Table (A.1).
### Table 0.1: Merging Land Use Classification

<table>
<thead>
<tr>
<th>Merged Land Classes</th>
<th>CCAP Land Use Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Urban</td>
<td>High Intensity Developed, Medium Intensity Developed, Low Intensity Developed, and Developed-Open Space</td>
</tr>
<tr>
<td>2. Agriculture</td>
<td>Cultivated Crops, Pasture/Hay</td>
</tr>
<tr>
<td>4. Open Water</td>
<td>Open Water</td>
</tr>
</tbody>
</table>

The four researched watersheds were extracted to determine their specific land use classification structure. The breakdown of each studied watershed as they vary from heavily agricultural to forest dominated is as follows:

![Maumee: Agriculture](image)

**Legend**

- Brown: Cultivated Crops
- Red: Developed, High
- Yellow: Developed, Low
- Orange: Developed, Medium
- Green: Developed, Open Space
- Blue: Open Water
- Greenish: Pasture/Hay
- White: Unclassified
- Blueish: Undeveloped

**Figure 0.4: Land Use Classification for Maumee Watershed**

The Maumee River watershed is a major tributary of Lake Erie and it is heavily dominated by row cropping. The watershed contains about 81% agriculture and 7% developed land (Figure A.4). Therefore, this watershed was the characteristic agriculturally dominated study area.
Next, the River Raisin is an example of a more mixed use watershed, but it still contains a large influence from the agricultural sector. This watershed contains 70% agricultural, 8% developed and 20% forested lands, a more even mix of land uses across the watershed (Figure A.5). The River Raisin represents a mixed use watershed for the study.

![Figure 0.5: Land Use Classification for the River Raisin and Milwaukee Watershed](image)

The Milwaukee Watershed was chosen as a representative urban watershed, as there are only a handful of urban dominated watersheds within the Great Lakes Basin. In 2001, the Milwaukee watershed had 28% developed lands, as seen in Figure A.5. In addition, the watershed is also composed of 44% agricultural and 27% forested lands.

Finally, a predominately forested watershed was chosen to understand the role of land use in nutrient loadings. With such sparse data of water quality, it is difficult to find a watershed that is highly undisturbed and has associated water quality measurements. Therefore, the Ontonagon River Watershed was selected that has a robust data set. The Ontonagon is 91% forested with only 3% of land devoted to agricultural purposes (Figure A.6).
The four studied watersheds represent a variety of dominant land uses. The spatial analysis is critical to understanding the land use role in nutrient transport, especially the anthropogenic forces on loading.

### B. Ordinary Least Squares Regression

Simple and multiple ordinary least squares regression procedures, based on the assumption of independence between observations, equal variances, and normally distributed populations, were used to best explain the variability of phosphorus loadings from the four candidate watersheds based on the general constituent model[^17]:

\[
\ln L = \ln(\beta_0) + \beta_1 \ln Q + \ln(\epsilon)
\]

**Equation 1: General Constituent Loading Model Equation**

where \(L\) is the dependent response variable (Load), \(Q\) is the independent variable (Flow), \(\beta_0\) is a constant, \(\beta_1\) is the model coefficient, and \(\ln(\epsilon)\) is the random variable, that are determined to be normally distributed with a mean of zero and constant variance. This model was chosen through the procedure of developing simple linear regressions and minimizing the heteroscedacity in the variance.

The following section provides step-by-step results in determining the overall best-fit candidate model for the four selected watersheds which maximized \(R^2\) and minimized average model prediction error (SE).

The loading was determined by calculating the concentration of total phosphorus at the gauging station multiplied by its associated measured flow \((Q\times C)\). The selected gauging stations were near the mouth of the watersheds and their drainage areas’ consisted of about 95% of the total watershed area. Therefore, it is assumed that the selected gauging stations are representative of the entire watershed. Upon a visual inspection of the all the data, it appears that a relationship existed between constituent load and flow (Figure A.7). Statistics and biology were used to begin to understand this relationship, although from Figure (A.8), it appears this relationship was non-linear.
Figure 0.7: Scatterplot of all Continuous Variables in the Dataset in the Maumee Watershed

Figure 0.8: Scatterplot of Load versus Flow in the Maumee Watershed (Non-linear relationship)
A simple linear regression model (SLR) was applied to each data set, comparing the constituent load versus flow to determine how constant the variance is after an initial trial model. Using SLR, the regression line only described a small portion of the variance in the data (Figure A.9) and the variance in the residuals is conical shape representing an extreme heteroscedacity. Therefore, the next step was to transform the data to find an intrinsically linear function that may describe this variance.

![Figure A.9: Simple Linear Model and Residual Variance in the Maumee Watershed (Notice the conical shape of the residuals versus the fitted values)](image)

From Figure A.10, the data required a transformation; therefore a natural logarithmic transformation was completed as suggested by previous authors\textsuperscript{13,17,19}.

![Figure A.10: Linear Regression on Transformed Load and Flow in the Maumee Watershed (Stabilization of the Variance)](image)
The loading and flow data was transformed to minimize the variance. From Figure A.10, use of a transformation greatly reduced the heteroscedacity in the variance and described much of the inherent trend in the data. The equation for the simple linear regression and transformed linear regression are as shown in Figure A.11. The SLR only accounted for about 78% of the variance but had an extremely high standard error, apparent by the conical shape of the residuals (Figure A.12). On the transformed data, linear regression accounts for the majority of the variance with an associated low standard error, proving that a logarithmic transformation of the data was useful in describing the loadings of phosphorus in the Maumee Watershed. This transformation also resulted in a near normal distribution of the residuals.

Linear Regression Equations and Fit Statistics for the Maumee Watershed

SLR: \[ L = -86.0 + 0.14Q \]
\[ R^2 = 0.7878 \quad SE = 9687 \]

Logarithmic Space Regression: \[ \ln L = -12.58 + 1.27 \ln Q \]
\[ R^2 = 0.9414 \quad SE = 0.451 \]
Back-transformed Equation: \[ L = 0.009Q^{1.27} \]

Figure 0.11: Regression Equations and Fit on the Maumee Watershed

Figure 0.12: Residuals versus Fitted Values for the SLR and Transformed Data in the Maumee Watershed

The data and regressions were also checked for seasonality. Watershed loadings were dominated by various seasons through precipitation, snow, and manure application. Therefore, this study looked at
the sine and cosine of time as a seasonality factor for the regression. This multiple regression was only completed on the Maumee Watershed, as it did not minimize the variance in the regression.

\[
\ln L = \beta_0 + \beta_1 \ln Q + \beta_2 \sin(T) + \beta_3 \cos(T)
\]

Equation 2: Regression with Seasonality (Maumee Watershed)

The R^2 only increased from 0.9414 to 0.9498; therefore it was decided that at this junction in the research, seasonality was not significant enough to perform further exploration. This analysis was completed on each target watershed; the equations and fit statistics are discussed in the following section.

C. Regression Loadings and Confidence Intervals

The Ordinary Least Squares Regression analysis was performed on each target watershed; the results from each watershed are summarized in Table (A.2). The prediction R^2 values ranged from 94.14% to 77.22%, with lowering SEs.

Table 0.2: Regression Models for Calculation of Phosphorus Loads (kg/d)

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Load Equation</th>
<th>Standard Error (Transformed Space)</th>
<th>R^2 (Transformed Space)</th>
<th>Linear R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maumee</td>
<td>( L = 0.009Q^{1.27} )</td>
<td>0.451</td>
<td>0.9414</td>
<td>0.7878</td>
</tr>
<tr>
<td>River Raisin (USGS)</td>
<td>( L = 0.033Q^{1.06} )</td>
<td>0.5683</td>
<td>0.7722</td>
<td>0.9041</td>
</tr>
<tr>
<td>River Raisin (Heidelberg)</td>
<td>( L = 0.021Q^{1.18} )</td>
<td>0.7812</td>
<td>0.7812</td>
<td>0.728</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>( L = 0.016Q^{1.12} )</td>
<td>0.5599</td>
<td>0.8001</td>
<td>0.703</td>
</tr>
<tr>
<td>Ontonagon</td>
<td>( L = 0.001Q^{1.48} )</td>
<td>0.5988</td>
<td>0.7765</td>
<td>0.5805</td>
</tr>
</tbody>
</table>

The results show that for most of the datasets, the use of a transformation provided greater understanding of the system variability. The River Raisin (USGS) data set had very few samples; therefore a SLR provided a much better fit. With the increasing amount of samples from Heidelberg College, the regression required a transformation to normalize the variance. The next step was to calculate loads and confidence intervals using the developed equations. For transformations into logarithmic space a bias is introduced, therefore a bias correction factor (BCF) was applied to each selected model when computing annual loadings due to the fact the above equations generally overestimate the mean by as much as 50%. The BCF used in this study was the load equation above multiplied by the variance of the residuals (\( \sigma^2 \)) in the following equation:
To use the above models (Table A.2) for prediction of loads in instances where there is only measured flow, confidence intervals were needed to bind the equations. The 95% confidence intervals were computed for the 2 year return flood flow period for the Maumee watershed (Table A.3).

Table 0.3: Confidence Intervals and Bias Correction Factor for the Maumee Watershed

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Reported Value</th>
<th>Upper Limit</th>
<th>Lower Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>8.55E-03</td>
<td>1.00E-02</td>
<td>7.29E-03</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>1.27</td>
<td>1.276</td>
<td>1.256</td>
</tr>
</tbody>
</table>

For a 2 yr Return Period Flow with/without BCF 1.107:
- $L=69,973$ kg/d
- $L_8=77,462$ kg/d
- CI: 49,498 to 98,918 kg/d
- CI$_8$ = 54,795 to 109,505 kg/d

As reported in Table A.3, the confidence intervals ranges were large for computing annual flow. Therefore, it was imperative to work to modify this regression model, with possibly the addition of further independent variables and unique data transformations. The confidence intervals were computed on the log Pearson Type III flood frequency analysis that was performed on each watershed.

With future climate change, it is important to know how changing flows will ultimately affect loads and the management of nutrients in each of the Great Lakes Watersheds. The use of return flow analysis produced estimates of daily streamflows for various recurrence intervals (Table A.4). These values will be used in conjunction with constituent models to predict extreme climatic loads (Table A.5). In addition to prediction of climatic loads, these flows can provide upper bounds of river flows/loads for further frequency and uncertainty analysis of watershed phosphorus export. Based on the probability density function of the watershed flow, the function can be used to build a probability density function for the description of watershed loading. This is only a sample application of the predictability of regression loading models for the Great Lakes watersheds.
Table 0.4: Flood Frequency Analysis: Maumee Watershed

<table>
<thead>
<tr>
<th>Return Period (years)</th>
<th>Skew Coefficient (k)</th>
<th>Discharge (cfs)</th>
<th>Discharge (m$^3$/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.08</td>
<td>5.69E+04</td>
<td>1.39E+08</td>
</tr>
<tr>
<td>5</td>
<td>0.86</td>
<td>7.63E+04</td>
<td>1.87E+08</td>
</tr>
<tr>
<td>10</td>
<td>1.22</td>
<td>8.74E+04</td>
<td>2.14E+08</td>
</tr>
<tr>
<td>25</td>
<td>1.57</td>
<td>9.99E+04</td>
<td>2.44E+08</td>
</tr>
<tr>
<td>50</td>
<td>1.78</td>
<td>1.08E+05</td>
<td>2.65E+08</td>
</tr>
<tr>
<td>100</td>
<td>1.96</td>
<td>1.16E+05</td>
<td>2.83E+08</td>
</tr>
<tr>
<td>200</td>
<td>2.11</td>
<td>1.23E+05</td>
<td>3E+08</td>
</tr>
</tbody>
</table>

Table 0.5: Application of Flood Frequency for the Maumee Watershed, Climatic Loadings

<table>
<thead>
<tr>
<th>Flood Return Period</th>
<th>Q (m$^3$/d)</th>
<th>Load (Based on Regression Equation, kg/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.87E+08</td>
<td>1.10E+05</td>
</tr>
<tr>
<td>10</td>
<td>2.14E+08</td>
<td>1.31E+05</td>
</tr>
<tr>
<td>25</td>
<td>2.44E+08</td>
<td>1.55E+05</td>
</tr>
</tbody>
</table>

As reported in Table (A.5), changes in climatic regimes can heavily influence the amount of phosphorus loading into the Great Lakes. The predicted regression models provide only an initial estimate to calculate watershed loads and future scenarios in the Great Lakes Basin.

**D. Regression Coefficients**

The predicted model coefficients from each regression, $\beta_0$ and $\beta_1$, directly relate flow to load by incorporating the influence of other factors not developed in the regression including basin characteristics. The developed coefficients provide evidence of how flow and amount of phosphorus in the watershed effect the loading equation. From Table (A.6), the model coefficients can changed based on land and soil characteristics.
### Table 0.6: Regression Model Coefficients and Basin Characteristics

<table>
<thead>
<tr>
<th>Watershed</th>
<th>$\beta_0$</th>
<th>$\beta_1$</th>
<th>% Agriculture</th>
<th>% Developed</th>
<th>% Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maumee</td>
<td>8.55E-03</td>
<td>1.27</td>
<td>81.36</td>
<td>7.03</td>
<td>23.0</td>
</tr>
<tr>
<td>River Raisin</td>
<td>2.15E-02</td>
<td>1.18</td>
<td>70.2</td>
<td>7.50</td>
<td>15.8</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>1.63E-02</td>
<td>1.12</td>
<td>44.0</td>
<td>28.2</td>
<td>12.4</td>
</tr>
<tr>
<td>Ontonagon</td>
<td>1.11E-03</td>
<td>1.48</td>
<td>3.36</td>
<td>0.62</td>
<td>11.8</td>
</tr>
</tbody>
</table>

Upon initial inspection, the higher $\beta_0$ and lower $\beta_1$ may be associated with heavily impacted watersheds, i.e., more anthropogenic changes. The greater the urban and agricultural land in the watershed, the less flow exerts control, through $\beta_1$, and the effect was more pronounced through $\beta_0$. This coefficient, $\beta_0$, may represent the amount of erodible phosphorus within that basin; therefore more disturbed watersheds would have greater phosphorus erodibility. On the other hand, a forest dominated watershed, such as the Ontonagon, flow would exert a greater control due to infiltration and interception from natural buffers in the physical system. There is a correlation between land use, % clay and phosphorus loading. This correlation may be linked to the model coefficients but must be developed further through investigation of other independent drivers in the regression, such as soil type, land use dominance and slope. To understand these connections, the research must be extended to additional watersheds across the Great Lakes Basin.

### E. Sustainability

Developing phosphorus constituent models is critical in the sustainable management of the watersheds and water resources, specifically in the Great Lakes Region. The Great Lakes is a vital source of fresh water for both the United States and Canada, therefore it requires management for all its uses and benefits: economic, social, and environmental. Through regression-based equations, managers, scientists, and researchers can determine water quality loadings from watersheds that directly impact the Great Lakes ecosystem. With this critical tool, nutrient loadings that drive economic and social structures of our system can be managed. For example, economically, the agriculture in the Great Lakes region impacts local, state, and federal companies and employees. There is a need for agriculture to supply society’s demand for food and for economic prosperity and growth. Using these regression models each watershed load can be quantified and then modeled back through the systems to identify areas of concern. These areas can benefit from applications of past or development of new best management practices that reduce the loading from these watersheds while continuing to economically prosper and fulfilling demands for food and fuel. The model provides a tool to sustainably manage the triple bottom line through all three pillars, attempting to find the best intersection of each pillar. The model will identify potential impacts on the Great Lakes, but also help to identify areas of change.
V. Conclusions and Future Work

Understanding the relationship between chemical constituents, flow, and human impacts is critical for the advancement of sustainable watershed management. This research project estimated phosphorus loadings from four targeted Great Lakes watersheds. The four watersheds were chosen due to the various land use that occur in each basin. To significantly understand constituent transport the relationship between the drivers and loads, including land use, soil composition, slope, and farming practices must be fully understood. This project sought to relate phosphorus load to flow as it varied from predominately forested watersheds to agricultural and urban dominated watersheds.

Through this research project, effective constituent transport models were developed that accounted for 75-94% of the variance in each watershed with relatively small standard errors. The results indicate the inter-play of land use, soils, and flow through the developed model coefficients. To explore this hypothesis further, the study will be expanded across many watersheds in the Great Lakes Basin. These results also indicate the potential to correlate loadings with changing climate and land use scenarios for future management.

In order to advance this research, the following next steps are recommended in two following areas: Extensions of the models: 1) Identify more watersheds in the Great Lakes Basin to study phosphorus loading and the importance of the model coefficients. 2) Develop multivariate regression models for phosphorus loading as a function of seasonality, slope, precipitation, soil composition, and cultivated crops. 3) Explore additional explanatory variable that influence phosphorus loading through literature and additional analysis. Limitations with the statistics: 1) Explore the use of maximum likelihood regression for censored data. 2) Determine the trend in these data sets and adjust for serial correlations. 3) Understand the role of outliers.

VI. Outcomes

Through the completion of the research project, there is a greater understanding of nutrient loadings around the mouths of the Great Lakes watershed, and estimates of P-loadings to Lake Erie and other Great Lake basins. Phosphorus is a key water quality issues in the Great Lakes, but now a better understanding the distribution and frequency will be helpful in scenario creation and development of a larger predictive water quality model. In addition, each member gained skills estimating pollutant loading from watersheds. The estimation of pollutants was highly linked to sustainable water management. Through this project, each member began to understand the linkage between economic, societal and environmental needs for water and nutrients. This is an especially important outcome, as future research and work will revolve around linking sustainability into water and ecosystem management.

Similarly, valuable information was discovered about the links between independent and dependent variables when dealing with nutrient loading in water quality management. This project has helped provide a link between anthropogenic activities and nutrient loadings from the Great Lakes watersheds. Understanding these linkages may ease the development and calibration of an intricate, data-driven watershed water quality model. The linkages can also contribute to the development of a new
classification system for the watersheds of the Great Lakes for use in empirical or statistical watershed modeling.

Working in this reciprocal mentoring project, team members have all gained greater understanding of the watershed-scale biogeochemical controls on phosphorus. This helps with further advanced water quality management and modeling. The project is directly related to Meredith Ballard’s doctoral dissertation and the MUSES Great Lakes project as it contributes to the development and calibration of a predictive watershed water quality modeling for phosphorus and suspended sediment. The conclusion drawn from the research project will also help advance the doctoral work as she adapts this initial conclusions to develop more sophisticated models of constituent transport in the Great Lakes Basin. In addition, the predictive water quality models will be used to test various land change and climate change scenarios. Through the developed linkages of this project, it will be possible to test relevant scenarios based upon the nutrients’ relationship to anthropogenic and natural forces. Another potential application would be the development of a journal paper or conference proceeding on the findings of this study and as it relates to water quality in the Great Lakes Basin and sustainable watershed management.
References


