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Research article

The Pressure of Society on Water Quality: A Land Use Impact Study of Lake Ripley in Oakland, Wisconsin

Kyle Whalley * **and Wei Luo**

Department of Geography, Northern Illinois University, 218 Normal Rd, DeKalb, IL 60115, USA

* **Correspondence:** Email: kylekwhalley@gmail.com

Abstract: Eutrophication of lakes occurs naturally over time, but the eutrophication rate can be accelerated by human activities. Agriculture land use can negatively impact water quality of lakes due to nutrient pollution. This research investigates the impacts of agricultural land use on the water quality of Lake Ripley in Oakland, Wisconsin from 1993 to 2011. This study performs a regression analysis which incorporates four years of National Land Cover Database (NLCD) data, eight spatial categories based on hydrological flow length across topographic surface, and a weighting technique to calculate land use percentages. The results indicate that the combination of agricultural land use and rainfall variables are significantly related to chlorophyll *a* and total phosphorus concentrations, while these variables do not appear to affect Secchi depth measurements. Due to the near flat topography of the Lake Ripley watershed, agricultural land use within the two spatial regions closest to Lake Ripley and its inlet stream had the largest impact on Lake Ripley's water quality.

Keywords: Agriculture; eutrophication; Lake Ripley; land use; nutrients; trophic state index; National Land Cover Database; and water quality

1. Introduction

Water quality of lakes can naturally degrade over time, although human based activities often accelerate the degradation and the eutrophication of water quality conditions [1]. Water quality consists of biological, chemical, and physical characteristics. Land use, impervious surfaces, residential population, weather, climate, geology, soils, and human activities around bodies of water can all affect the resulting water quality.

Changes in residential, urban, and agricultural land use can alter the amount of nutrients and pollutants that get added into a water body through runoff processes. Runoff occurs as surface water is unable to infiltrate the ground due to impervious surfaces, compact soils, saturated soil conditions, or when the infiltration rate is lower than the precipitation rate [2]. Runoff collects and carries pollutants and nutrients such as gasoline, fertilizers, and manure downstream within a watershed and is often directed into lakes since they are low lying depressions. Septic tanks and sewer lines can degrade over time causing leaks which pollutes the groundwater [3]. The pollutants within the groundwater also affect the water quality of water bodies if they are not removed before entering a lake, river, or stream.

The addition of excess nutrients in lakes decreases water quality conditions and potentially can lead to the eutrophication and emergence of harmful algae blooms (HABs). In the United States Midwest, where soils are especially fertile, suitable for cultivating crops, agricultural land use makes up a major portion of the landscape [4]. With a large area devoted to agriculture, crop optimizing applications such as manure, fertilizers, herbicides, and pesticides cover a large area of land and increase the potential of water contamination.

In this study, the relationships between agricultural land use, rainfall events, and water quality conditions of Lake Ripley in Oakland, Wisconsin were examined. Lake Ripley is a small recreational lake in southern Wisconsin that has been extensively monitored and researched by the Lake Ripley Management District (LRMD); however, an assessment of the human impacts of land use and impervious surfaces on the water quality of Lake Ripley has not been conducted. This paper aims to understand how agricultural land use affects the water quality of Lake Ripley. The goal of this paper is to answer the following question: How have changes in agricultural land use within the Lake Ripley watershed affected the chlorophyll *a*, phosphorus, and Secchi depth measurements of Lake Ripley within two days of rainfall events between 1993 to 2011?

Several studies have investigated the relationship between land use, impervious surfaces, and water quality. Past research has generally focused on agricultural and urban land uses. In urban landscapes, pollution and impervious surfaces are more prevalent throughout the area. Roads are a type of impervious surface that alters and disrupts natural hydrology flow patterns [5,6]. Generally, as the amount of impervious surfaces within a watershed increase, the water quality decreases [7].

Specific types of land use including urban, residential, and agricultural have a negative effect on the water quality [8]. Several authors identified a positive relationship between nitrogen and phosphorus in water bodies and agricultural land use [8–13]. Stream water clarity conditions that run through agricultural land use have higher turbidity levels than streams that meander through forested areas [14]. Leaking septic tanks in residential areas have been identified as a contributor to the total phosphorus concentration of surface waters [15]. The presence of forested land use was determined to have a negative relationship with water quality degradation [8,16]. Forest land use around a lake seemingly improves or maintains the water quality because surface water carrying nutrients and pollutants is able infiltrate into the ground while trees and plants remove some of the nutrients which prevents these substances from reaching and degrading lakes.

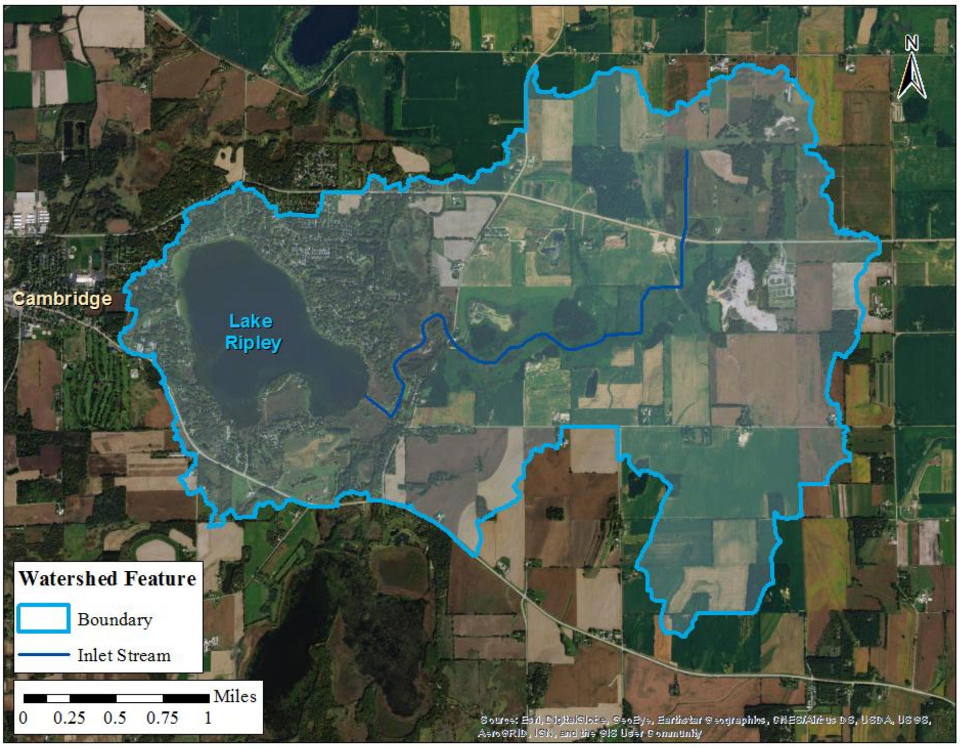
Sliva and Williams tested the relationship between land use and water quality using two different spatial classification methods [16]. The first classification utilized a 100 meter (m) buffer around rivers and the second included the entire watershed. Sliva and Williams concluded that studying the effects of land use on water quality using the entire watershed improved the results of the correlation and the multiple regression analysis [16]. A study from Nielsen et al. also found that the relationship between water quality variables and land use was the strongest when the entire watershed is examined [17]. This study tested five different buffer sizes including 25, 50, 100, 200, and 400 m zones around streams and lakes in addition to analyzing the land use effects within the entire watershed.

While numerous studies have investigated the impact of land use on water quality conditions in streams, rivers, and lakes, the Lake Ripley watershed has not been fully examined. Additionally, while past water quality land use studies of other watersheds used only distance buffers or examined the entire watershed, this study takes into account both distance and topography to analyze the relationship between land use and water quality. Since topography can affect precipitation, runoff, and drainage patterns, it is a crucial element to understanding the land use areas that affect nearby stream, river, and lake water quality.

Lakes are commonly classified by their trophic state which is defined by three water quality variables including chlorophyll *a*, phosphorus, and Secchi depth measurements [18,19]. There are three primary trophic state categories: oligotrophic, mesotrophic, and eutrophic, which are determined by the amount of nutrients and water clarity of the lake. Sometimes an additional category called hypereutrophic is included in lake classification. Oligotrophic water characteristics consist of low phosphorus and chlorophyll *a* concentrations, and a high Secchi depth measurement indicating an increased visibility or clarity in the water. Oligotrophic lakes are often deep lakes that are unable to support large numbers of fish due to the lack of nutrients available in the water. In contrast, eutrophic and hypereutrophic lakes have very high levels of phosphorus and chlorophyll *a*, and have low Secchi depth readings which translates as very low water clarity. Eutrophic and hypereutrophic lakes are often old, shallow lakes that support a large number of aquatic organisms with the surplus of nutrients, but they are more vulnerable to hypoxic and anoxic conditions [20]. Mesotrophic conditions have moderate levels of phosphorus and chlorophyll *a,* and have a moderate water clarity.

2. Lake Ripley Background

Lake Ripley was created by the last retreating glacier in Wisconsin around 12,000 years ago which left behind a sheet of ice positioned in a topographic depression [21,22]. When the ice sheet in the topographic depression melted, Lake Ripley, a kettle lake, was formed. Currently, Lake Ripley is situated between two townships, Cambridge and Oakland, in Jefferson County, Wisconsin and is located approximately 26 miles (41.84 kilometers) to the east-southeast of Madison, Wisconsin. Lake Ripley is positioned on the western region of the Lake Ripley watershed, which encompasses 4,687.99 square acres (1897.16 hectares) (Figure 1). Lake Ripley has been a recreational destination for locals and vacationers alike since 1881 [22]. Vacationers have traveled from nearby cities of Chicago, Madison, Milwaukee, and Rockford to enjoy recreational activities such as fishing, swimming, boating, and sightseeing. The bathymetry of Lake Ripley is characterized by two main shallow bays in the southeast and southwest while the center of the lake is the deepest point at 44 feet (ft) (13.41 m) [22]. Including the shallow bays and the deepest area, Lake Ripley has an average depth of 18 ft (5.49 m) [23].



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1: The Lake Ripley watershed within Jefferson County, Wisconsin derived from a series of hydrology tools in ArcGIS.

Lake Ripley is considered to be a drainage lake due to the presence of an inlet and outlet stream that contributes to the water volume and water quality of the lake [21]. Drainage lakes are typically found to have more nutrients than other lakes. With an inlet stream flowing into the lake, it becomes easier for sediments, nutrients, and pollutants to be transported into Lake Ripley through the means of runoff into the inlet stream or directly into Lake Ripley.

During the summer months, Lake Ripley becomes stratified forming an epilimnion, thermocline, and hypolimnion layers, and water present in depths greater than 20 ft (6.096 m) can become anoxic [22]. In the winter, anoxic conditions in the stratified lake are not a concern because of the depth of Lake Ripley [22]. Since Lake Ripley experiences summer and winter stratification and turnover events in the spring and fall, the lake is considered to be a dimictic lake. This type of lake classification means that the waters of Lake Ripley mix twice annually. The trophic state of Lake Ripley is generally classified as meso-eutrophic since the water conditions have fluctuated between the mesotrophic and eutrophic categories in recent years [22].

Although Lake Ripley receives much of its water from the inlet stream, approximately 30% of the water contributing to Lake Ripley is groundwater [22]. While Lake Ripley is susceptible to nutrient runoff from residential and agricultural areas, septic tanks are not contributing to the nutrients of the lakes. In 1984, septic tanks in homes were replaced with a city sanitary sewer system which removes the possibility of leaking septic tanks, but creates the possibility of leaking sewer lines contributing to the phosphorus and nitrogen concentrations within Lake Ripley [22]. Effluent from the wastewater treatment plant is discharged outside of the Lake Ripley watershed and therefore, has no impact on Lake Ripley [22].

A study in 2009 identifies that 48.4% of the Lake Ripley watershed is comprised of agricultural land with residential and wetland areas representing the second and third most prominent land use classifications at 12.6% and 11.6% [22]. A 2011 land use map (Figure 2) is shown below. Jefferson County farmers as a whole primarily grow corn and soy beans. In 2012, Jefferson County produced over 9 million bushels (317,200 m^3) of corn and over 1,500 thousand bushels (52.86 m^3) of soy beans [24]. Corn in particular requires a high amount of nitrogen, phosphorus, and potassium to optimize production and thus increases the likelihood of nutrient runoff [25]. However, most of Jefferson County has adopted a nutrient management plan (NMP) to attempt to reduce and control the amount of nutrient runoff. Farmers and consultants examine variables such as slope, soil type, nutrient applications, and crop rotations in order to develop an individual NMP [26].

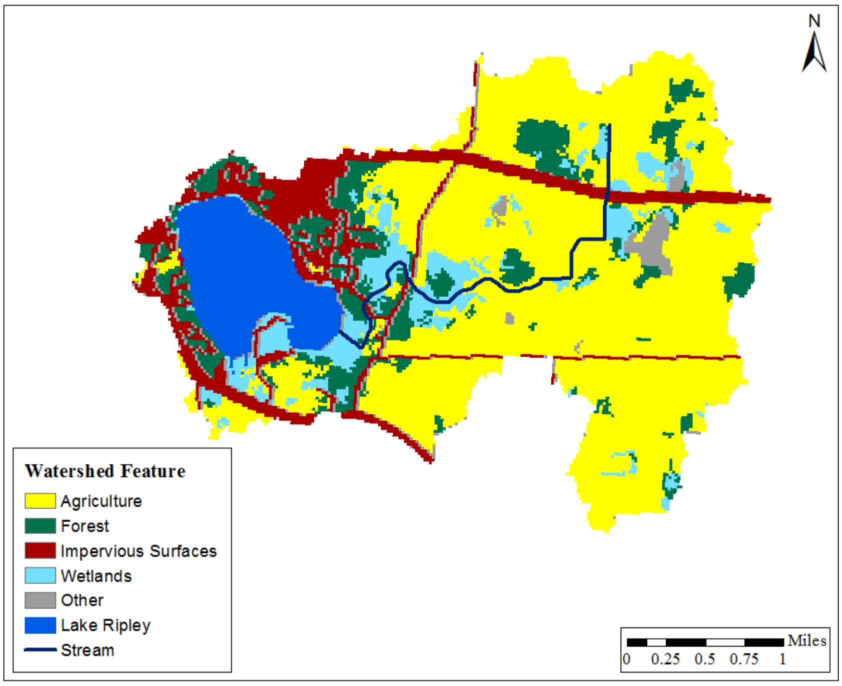


Figure 2: Land use within the Lake Ripley watershed in 2011. Impervious surfaces within this map include moderate to highly developed areas such as commercial and residential land.

3. Materials and Methods

3.1. Regression Research Design

In this study, an investigation of agriculture land use, rainfall events, and the water quality of Lake Ripley was examined from 1993 to 2011 during the spring and summer months for Lake Ripley. A model was developed to help answer the research question which utilizes an individual water quality parameter as the dependent variable along with the percentage of agricultural land use and rainfall as explanatory variables (1). The water quality variables inserted as the dependent variable in the equation includes chlorophyll *a*, total phosphorus, and Secchi depth. Several regressions were then performed in Statistical Package for the Social Science (SPSS) to identify the relationship between the three trophic state variables and the explanatory variables. The null hypothesis of the regression analysis states that agricultural land use and rainfall have no effect on the trophic state variables (2), whereas the alternative hypothesis states that agricultural land use and rainfall influence the concentrations of the trophic state variables (3).

$$Water\ Quality = \%\ Agricultural\ Land\ Use + Rainfall \tag{1}$$

$$H_0: Water\ Quality \neq f(Agricultural\ Land\ Use + Rainfall) \tag{2}$$

$$H_1: Water\ Quality = f(Agricultural\ Land\ Use + Rainfall) \tag{3}$$

First, the Lake Ripley watershed was delineated from a Jefferson County digital elevation model (DEM) that was derived from light detection and ranging (lidar) and global positioning system (GPS) data with a 5 ft (1.52 m) spatial resolution. Since lidar derived DEMs do not include features such as culverts, which are important for accurately representing flow patterns and delineating true watershed boundaries, culvert locations were manually collected in the field using a GPS unit. Polylines were created at culvert locations in ArcGIS and an interpolation procedure was performed to fuse the polylines with the DEM, which lowers the elevation of the road barriers along the culvert lines, essentially simulating the effects of the presence of culverts to allow water to flow across road barriers [27]. After modifications of the DEM were made, the areas that contribute to Lake Ripley upstream of the outlet stream were defined using spatial analysis hydrology tools in ArcGIS.

3.1.1. Agricultural Land Use

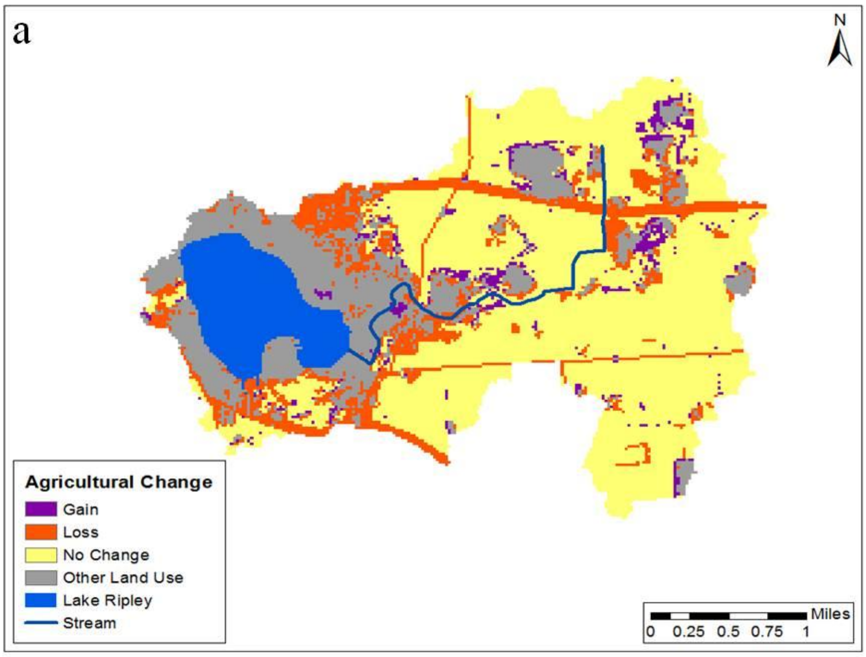
To analyze the human impacts on the water quality of Lake Ripley, a land use dataset was obtained from the National Land Cover Database (NLCD) [28]. Four different years of land use data from the NLCD were utilized: 1992, 2001, 2006, and 2011. The land use files consist of water, developed, barren, forest, shrubland, herbaceous, planted/cultivated, and wetland land use categories. The planted and cultivated land use category which includes pastures and cultivated cropland were utilized to analyze the effects of the surrounding agricultural land use on water quality of Lake Ripley. Pastures and cultivated cropland were particularly examined due to potential runoff of nitrogen and phosphorus from agricultural lands.

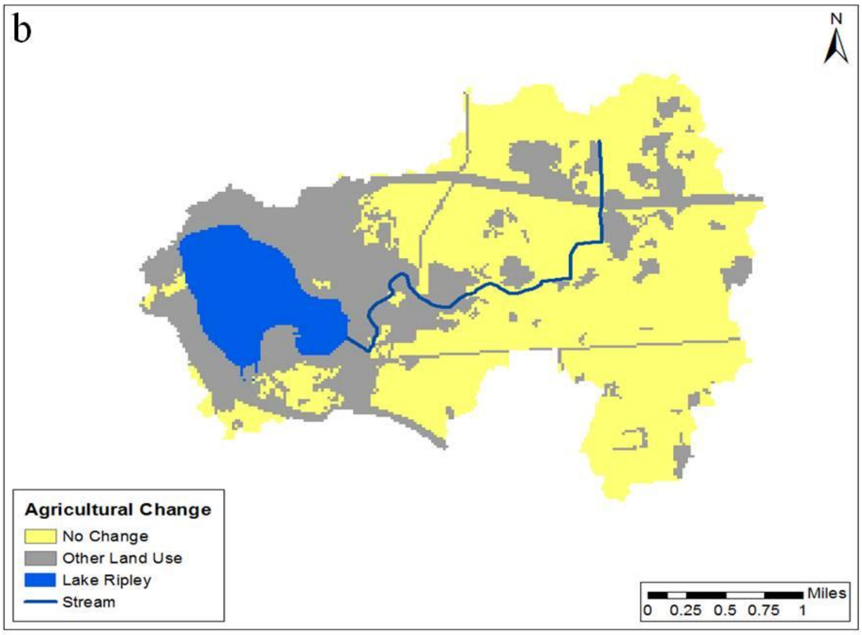
The NLCD years were obtained remotely through the usage of the Landsat 5 Thematic Mapper (TM) images (with a spatial resolution of 100 ft or 30.48 m) [28]. The NLCD collection process utilized at least two different scans to validate the type of land use for the leaf-off (spring) and leaf-on (summer) seasons [29]. Leaf-off and spring classifications were utilized as the baseline imagery since the data obtained from Landsat 5 TM for the spring season more accurately describes land cover characteristics [29].

Agricultural land use percentages were compiled for the Lake Ripley watershed for the four NLCD years (1992, 2001, 2006, and 2011) from the leaf-off and spring imagery. The NLCD data collection dates for Lake Ripley for all the NLCD years were conducted in April or May during spring and leaf-off periods. Land use data in the 1992 and the 2001 NLCDs were actually collected on May 15, 1993 and April 24, 2000 for the Lake Ripley watershed, which are both one year off from the NLCD years. Due to the constraints of available NLCD land use products, the impacts of agricultural land use on water quality of Lake Ripley was examined from the NLCD in 1993 to the 2011 NLCD. In geographic information systems (GIS), each NLCD year for the study area was clipped from the national data. Additionally, three change detection maps and a table were created to display agricultural land use changes between NLCD years within the watershed (Figure 3 and Table 1).

Table 1. Agricultural Land Use Change

Years	Gain	Loss	No Change
1993–2001	4.9%	19.6%	75.5%
2001–2006	0.0%	0.0%	100.0%
2006–2011	0.0%	1.1%	98.9%





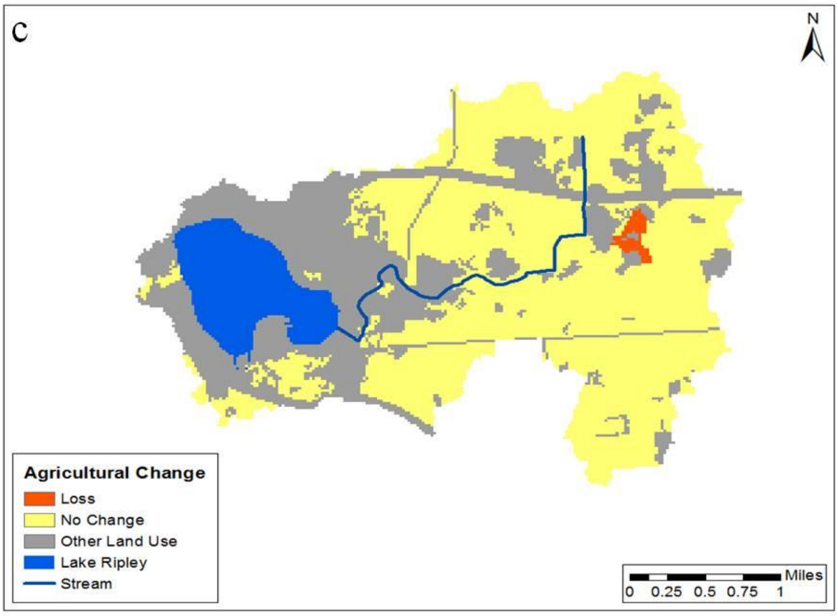


Figure 3: A set of change detection analysis maps that display spatial changes of agricultural land use between each NLCD year within the Lake Ripley watershed. There are three different possible options for agricultural land including an increase (gain), a decrease (loss), or no change. Other land use types that do not change from agricultural land or change to agricultural land are indicated in gray. Change detection maps were created for a) 1993 to 2000, b) 2000 to 2006, and c) 2006 to 2011.

3.1.2. Weighting Technique

A weighting method was used on the percent agricultural land use data to place a higher value on land cover that is closer to Lake Ripley and the inlet stream based on topography and the watershed flow network (i.e., flow length). The weighting method adjusts the data to model the concept that areas closer to Lake Ripley and the inlet stream have a higher impact on the water quality than distant areas. This weighting technique was created in ArcGIS from the Jefferson County DEM and the use hydrological tools. Several hydrological tools in ArcGIS (including fill, flow direction, flow accumulation, pour point, and flow length) were used to derive the flow length distances away from Lake Ripley and the inlet stream, which were divided into eight classes of equal quantiles that represent areas near and far from Lake Ripley and the inlet stream (Figure 4). Eight spatial classes were chosen because the number and size of the categories along with the weights applied to them provided the strongest relationship between the land use and the trophic state variables. Many other combinations of spatial classes were tested, however, no other combination had a stronger land use and trophic state relationship than the eight spatial classes.

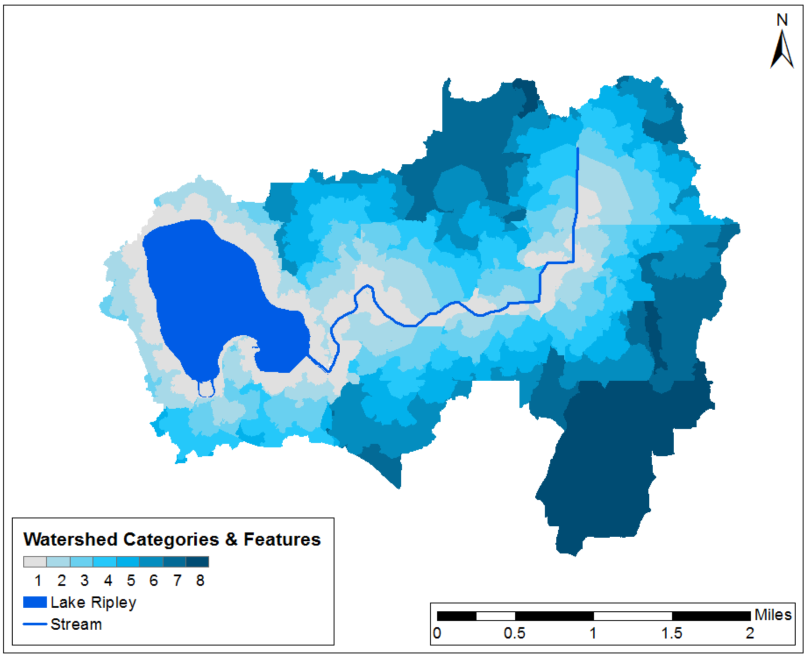


Figure 4: Eight weighting classes calculated from the flow length tool in ArcGIS. Class 1 is closest to stream or lake, class 8 is farthest based on hydrologic flow length across the topographic surface. These classes are utilized to acquire the percent agriculture land use value for each class. The classes are then weighted and combined to obtain a single agriculture land use percentage value for each of the NLCD years within the Lake Ripley watershed.

These eight spatial classes based on flow length distances away from Lake Ripley and the inlet stream were utilized as zones to calculate the percentage of agricultural land within each class use using zonal statistics for the NLCD years (Figure 5). Once the agriculture percentages within each zone were obtained through zonal statistics, the eight classes were then weighted. After finding the strongest relationship between the land use and the three trophic state variables, the two nearest classes to Lake Ripley were emphasized, whereas the six most distant classes were not incorporated in the analysis since the addition of the outermost six classes into the equation weakened the land use and water quality relationship. The closest category (C1) nearest to Lake Ripley was multiplied by 0.95 and the second (C2) was multiplied by 0.05 (Equation 4). Similar to the number of classes, several other weighting values were tested, but the 0.95 and 0.05 weighting values provided the strongest relationship between the land use and the trophic state variables. The weighted agricultural land use percentages within the two nearest categories were added up to provide an overall percentage for the agricultural land use during each NLCD collection date. Once the agricultural percentages were determined for the four NLCD dates, an interpolation of the agricultural data was conducted to provide an agricultural land use percentage for all the days between the NLCD dates. Since land use data does not commensurate with the Lake Ripley water quality data, it is assumed that the land use changes linearly between NLCD dates and is a reasonable way to estimate the land use composition within the Lake Ripley watershed for dates without land use data.

$$Agricultural\ Percentage = (C1 * 0.95) + (C2 * 0.05) \tag{4}$$

Where C1 and C2 represent the agricultural percentage in each of the two zones

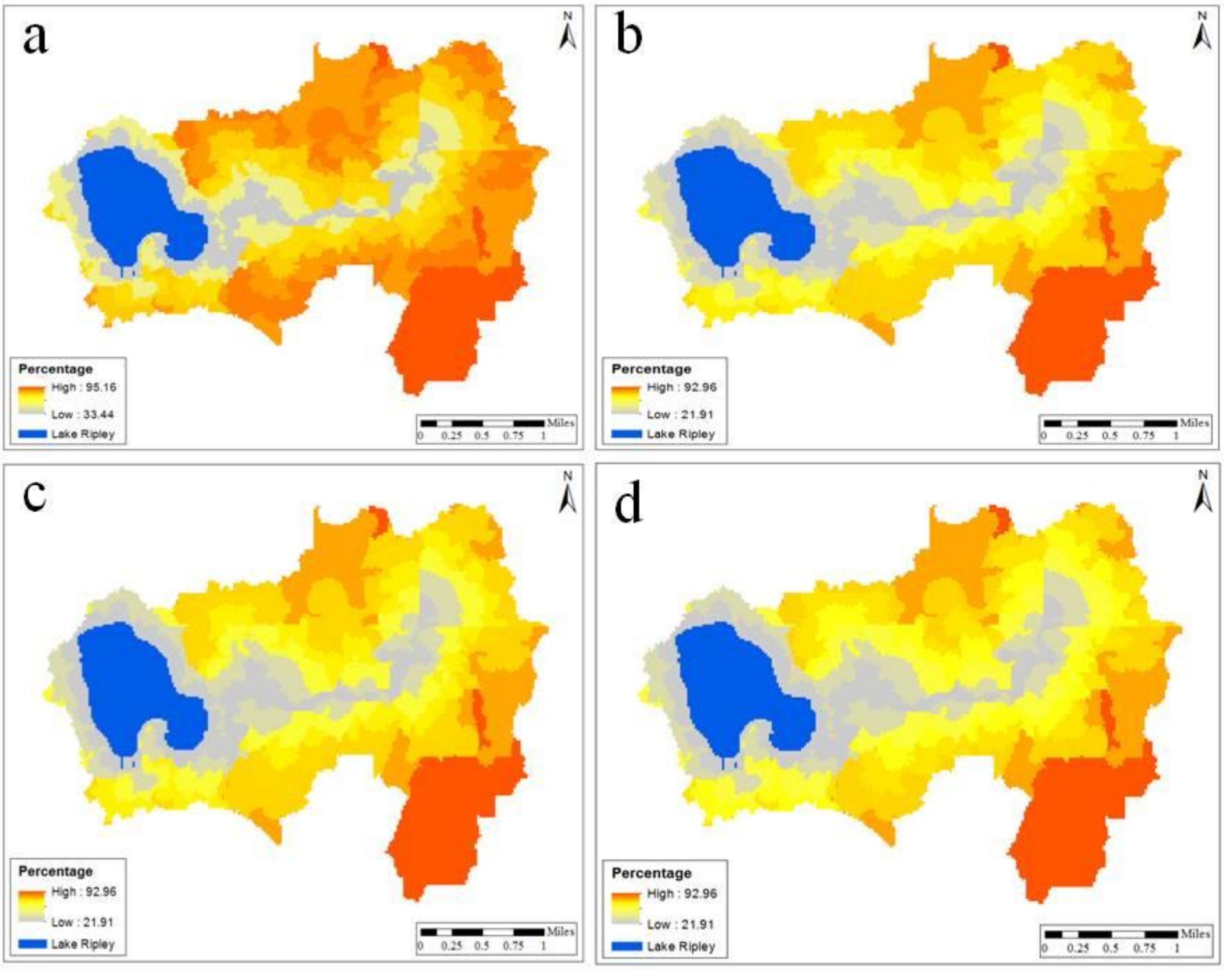


Figure 5: Percentage of agricultural land use for each of the eight classes within the Lake Ripley watershed calculated from the NLCDs for a) 1993, b) 2000, c) 2006, and d) 2011. In each NLCD year, the classes nearest to Lake Ripley and the inlet stream have the lowest percentage of agricultural land use, whereas the outermost class has the highest percentage of agricultural land use.

3.1.3. Rainfall Events

Daily rainfall data from March 1993 to September 2011 were compiled and used from Weather Underground (Figure 6) [30]. Precipitation data for the winter and late fall months were not compiled due to the absence of water quality data. Only rainfall events were utilized as other forms of precipitation such as snow, sleet, and hail could have a different or delayed effect on agricultural runoff. Due to historical data availability, rainfall data for Madison, Wisconsin was generated and utilized in this study as the nearest replacement for Cambridge and Oakland townships.

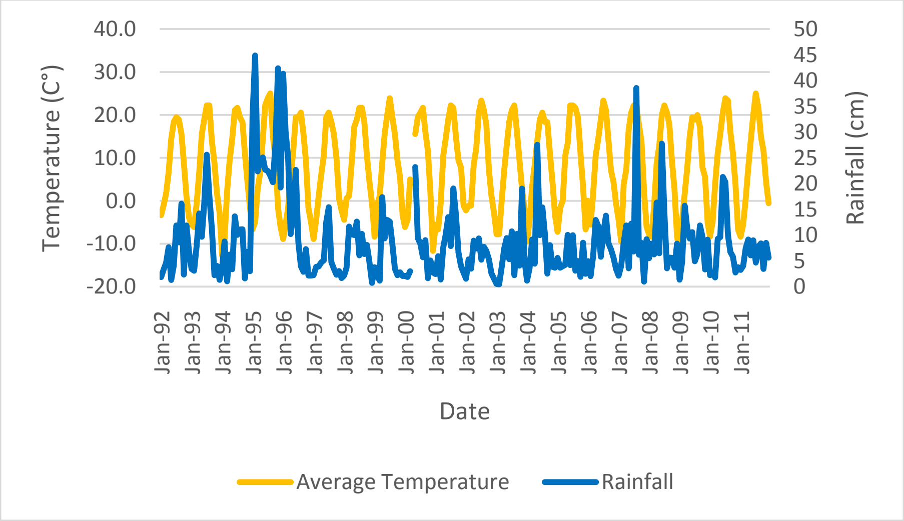


Figure 6: Average temperature (℃) and total rainfall (cm) of Madison, WI from 1992 to 2011.

3.1.4. Water Quality

The water quality variables analyzed include the trophic state variables: chlorophyll *a*, phosphorus, and Secchi depth. Tests for chemical, metals, and other substances were not included in this study since these variables were either not measured or not monitored regularly at Lake Ripley. Both chlorophyll *a* and phosphorus were measured in micrograms per liter (μg/L) while Secchi depth was measured in feet. Data from the National Water Quality Monitoring Council (NWQMC) was utilized for this study which is a compilation of Environmental Protection Agency (EPA) and United States Geological Survey (USGS) water quality samples. These samples were collected at the deepest part of the lake and at several depths. In this research, an analysis of water quality parameter data was conducted using near surface water samples that are less than 6 ft (1.83 m) deep, except for Secchi depth or water clarity, which is measured by lowering a Secchi disk into the water until the disk can no longer be seen by the observer at the surface. Water samples were collected and sent to a laboratory in Madison, Wisconsin to test for chlorophyll *a* and phosphorus concentrations.

Chlorophyll *a* samples in this study were collected using two different techniques which include the spectrophotometric and fluorescence methods. A correction for pheophytin was conducted in the spectrophotometric technique, although no correction was made for the fluorescence technique. The change methodology and pheophytin correction occurred in 2002 as a result of the change in the instruments used to determine chlorophyll *a* concentrations. With the switch to the fluorescence technique, Kennedy-Parker, Krinke, and Bowman compared chlorophyll *a* concentrations of random samples using the two techniques [31]. The two techniques were determined comparable which allows for a full analysis of chlorophyll *a* samples from 1993 to 2011 [31]. Water quality samples of the three trophic state variables used in this study are displayed below (Figure 7, Figure 8, and Figure 9).

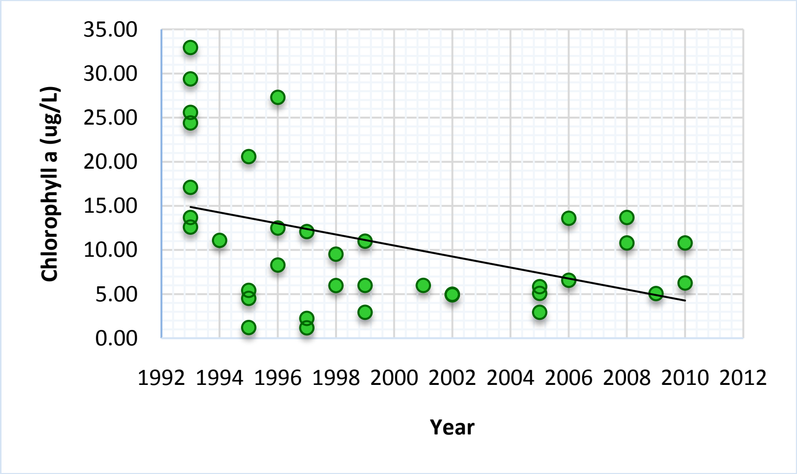


Figure 7: Chlorophyll *a* concentrations obtained from Lake Ripley from 1993–2011.

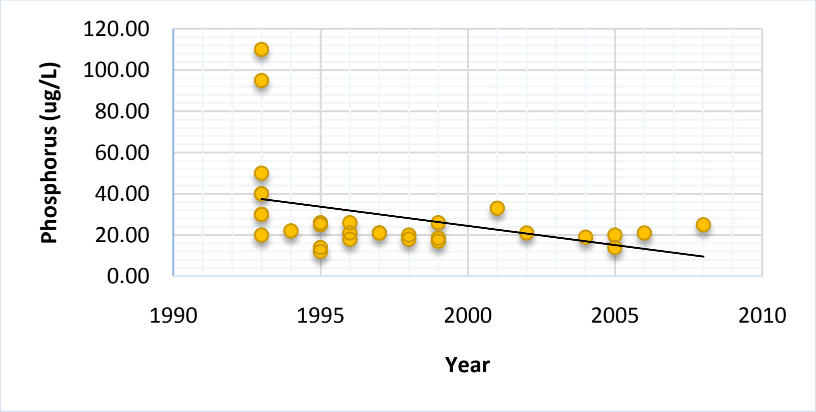


Figure 8: Phosphorus concentrations obtained from Lake Ripley from 1993–2011.

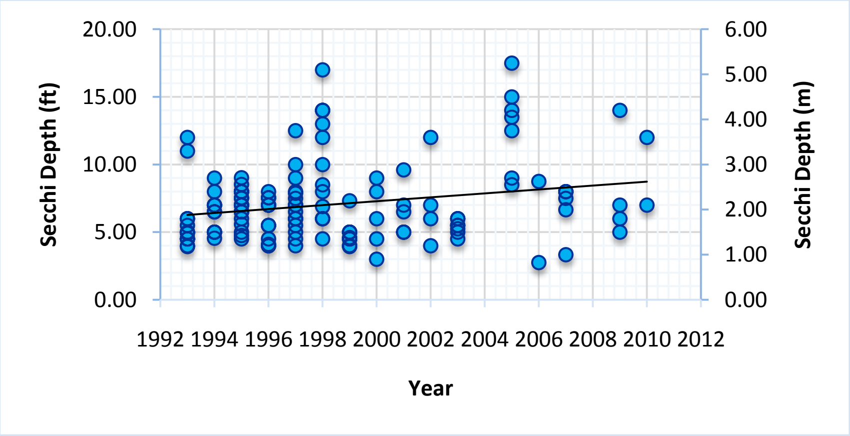


Figure 9: Secchi depth measurements obtained from Lake Ripley from 1993–2011.

3.1.5. Data Alignment Process

The data collection process resulted in the creation of three separate worksheets in Microsoft Excel which includes a worksheet for daily interpolated agricultural land use (percentage), rainfall events, and water quality sampling events at Lake Ripley from 1993 to 2011. Water quality sampling dates were sorted and aligned with rainfall data. Water quality sampling dates that were within two days of a rainfall event were included in the regression analysis, whereas all water quality samples outside of this timeframe were excluded from this analysis. This two day time period was selected because of the strong relationship between total rainfall and several water quality parameters within two days of a rainfall event [32]. Documented rainfall events that occurred during the same day as the water quality sampling event were not considered as a rainfall event within the two day time frame since the weather data was documented by day and not by hour. Therefore, with this rainfall data, it is impossible to determine whether a rainfall event on the same day as a water quality sampling event occurred before or after the water quality sample. In the circumstance that rainfall events occurred for the two days prior to a water quality sampling event, the rainfall totals for each day were summed up and used together as one rainfall value that aligns with the water quality sampling event. Once the water quality and rainfall events were aligned by date, the agricultural land use percentage was also identified. Three regressions were performed in SPSS to determine the relationship between the independent variables, agricultural land use and rainfall events, with the dependent trophic state variables (see Equation (1)). Due to a heteroscedastic variance and a skewed right distribution in two of the three models, the natural log was taken for the phosphorus model and all the variables were logged for the Secchi depth model to normalize the distribution.

3.2. Trophic State Index (TSI) Trend

Using the trophic state variables, a TSI score can be calculated. The TSI chart ranges from 0 to 100, with oligotrophic conditions having TSI score of less than 40, mesotrophic conditions from 40 to 50, eutrophic conditions from 50–70, and hypereutrophic conditions from 70–100 (Table 1). Each trophic state variable has a separate equation to calculate a lake's overall TSI value (Equation (5), Equation (6), and Equation (7)) [33]. However, it is recommended that the chlorophyll *a* data should be utilized to calculate the overall TSI value of a lake and Secchi depth data should be utilized in the absence of chlorophyll *a* data [33,34]. Chlorophyll *a* is often utilized to the calculated the overall TSI value because out of the three trophic state variables, it best models the algal biomass of a lake [34]. Thus, the chlorophyll *a* annual values were then utilized to calculate a TSI score for each year.

Table 1. TSI Classification Chart [22,35]

Trophic State	Trophic State Index (TSI)	Chlorophyll *a* (μg/L)	Secchi Depth (ft) [m]	Total Phosphorus (μg/L)
Hypereutrophic	100			
	70	56.0	1.6 [0.49]	96.0
Eutrophic				
	50	7.3	6.5 [1.98]	24.0
Mesotrophic				
	40	2.6	13.1 [3.99]	12.0
Oligotrophic	0			

(Values indicate boundary between states)

$$TSI(CHL) = 9.81\ln(CHL) + 30.6 \tag{5}$$

$$\mathrm{TSI(TP)} = 14.42\ln(\mathrm{TP}) + 4.15 \tag{6}$$

$$\mathrm{TSI(SD)} = 60 - 14.41\ln(\mathrm{SD}) \tag{7}$$

where CHL represents chlorophyll *a*, SD represents Secchi depth, and TP represents total phosphorus.

The TSI scores of Lake Ripley from 1989 to 2015 fluctuates between mesotrophic and eutrophic conditions (Figure 10). Lake Ripley has a slight downward trend in TSI which indicates there are lower amounts of total phosphorus and chlorophyll *a* in the lake which also results in a higher water clarity. This is consistent with the findings of Dearlove (2009) who classified Lake Ripley as meso-eutrophic because of the lakes fluctuation between the two different trophic states [22].

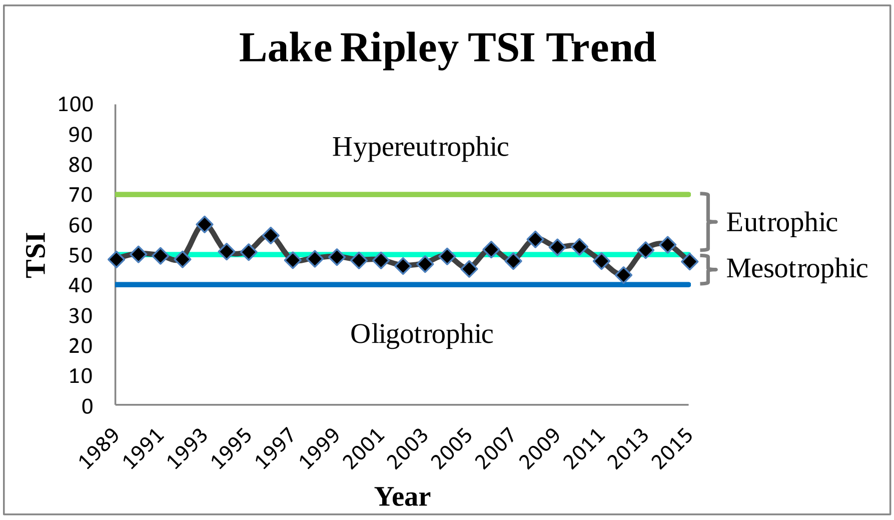


Figure 10: Lake Ripley TSI scores (calculated from chlorophyll *a* data) from 1989 to 2015.

4. Results

4.1. Regression Analysis

4.1.1. Model Statistics

The relationship between the dependent trophic state variable and the independent agricultural land use and rainfall variables is displayed in Equations (8), (9), and (10). Chlorophyll *a* and phosphorus concentrations increase with inches of rain and the percentage of agricultural land use, whereas the Secchi depth measurement decreases as these two independent variables increase. Chlorophyll *a* has a unique intercept value (-17.866) indicating a negative chlorophyll *a* concentration without the addition of rain or agricultural land use. However, the lowest agricultural land use percentage from 1993 to 2011 is 22.43% which provides a minimum chlorophyll *a* concentration of 5.55 µg/L without the addition of rainfall data. Furthermore, on the upper end of the spectrum, chlorophyll *a* can reach up to 19.49 µg/L with an agricultural percentage 34.33% and 1.43 inches of rain. The phosphorus equation provides a minimum value of 16.95 µg/L and a maximum value of 42.55 µg/L. Lastly, the Secchi depth equation provides a minimum value near 0 ft (or m) and a maximum of 11.12 ft (3.39 m) of visibility. While it is possible to have calculated water quality values that exceed these maximum values or are below these minimum values, the three regression models were not calculated for these ranges due to a low number of samples outside of this range.

$$\text{Chlorophyll a} = -17.866 + 1.061\text{r} + 1.044\text{a} \tag{8}$$

$$\text{Total Phosphorus} = \text{e}^{1.751+0.246\text{r}+0.048\text{a}} \tag{9}$$

$$\text{Secchi Depth} = 10^{1.046-0.041\text{r}-0.178\text{a}} \tag{10}$$

For each model, the F-calculated and F-critical values were determined using the regression results from SPSS and a formula in Microsoft Excel. The implied null hypothesis that the combination of agricultural land use and rainfall variables do not affect water quality was rejected for both the chlorophyll *a* and phosphorus models since these models are significant at the 0.05 level (meaning the variables affect the water quality), while it was accepted for the Secchi depth model (meaning the variables do not appear to affect Secchi depth measurements) (Table 2 and Table 3). The decision to reject or accept the null hypothesis is determined by the F-calculated and F-critical values. If the F-calculated value is less than the F-critical value then the decision is to accept the null hypothesis. On the other hand, if the F-calculated value is greater than the F-critical value, then the null hypothesis is rejected and the alternative hypothesis is accepted.

Table 2. Null Hypothesis Decision

Water Quality Variable	F-Calc	F-Crit	Decision
Chlorophyll *a*	9.208	3.267	Reject Ho
Total Phosphorus	5.475	3.328	Reject Ho
Secchi Depth	2.495	3.063	Accept Ho

where F-Calc is the calculated value and F-Crit is the critical value.

Table 3. Model Significance

Water Quality Variable	Model	Sum of Squares	df	Mean Square	F	Sig.
Chlorophyll *a*	Regression	860.758	2	430.379	9.208	0.001
Total Phosphorus (ln)	Regression	2.051	2	1.025	5.475	0.010
Secchi Depth (log)	Regression	0.124	2	0.062	2.495	0.086

Based on the F-calculated and F-critical values of each model, the null hypothesis was rejected for both the chlorophyll *a* and phosphorus models, while it was accepted for the Secchi depth model. Therefore, the combination of agricultural land use and rainfall variables affect the chlorophyll a and phosphorus concentrations in Lake Ripley. Since the Secchi depth model accepts the null hypothesis, the relationship between the water quality of Lake Ripley and the two independent variables is not clear from this dataset. The models statistics including the sum of squares and mean square values widely differ from one another and this is caused by the different normalization methodologies used on the models. The R-squared values of each model were similar to the findings of Nielsen et al., who had an R-squared value of 0.17 for chlorophyll *a* and 0.26 for total phosphorus [17] (Table 4). The Lake Ripley watershed from 1993 to 2011 displays higher adjusted R-squared values at 0.319 for chlorophyll *a* and 0.236 for total phosphorus. Secchi depth was not studied by Nielsen et al. [17].

Table 4. Model R-Squared Values

Water Quality Variable	R-Squared	Adjusted R-Squared	Std. Error of the Estimate
Chlorophyll *a*	0.358	0.319	6.837
Total Phosphorus (ln)	0.289	0.236	0.433
Secchi Depth (log)	0.036	0.022	0.158

The parameters of the models (Table 5) provide information about the intercept, variable rates, error, and significance. Agricultural land use is significant at the 0.05 level for both the chlorophyll *a* and total phosphorus models. Agricultural land use in general helps explain the variance of the model, whereas the other explanatory variable, rainfall, is less helpful in explaining variance of the model.

Table 5. Model Parameters

Water Quality Parameter	Independent Variable	Unstandardized Coefficients		Sig.
		B	Std. Error	
Chlorophyll *a*	Constant	-17.866	6.824	0.013
	Rainfall (in)	1.061	2.958	0.722
	Agriculture (%)	1.044	0.251	0.000
Total Phosphorus (ln)	Constant	1.751	0.494	0.001
	Rainfall (in)	0.246	0.226	0.286
	Agriculture (%)	0.048	0.018	0.012
Secchi Depth (log)	Constant	1.046	0.309	0.001
	Rainfall (in)	-0.041	0.023	0.074
	Agriculture (%)	-0.178	0.213	0.404

4.1.2. Model Diagnostics

To analyze the reliability of the models, diagnostics including multicollinearity, heteroscedasticity, and autocorrelation were investigated. With the normalized distribution of the trophic state variables, all three models displayed homoscedastic variances. With each model having two explanatory variables, agricultural land use and rainfall, there were no collinearity issues based on the tolerance and variance inflation factor (VIF) values (Table 6).

Table 6. Collinearity Diagnostics

Water Quality Variable	Tolerance	VIF
Chlorophyll *a*	0.973	1.027
Total Phosphorus (ln)	0.920	1.087
Secchi Depth (log)	0.939	1.065

The issue of spatial and temporal autocorrelation was also examined using the Durbin-Watson test. The calculated Durbin-Watson values from the regression output in SPSS were compared to the lower and upper critical values to determine if autocorrelation is present for each of the three regression models [37] (Table 7). These critical values were determined based on the 0.05 alpha value, the regression sample size, and the two independent variables in each model. The results indicate that the chlorophyll a regression has no autocorrelation, the Secchi depth regression is positively autocorrelated, and the test for the phosphorus regression is inconclusive. With an inconclusive test, the expectation is that there is no autocorrelation present. While the Durbin-Watson test indicated that there is temporal autocorrelation within the Secchi depth model, the autocorrelation can be overlooked since this research is only analyzing the past water quality relationships and is not projecting conditions into the future.

Table 7. Autocorrelation Diagnostics

Water Quality Variable	Durbin-Watson Value	Sample Size	Lower Critical Value	Upper Critical Value	Autocorrelation Decision
Chlorophyll a	1.676	36	1.35	1.59	None
Phosphorus	1.446	30	1.28	1.57	Inconclusive
Secchi Depth	1.068	136	1.71	1.76	Positive

5. Discussion

Many factors could contribute to the water quality of Lake Ripley, such as weather, runoff, the presence of vegetation, the amount of nutrient application, the timing of nutrient application, crop types, slopes, the duration and distance it takes nutrients to reach the water, groundwater, sewer system conditions, and the presence and quantity of aquatic organisms that utilize the nutrients within the water. For agricultural land, the relationship with the water quality of Lake Ripley is also dependent on the how farmers operate their land. A NMP can change from year to year altering the crop type, amount of nutrients applied to fields, and tillage practices. By changing these variables, the potential of nutrient pollution of Lake Ripley will vary year to year and this variation was not incorporated in this study.

A seasonal fluctuation between the three trophic state variables (Table 8) shows that the spring months have low nutrients and highest water clarity, the summer months are high in nutrients and the lowest water clarity, whereas the fall has moderate nutrient levels and water clarity and also the lowest total phosphorus amount when the outlier is removed. When including the outlier, total phosphorus average in the fall has a value of 60 µg/L making it by far the highest total phosphorus average out of all the seasons. Additionally, one runoff event could remove nutrients from land surfaces leaving no or little remaining nutrients available to be transported and deposited within Lake Ripley during another runoff event. This type of scenario could help explain the effect of rainfall within the regression analysis. In the late fall and winter months, the majority of fields are bare and void of crops creating the potential for increased sediment and nutrient runoff. With the absence of regularly tested water quality data during these months, a year round land use impacts analysis could not be achieved. The addition of late fall and winter month data likely would have generated a stronger, positive relationship between the agricultural land use and the three trophic state variables.

Table 8. Lake Ripley Water Quality by Season

	Spring (Mar-May)	Summer (Jun-Aug)	Fall (Sept)
Chlorophyll *a* (μg/L)	9.84	11.23	11.09
Total Phosphorus (μg/L)	23.875	27.625	20
Secchi Depth (ft) [m]	9.72 [2.96]	6.52 [1.99]	7.73 [2.36]

The accuracy of some of the data used in this study could have a negative effect on the results of this study. For example, the 1993 NLCD year likely has some error since the presence of impervious surfaces is less than what the late 1900 aerial photographs show. The rainfall data location could present issues since the rainfall data was obtained for Madison, Wisconsin due to the lack of historic data for Oakland, Wisconsin; the rainfall amount that fell in Madison, may not have been the same as the rainfall amount that occurred in Oakland, Wisconsin. Lastly, the spatial weighting boundaries created for the regression analysis could be improved by adding the location of all culverts within the watershed and incorporating them in the DEM before creating the weighting classes using flow length.

While the literature emphasizes that examining land use within the entire watershed provides the strongest relationship between land use and water quality, this study only examined the land use nearest to Lake Ripley and its inlet stream due to optimal agricultural land use and water quality relationships. The near flat topography within the Lake Ripley watershed is likely the primary reason why land use near Lake Ripley and its inlet stream had the largest impact on the water quality of Lake Ripley. The topography within a watershed plays a role in determining the areas of land that have an impact on the water quality.

This research focused only on determining the general areas that impact the water quality of Lake Ripley and the relationships between land use and the water quality variables. Future studies can address the location of nutrient pollution sources, e.g., by examining nutrient loading, isotopes, and NMPs to determine changes in nutrient applications and to understand where nutrients are coming from. Once the nutrient pollution sources are identified, management actions can occur to protect Lake Ripley.

6. Conclusions

This study offered an additional technique for analyzing watershed water quality by incorporating eight spatial classes based on hydrological flow length to examine the relationship between water quality of Lake Ripley and agricultural land use. Three total regression analyses were performed using water samples within two days of a rainfall event, one for each of the three trophic state variables. The results of the regression analysis show that increasing amounts of rainfall and agricultural land use lead to a higher chlorophyll *a* and total phosphorus concentration and a lower water clarity measurement. A statistically significant relationship was observed between chlorophyll *a*, agricultural land use, and rainfall as well as between phosphorus, agricultural land use, and rainfall. However, the relationship between Secchi depth, agricultural land use, and rainfall was not found to be significant. Adjusted R-squared values for chlorophyll *a* and total phosphorus were 0.319 and 0.236, respectively, higher than the R-squared values of similar studies from the literature. Agricultural land use was the primary explanatory variable that affects the water quality of Lake Ripley as it was statistically significant in both the chlorophyll a and phosphorous models. The rainfall variable was not a statistically significant predictor of water quality. The two nearest regions to Lake Ripley and its inlet stream were the most influential in affecting the water quality of the lake due to the nearly flat topography of the watershed.

Conflict of Interest

All authors declare no conflict of interest.

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