## Abstract

*Lake Lorraine is a shallow, 155-acre seepage lake in Southeastern Wisconsin and is part of the Whitewater Creek Watershed. The lake has been eutrophic since at least the 1970's and is generally murky and weed-covered in summer months. Through research of erosion, soil content, and nutrient loading, it has been found that the lake is being affected by multiple natural and anthropogenic factors which are contributing to its' state of eutrophication. Based on the amount of nutrients found in soil cores using Portable X-Ray Fluorescence and Loss-on-Ignition techniques and the geography of the area, it has been discovered that the excess nutrients in the lakebed are contributing to increased plant growth and development. The geography and surrounding land use of the Lake Lorraine Watershed has also shown that the lake is susceptible to increased amounts of nutrient loading from surrounding agricultural runoff as well as possible faulty septic systems in the surrounding neighborhoods. Through utilization of the Revised Universal Soil Loss Equation (RUSLE) and a modified DRASTIC model, we determined that the lakeshore is susceptible to erosion and the lake itself is susceptible to further nutrient loading. Overall, our research shows that Lake Lorraine is significantly susceptible to excess nutrient loading, and vulnerability of erosion, which all contribute to its increased amounts of plant growth, development, and difficulty to manage properly. Because of our research, we recommend that septic systems are kept up to date, riparian zones are maintained, and no wake laws should be in place.*

## Introduction

Lake management is necessary to maintain a lake's health due to all the influences that can affect its health. When a lake's health is compromised, remediation must begin. In order to do so, the negative contributors need to be identified. One major contributor to a lake's health is nutrient loading. The ability to predict and monitor nutrient loading within a watershed is an important factor in determining the types of flora and fauna within an aquatic ecosystem and will aid in the protection of the ecosystem's future health. Nutrient loading can occur both naturally through the growth and decay of plant and animal material, and anthropogenically via failing septic systems and agricultural runoff (Søndergaard, Jensen, & Jeppesen, 2001).

Lake Lorraine is located in Walworth County, Wisconsin, (42° 43′ 56″ N, 88° 44′ 34″ W) and is a 155-acre seepage lake. As part of the Whitewater Creek Watershed, the lake is shallow with depths from an average of three to fifteen feet. The lake has almost exclusively been known as eutrophic since 1979 (Wisconsin Department of Natural Resources, 2017c) and is often murky and weed-covered in the summer months (WDNR, 2017a). Lake Lorraine contains many bogs and lily pads that support a variety of wildlife, including: muskrats, herons, and other waterfowl. According to the US Census of 2010, the human population around the lake is relatively low with about 324 residents, and the land surrounding the lake is primarily agriculture making up 64.65% of the total area. The remaining 35% of the land is made up of forests, wetlands and suburban areas, (WDNR, 2011). Lake Lorraine has also become home to a couple prominent invasive species including the Curly-Leaf Pondweed (*Potamogeton crispus*) and Eurasian Water-Milfoil (*Myriophyllum spicatum*) (WDNR, 2011).

Lake Lorraine also has a history of holding excess nutrients due to agricultural and other anthropogenic activities. The lake was assessed during the listing cycle of 2018 and chlorophyll data exceeded the 2016 WisCALM thresholds for recreational use (WDNR, 2017a). This is recent proof of the excess nutrient load within the lake, as excessive chlorophyll is evidence of nutrient overload contributing to excess plant growth. According to the Walworth County Land Use & Resource Management Deputy Director, Shannon Haydin, the current budget for lake maintenance is about $20,000 a year while the main goal is to remove weeds and invasives from the lake. From 2015 to 2017, the town of Richmond has tried the chemicals 2,4-Dichlorophenoxyacetic acid, Aquathol Super K and Rodeo Glyphosate in attempts to clear some of the elodea, eurasian water milfoil, and white water lily from the lake. While the weed removal dampens some of the overgrowth, many of the aquatic plants will still need to be maintained in the lake on a yearly basis.

The purpose of this project is to determine the status and nutrient load of Lake Lorraine, and to determine what, if anything, should be done to improve the state of the lake and make recommendations. We will look at three areas in order to determine the status of the lake. Those areas include the legacy phosphorus levels in the lake, the potential sources of excess nutrients that run off into the lake, and how much erosion will occur if vegetation is removed from the lake shore. The first question is whether or not legacy phosphorus is within the lake sediment, and what may be the source of it. The second question is to see where are nutrients getting into the lake and what is the source of the nutrients, septic system groundwater contamination or surface water runoff. The final question to observe how much erosion would occur if lake shore vegetation is removed and what the effects could be.

Based on the amount of weed cover and turbidity of Lake Lorraine, we predict that the lake is afflicted with legacy phosphorus. This nutrient can cause problems with internal phosphorus loading in the lake. It has been found that shallow lakes, like Lake Lorraine, are much more difficult to manage and reduce the trophic state (Welch & Cooke, 1995;Søndergaard et al, 2001;Stauffer, 1985). A primary link to the difficulty in managing shallow eutrophic lakes is the phosphorus within the sediments (Welch & Cooke, 1995). The longevity of internal loading for overall lake phosphorus-concentrations relate mainly to the flushing rate, loading history, and chemical characteristics of the sediment, for example, its phosphorus binding tendencies (Søndergaard et al, 2001;Stauffer, 1985). Another aspect to consider is the amount of external phosphorus that enters the lake. If external sources of phosphorus still exist, lowering the internal phosphorus levels will be difficult. We will determine the nutrient content by taking soil cores from the lake and using the loss-on-ignition and PXRF tests to determine their composition.

Evidence of both agricultural runoff and faulty septic systems are potential suspects for nutrients entering the lake. Anthropogenic land use around lakes is known to cause changes in the aquatic communities. Both floral and fauna communities are shown to respond negatively to increased land development bordering lakes; especially shallow seepage lakes. The relative role of environmental, spatial, and land use patterns is a significant driver to explaining aquatic macrophyte community composition and in the variation of plant communities.  Specifically, increased agricultural development leads to decreased clarity and increased plant development (Mikulyuk, Sharma, Van Egeren, Erdmann, Nault, & Hauxwell, 2011). Floating-leaf species, such as lily pads, are positively correlated with increased agricultural disturbance. The increased density of lily pads on the east and west side of Lake Lorraine is most likely caused by an agricultural influence. Another study on a shallow, seepage lake in Northern Wisconsin found anthropogenic influence plays a significant role in this type of lake’s health. Anthropogenic land use changes have a much larger impact on a lake’s trophic status than the natural water level fluctuations and other natural lake changes or processes (Garrison, LaLiberte, & Ewart, 2010). Major alterations by people along the lakeshore are a main cause for phosphorus, nutrients, and sediment increase in shallow, seepage lakes. Building homes with septic systems that could potentially be leaking due to their type and age is probably a major factor in the lakes excess nutrients. To show the impact of septic systems, they will be mapped using ArcMap and various

GIS modelling techniques. The map will show areas of risk where septic systems may leak into groundwater and into the lake.

Finally, in terms of erosion around the lake; if more weeds and cattails were to be removed from the shoreline we predict an increase in shoreline erosion. It has been shown that the direct removal of vegetation and mechanical damage to the shoreline increases the amount of erosion (Ostendorp et al, 1995). Mechanical damage can include anything from wind or boat-caused waves, to floating bogs and driftwood. Taking into consideration that this lake already has a mucky bottom and loose shoreline; removing more vegetation and increasing boating access could only lead to more erosion of the shoreline. Additionally, researchers have found that lakeshore reed management, through harvesting and/or burning, has an overall negative effect on the number of invertebrates, bird species (both passerine and local), butterflies, bees, and spiders (Valkamaa, Lyytinena, & Korichevab, 2008). The data collected from Lake Lorraine will be used to observe similar shoreline damages. A RUSLE model will show potential erosion around the lake through the creation of a risk analysis using ArcMap, while also show where agricultural runoff is loading nutrients into the lake.

By studying Lake Lorraine, we can determine how natural and anthropogenic influences can affect the lake, and similar lakes throughout the world. The data obtained in this study can be used to help with future lake studies, and will help create possible solutions to solve nutrient loading problems in lakes worldwide. The data can help assist with future planning in protecting Lake Lorraine through observing which factors create the largest impacts within the lake.

## Materials & Methods

### Field Site:

Lake Lorraine located in Walworth County, Wisconsin, (42° 43′ 56″ N, 88° 44′ 34″ W) is a 155-acre shallow seepage lake with water depths ranging from an average of three to fifteen feet (Fig. 1).. The land around Lake Lorraine used to be marshland. Today, around 65% is agriculture and the remaining 35% is forests, wetlands and suburban areas (WDNR, 2011). Lake Lorraine has many bogs and natural vegetation along the lakeshore, which supports lots of wildlife.. The center of the lake is covered with natural and invasive weeds throughout parts of the year.

## Data Collection:

<u>Soil Core Collection</u>

In order to obtain legacy phosphorous samples, soil cores needed to be collected from the lake sediment at its bed. These cores were collected from two locations with varying depths and vegetative cover. These two sites were selected to achieve the greatest variance between the locations. Soil sampling was carried out using a boat on a calm day. The cores were collected using the 1-inch diameter metal pipe with length extensions for deeper areas of water. The 1-inch pipe was pushed carefully into the lake bed and then the pipe was driven down as far as possible with a hammer to reach the greatest depth and obtain as much of the soil profile as possible. The pipe was then pulled from the sediment and carefully sealed with a cloth and rubber band at the bottom end before exiting the water in order to inhibit contamination. This process was completed at both locations. Core one was obtained from the shallow, weedy bay on the west side of the lake, and core two was from the clear and deepest part of the lake where water depth was 15 feet (Fig. 1).

Once samples were taken from the lake, the cores then were extracted from the pipe. The samples were obtained by using a cloth and a metal rod to push the soil out of the pipe. The cloth was placed at one end and was used in conjunction with the metal rod to carefully push the soil core out onto aluminum foil. The soil cores were then taken to a cool, dry place to dry in order to complete analysis.


**Figure 1.** *This image illustrates the places where core samples were taken within Lake Lorraine in order to conduct the experiment.*

Septic Data Collection

To obtain the septic data, the Walworth County's online OneView Mapping Application (Walworth County Government, 2017) was used. The map was zoomed in to the Lake Lorraine watershed so the individual parcels could be viewed. Within each parcel there was a link titled "EnerGov Link" where septic data could be found if it was available. For each parcel the data recorded included the Tax Parcel ID, the septic type, the year the septic system was installed, and the rating dictating the status of the septic system. The rating for each septic system was determined using information given by Shannon Haydin, the Walworth County Land Use & Resource Management Deputy Director. Non-pressurized systems were low risk, holding tanks were moderate risk, and mound systems were high risk. In addition, any system that was older than 1990 was considered a "high risk" since the lifetime of a septic system is approximately 25 to 30 years. Systems of "low risk" were given a value of 1, systems of "moderate risk" were given a value of 2, and system deemed to be "high risk" were given a value of 3. These data were collected for over 500 parcels and then joined to a tax parcel layer (provided by Shannon) in ArcMap. To ensure the formatting matched for the join the attribute table for the parcel layer in ArcMap was exported. Then the recorded Tax Parcel IDs were compared to the TAXKEY column from the exported table to verify that they matched. If discrepancies were found we looked into the available information for that parcel and manually changed the Tax Parcel ID to match arc. Once it was verified that they matched the excel table was joined to the tax parcel layer.

## Soil Core Testing:

Soil Core Profiles

After air drying the soil cores, soil profiles were completed. Each core was divided into 5 centimeter samples using a knife. The soil color was determined using a Munsell color booklet (Munsell Color Notation & Color Test: Dimensions of Color, 2011). Soil samples with organic material that was visible to the eye were noted. Afterwards, each sample was ground up using a mortar and pestle and passed through a 2 mm sieve to filter out the larger chunks from the samples.

Portable X-Ray Fluorescence Testing

The Portable X-Ray Fluorescence (PXRF) test was used to determine the major compounds in our soil cores. A Trace Element Analysis using the Bruker S1 Turbo SDR Portable XRF Spectrometer GeoQuant program was used to analyze the soil for all major elements. A small amount of each sample was placed into an analysis cup and placed onto the device. Each sample was run three separate times, for two minutes each, and then averaged to reduce potential error. Every sample was mixed and reassorted before and after each run to ensure the full sample was analyzed. After each sample had been run three times, the soil was placed back into our separate soil core samples to ensure as complete accuracy as possible for Loss-on-Ignition test. The results were viewed in parts per million (PPM).

Loss-on-Ignition Testing

The second test performed on the soil samples was the Loss-on-Ignition test or LOI. LOI measures the percentage of organic material in a soil sample by burning off the organic material. For this test, a crucible was weighed on a scale that was accurate to three decimal places. The samples were added and the crucible was weighed again to measure the weight of the soil. The samples should have weighed 10 grams each. However, some samples did not have enough soil to weight 10 grams, but were made as close as possible to the target weight. The samples were placed in a drying oven at 100 degrees Celsius to dry for 24 hours. The next day, the samples were placed in a dessicator to cool for at least two hours. A dessicator was used so water could not get into the samples and to cool the crucibles faster. After cooling, each sample was weighed. Afterwards, the soil samples were placed in a muffle oven and were heated at 360 degrees Celsius for two hours. After heating, the samples were placed in the dessicator to cool for an hour. After cooling for an hour, each sample was weighed on a scale again. The LOI equation ((Initial Weight-Final Weight)/(Initial Weight)×100) was then used to determine the percentage weight of the sample that was lost when it was heated at 360 degrees Celsius.

## Risk of Soil Erosion:

Risk Analysis (RUSLE2 and WEPP)

Most of the aforementioned data collected was used to create a risk analysis for areas that contributed most to excess nutrient loading. A risk analysis was derived within ArcMap by using various data sources: parcel zoned septic data from Walworth County (Walworth County Government, 2017), soil layers from the Web Soil Survey (SSURGO), topography from the United States Geological Survey (USGS), depth to water table from the WI DNR and USGS, net recharge from the National Weather Service (NWS), Midwest Regional Climate Center and USGS, aquifer media from the WI DNR, soil media from the Web Soil Survey (SSURGO), impact of vadose zone from the WI DNR, and hydraulic activity from the Web Soil Survey (SSURGO), and land use from the Southeastern Wisconsin Regional Planning Commission. Each one of these layers was processed to prepare for a raster calculation, the results of which provided a value of risk potential for pollution and erosion.

The RUSLE2 model was created to replace the old, outdated USLE model, or universal soil loss equation. The RUSLE2 model allows users a more comprehensive view of rill and interrill erosion. RUSLE2 utilizes 4 layers: soil, topography, climate, and land use. The WEPP model was also created to replace the USLE model. WEPP, or water erosion prediction project, is a physically based erosion model used to simulate real world erosion mechanics (Laflen et al., 1991). The model, similar to RUSLE2, utilizes 4 layers for input. These layers are climate, topography, soil, and vegetation management. These layers, once put into the model, will give us a secondary source of data to back up our RUSLE2 data. For this analysis, a modified version of WEPP and RUSLE2 were used by running a raster calculator in ArcMap with the needed layers.

Risk Analysis (Modified DRASTIC Model)

As part of Applied Environmental and Natural Resource GIS, during the Spring 2017 semester, a risk analysis was done for the whole of Walworth county (Appendix 1). In this report the DRASTIC model was used to find areas of the county where the water table may be at risk for nitrogen pollution. Within this model it was found that the water table around Lake Lorraine was at risk for pollution. For this report we continued where that project left off and ran the DRASTIC model for just the watershed of Lake Lorraine. For methods on how each layer was obtained for the model, refer to the full report in the appendix. From the final layers obtained last semester, they were clipped to the watershed area and the model was run.

# Results

## Septic Data:

A map was created to visually represent the data and perform analysis. Any septic system deemed a "low risk" and any tax parcel without a septic system was assigned the color green. "Moderate risk" parcels, containing holding tanks, were assigned yellow. "High risk" parcels with mound systems and old septic systems were assigned red. Most of the parcels with poor status were located in the neighborhoods to the north and south of the lake (Fig. 2). To the east of the lake, the parcels were mainly agricultural and did not include a septic system. Overall, 81% of the parcels within the watershed have low risk septic systems, 5% have septic systems with a moderate risk, and 25% of the parcels have septic systems at high risk of leaking into the water table.

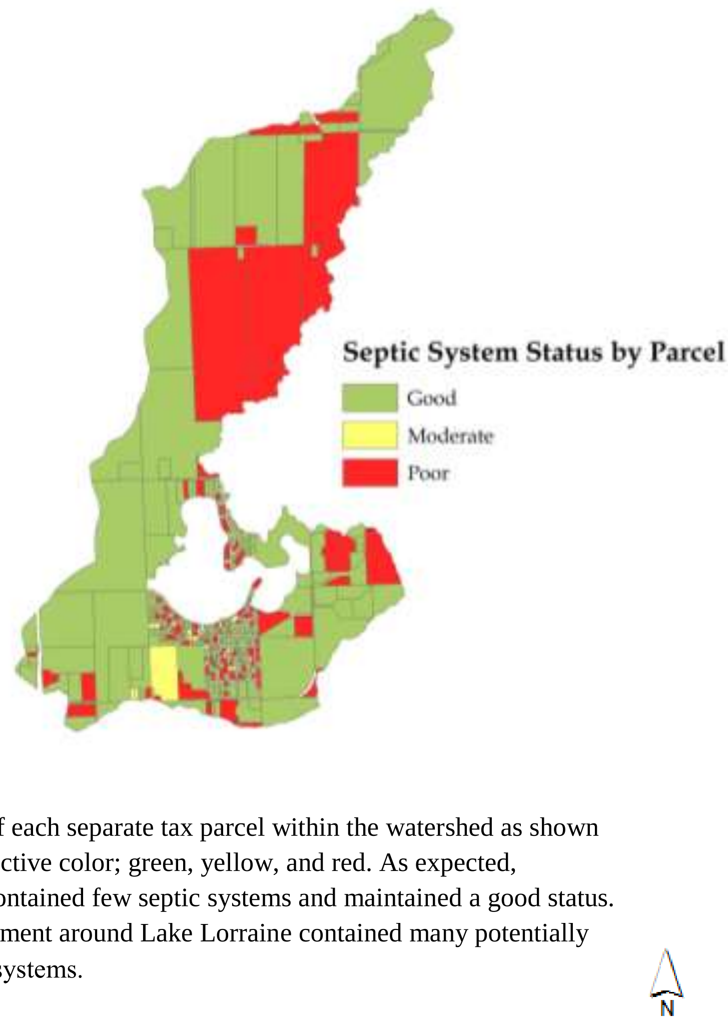



**Fig. 2:** The state of each separate tax parcel within the watershed as shown through their respective color; green, yellow, and red. As expected, agricultural land contained few septic systems and maintained a good status. The urban development around Lake Lorraine contained many potentially "high risk" septic systems.

## Excess Nutrient Risk:

By combining the septic data with a modified DRASTIC model, areas of risk were determined. Areas of risk are where there may be excess nutrient load within the watershed. Areas of red/dark orange are of higher risk for nutrient loading, yellow to orange are of moderate risk, and areas of green are of low risk for excess nutrients getting into the groundwater (Fig. 3). In the northern portion of the watershed, areas of agriculture are at higher risk for excess nutrients. In residential areas, there is a low to moderate risk of excess nutrients entering the groundwater. Within the watershed 18% of the area is at low risk, 64% is at a moderate risk, and 18% of the area is at high risk for nutrients getting into the water table.

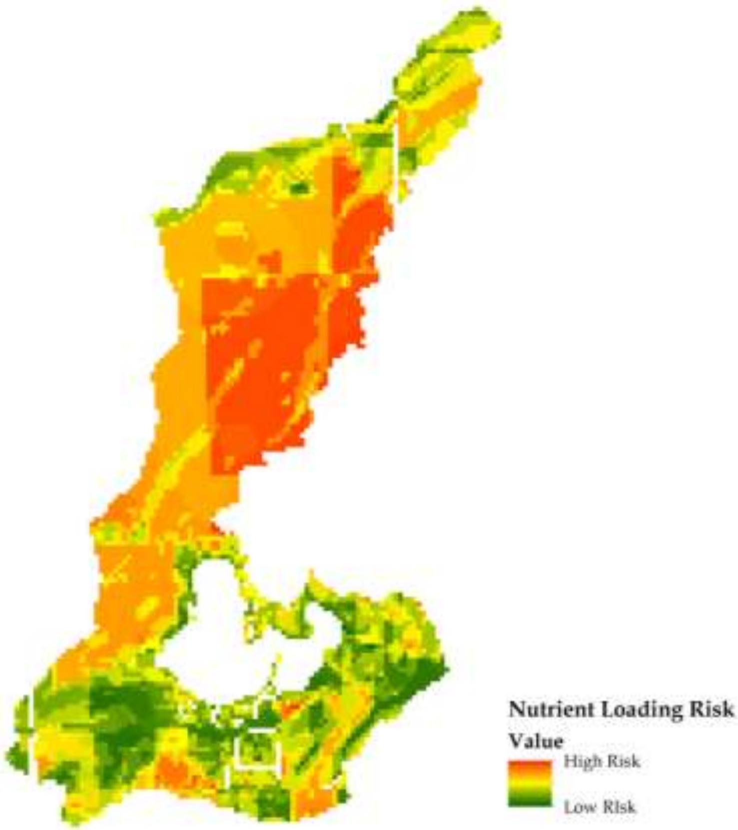



**Fig. 3:** Map of the Lake Lorraine watershed showing the range of risk for excess nutrient loading in the water table. Red shades are higher risk and areas of green are of lower risk.

## Soil Cores:

<u>Soil Core Profiles</u>

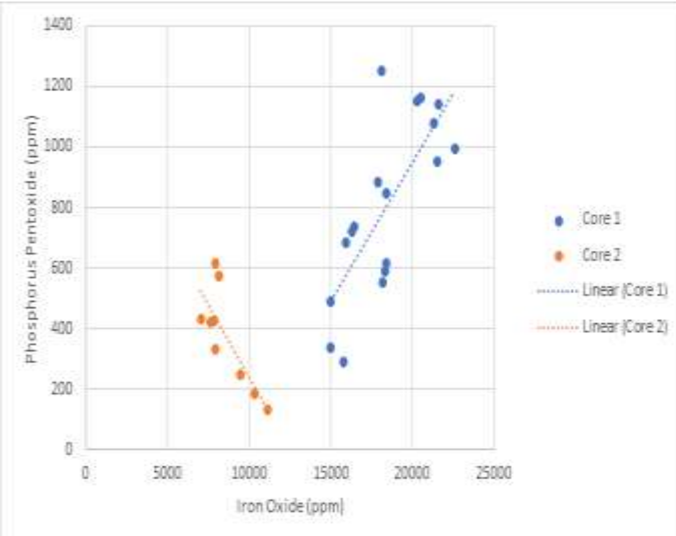
The lakebed of Lake Lorraine contains different types of soils with almost all of the sample data containing some amount of visible organic matter with the exception of soil core 1, 25-30 cm (Table 1). Soil core 1's soil color also changed the deeper the depth in the core while soil core 2 was consistent throughout. The hue of all the samples was yellow red (10YR and 5YR) but the hue was slightly different for soil core 1 due to the value of 10 versus the value of 5 for soil core 2. Soil core 1 0-5 cm and 5-10 also differed from the rest of the soil core 1 samples. Soil core 1 0-5 cm had a value of 3 for the value (how light and dark the color is) attribute while the rest of the samples for soil core 1 had a value of 4. This indicated soil core 1 0-5 cm was darker in value. Soil core 1 5-10 cm had a chroma (strength of color) of 1 while the the other soil core 1 samples had a chroma of 2. This indicated soil core 1 5-10 had a weaker color than the other samples of soil core 1.

**Table 1**. The classes of soil in the soil cores. Soil Core 1 samples were in the 10YR class of soils but the 0-5 cm sample and the 5-10 cm sample were 3/2 and 4/1 respectively. Soil Core 2 samples were all 5 YR 2.5/1. All samples with the exception of the Soil Core 1, 25-30 sample contained organic matter.

| | | | |
|---|---|---|---|
| Soil Core 1 | | | |
| | Sample (cm) | Soil Type | Organic Matter |
| | 0-5 | 10YR 3/2 | Yes |
| | 5-10 | 10YR 4/1 | Yes |
| | 10-15 | 10YR 4/2 | Yes |
| | 15-20 | 10YR 4/2 | Yes |
| | 20-25 | 10YR 4/2 | Yes |
| | 25-30 | 10YR 4/2 | No |
| Soil Core 2 | | | |
| | 0-5 | 5YR 2.5/1 | Yes |
| | 5-10 | 5YR 2.5/1 | Yes |
| | 10-15 | 5YR 2.5/1 | Yes |

Portable X-Ray Fluorescence Tests

The Portable X-Ray Fluorescence (PXRF) test determined the major compounds in our soil cores to be iron oxide, phosphorus pentoxide, and calcium oxide. The average amount of phosphorus pentoxide is high in the first five centimeters of the lakebed and generally decreases until depths of 20 and 25 centimeters (Fig. 6). Fig. 6 also shows that there is a higher amount of phosphorus pentoxide in Soil Core 1 compared to Soil Core 2 in the directly comparable depths. Iron oxide and phosphorus pentoxide have a significant positive correlation in Soil Core 1 ($r=0.7535$, $n= 18$, $p=0.0005$) and a significant negative correlation in Soil Core 2 ($r=-0.7927$, $n=9$, $p=0.0189$) (Fig. 4). Calcium oxide and phosphorus pentoxide have a statistically significant negative correlation in both core samples (Core 1: r=0.-8126, $n=18$, $p=0.0007$, Core 2: $r=-0.8870$, $n=9$, $p=0.0033$) (Fig. 5).



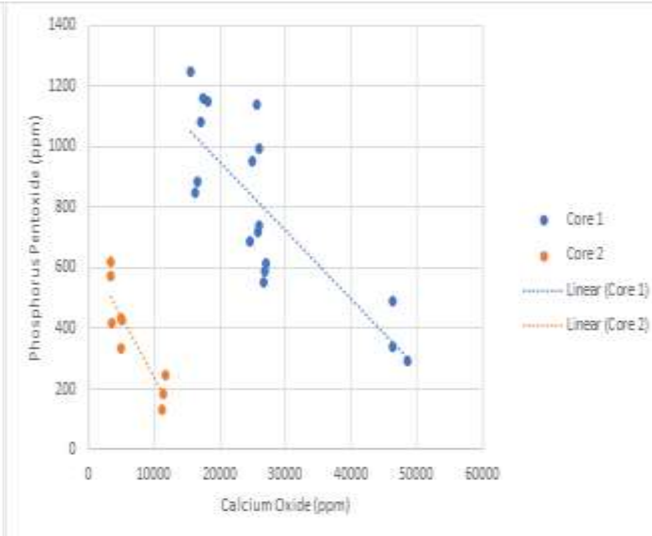
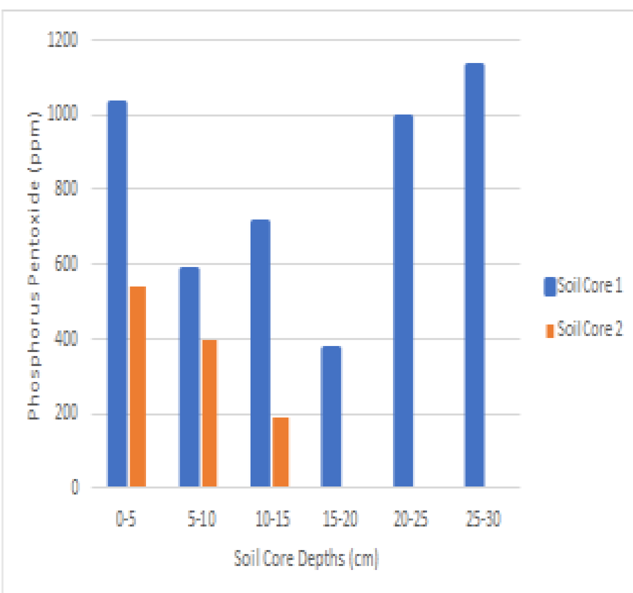




**Fig. 4**: The relationship between iron oxide and phosphorus pentoxide for Soil Core 1 (n=18) and Soil Core 2 (n=9). There was a significant positive correlation between iron oxide and phosphorus pentoxide for Soil Core 1 (r=0.7535, p=0.0005) and a significant negative correlation between iron

**Fig. 5**: The relationship between calcium oxide and phosphorus pentoxide for Soil Core 1 (n=18) and Soil Core 2 (n=9). There was a significant negative correlation between calcium oxide and phosphorus pentoxide for Soil Core 1 (r=-0.8126, p=0.00007) and a significant negative correlation between calcium oxide and phosphorus pentoxide for Soil Core 2 (r=-0.8870, p=0.0033)



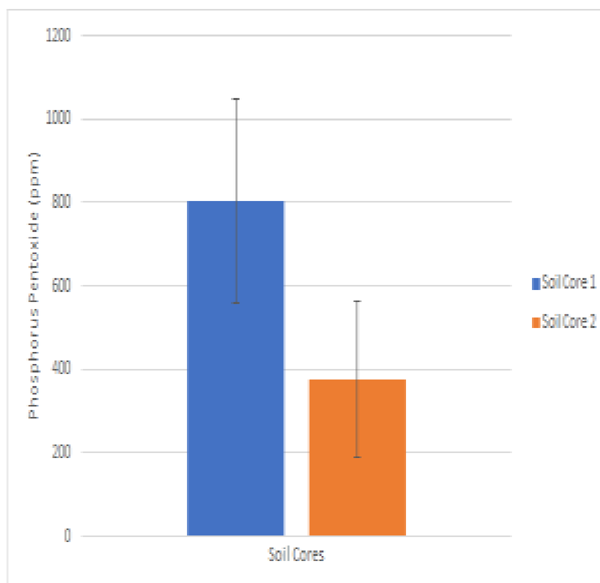




**Fig. 6**: A comparison of phosphorus pentoxide amounts at different depths in the soil cores. Soil core 1 contained more phosphorus pentoxide than soil core 2 for each comparable depth.

he
pho
sph

T

**Fig. 7:**The average of phosphorus pentoxide for soil core 1 and 2. Soil core 1 had a higher average. The difference was statistically significant (n=27, p=0.0004).

orus pentoxide amount is greater in soil core than soil core 2 (Fig. 6). Soil core 2 averages decrease through each 5 centimeters of depth. Soil core 1 has a high amount (1029 ppm) at 0-5 cm and then has lower amounts for the 5-10, 10-15, and 15-20 centimeter depths. At 20-25 cm and 20-25 cm depths the amount goes back up. Soil core 1 has averages of 1029±256 ppm, 585±231 ppm, 715±229 ppm, 375±241 ppm, 994±251 ppm, and 1130±261 ppm for 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-25cm, and 25-30cm respectively. Soil core 2 has averages of 538±185 ppm, 398±180 ppm, 189±261 ppm for 0-5 cm, 5-10 cm, and 10-15 cm respectively. Soil core 1 had a higher average amount of phosphorus pentoxide at 805±245 ppm while soil core 2 had an average of 375±187 ppm (Fig. 7). There was a significant difference in the average (T-test, n=27, p=0.0004).

Loss-on-Ignition Tests

The organic content of Soil core 2 increases with depth (Fig. 8). Soil core 1 organic matter was fairly consistent for the first 20 centimeters of depth but then saw a drop of about 20% for the last 10 centimeters of depth. Soil core 1 had more organic content in the 0-5 range compared to Soil core 2 but Soil core 2 had more organic content in the 5-10 and 10-15 ranges. Soil core 1 had an average of 39.27±4.56, and soil core had an average of 52.46±10.88 (Fig. 9). There was no significant difference in organic matter percentage in soil core 1 and soil core 2 (T-test, n=9, p=0.215).

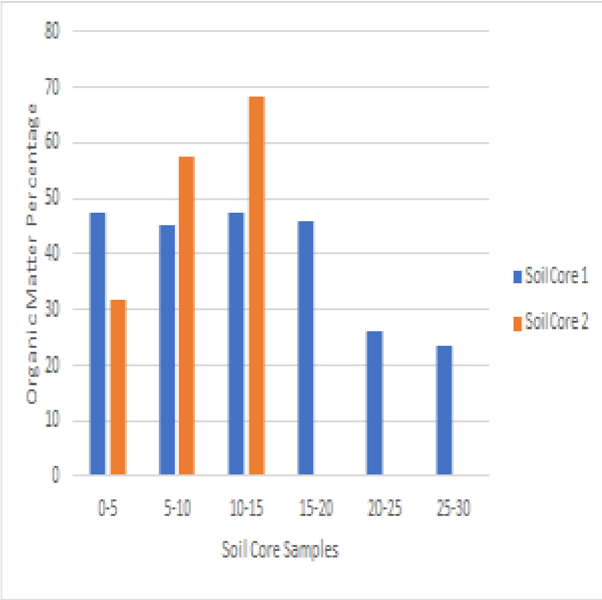



**Fig. 8:** The loss-on-ignition tests provided the percent of organic matter lost after heating at 360 degrees Celsius for 2 hours. Core sample 1, from the deepest part of the lake, has about the same percent OM for the shallowest 20 centimeters, and a decrease in OM in the deepest 10 centimeters. For core 2, from the shallow west end of the lake, shows an immediate low percent of OM, and an increase as depth of the sample increases.

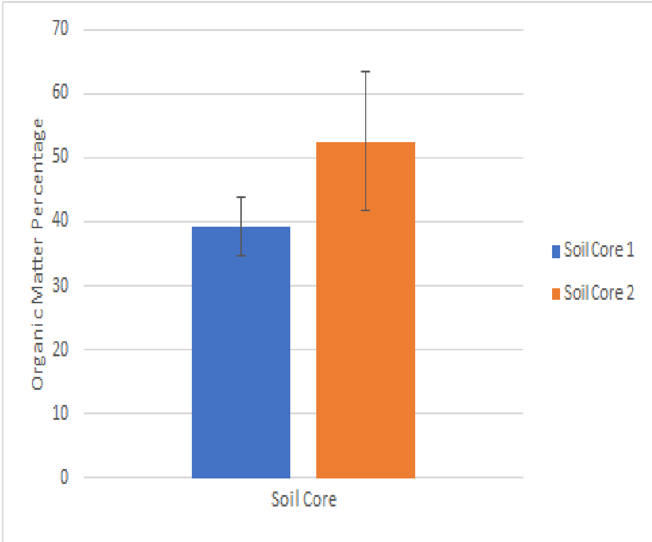
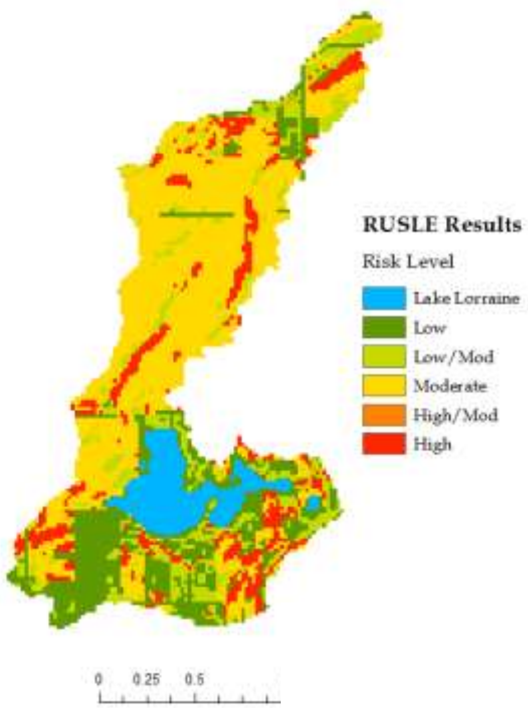



**Fig. 9**: The average organic matter percentage for Soil Core 1 and 2. Soil core 1 had a lower average than soil core 2.

## Erosion Analysis:

For erosion analysis a modified RUSLE2 equation was created by our team. Figure 10 represents the visual model created using said model. The areas to the north (top portion of the map), with “high” to “moderate risk”, are agricultural areas. The areas of “high risk” also line up with our topography DEM in Figure 1. Figure 11 represents a shaded relief map of the Lake Lorraine watershed. Areas of green/blue represent areas of low topography whereas areas of red/grey represent areas of high topography. Note the elongated green portion to the north of the lake. This area represents the water flow into the lake from the northern portion (top of the map) of the watershed. These areas are also indicated of “high” to “moderate risk” in our erosion model. (Fig. 10).




'ig. 10: Erosion analysis created using our model ı ArcGIS. Areas of “high risk” are indicated by ɛd, “moderate risk” by orange and yellow, and low risk” by green.

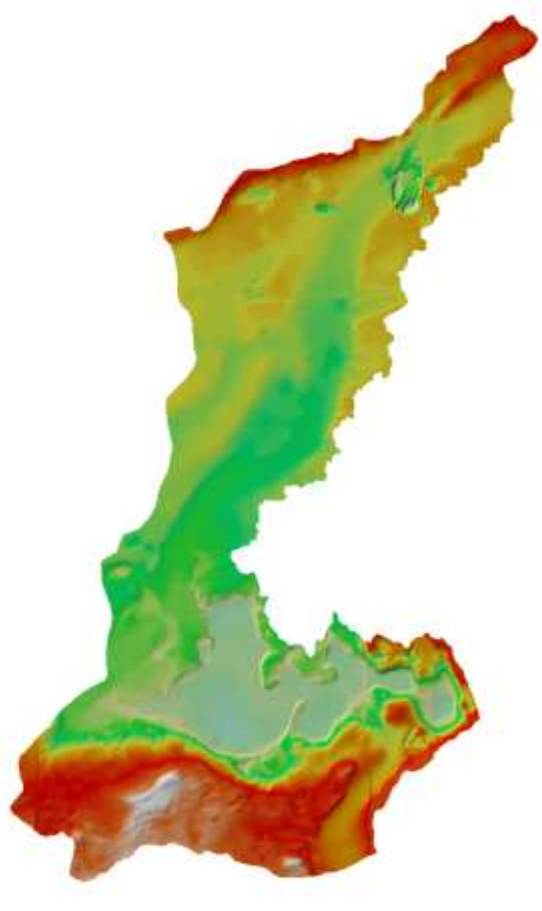


**Fig. 11:** This rel ... ɔ the Lake Lorraine watersh ... nd our erosion analysis. ... hout the watershed.

## Discussion

Key Findings:

We found that Lake Lorraine has been a eutrophic lake for at least half a century, and is continually at risk of being over-nourished with nutrients due to the surrounding land use and geographic structure, which also contributes to erosional susceptibility (WDNR, 2017b).

Legacy Phosphorus:

Our hypothesis that Lake Lorraine is afflicted by legacy phosphorus is supported by our findings from the PXRF testing and the Loss-on-Ignition testing. It is also supported by our findings from the RUSLE model. The soil color indicates the composition and conditions under which it was formed. The Munsell color system indicates the hue (color), value (lightness of a soil), and chroma (strength of color). As the value decreases, darkness increases, and as chroma decreases, the weakness of color decreases (Munsell, 2011). The samples were all of the YR or yellow-red variety. Yellow-red soil colors indicate the presence of iron, as iron leaves small yellow or red crystals (USDA, n.d.) and the PXRF results also indicated a large amount of iron oxide in each sample. Organic matter also affects the color as it decomposes to humus, which is black in color. Soil core 1 (0-5 cm) had a value of 3, which means the soil was darker in color compared to the rest of the samples from soil core 1 and the Loss-on-Ignition test results showed soil core 1 (0-5 cm) had the most organic matter percentage of all the samples for soil core 1. All soil core 2 samples had a value of 2.5 meaning they were even darker than soil core 1. All samples contained some visible organic matter with the exception of soil core 1 (25-30 cm). Soil core 1 (25-30 cm) was the deepest sample which also means it is the oldest in age. The fact that it did not contain any visible organic matter was consistent with the Loss-on-Ignition results as that sample contained only 23.7% organic matter, which was the smallest organic matter percentage.

The PXRF tests showed evidence that soil core 1 is located in a phosphorus sink in the lake. Soil core 1 had higher phosphorus pentoxide amounts and a smaller organic matter percentage than soil core 2. This indicates less plant growth in that area to take up and process the phosphorus in the sediment. Therefore, phosphorus can accumulate in this area. On the contrary, soil core 2 had a higher organic matter percentage and smaller phosphorus pentoxide amount. More phosphorus is being taken up for photosynthetic organism growth in that area. The eutrophic Poyang Lake in China had an average value of 709 ppm of phosphorus in the lake sediments (Wang, 2015). Dongting Lake, also in China, was found to have 703 ppm of phosphorus (Wang, 2016). Lake Lorraine had an average of 805 ppm of phosphorus. This means that Lake Lorraine is slightly more eutrophic than both of these lakes. Furthermore, the phosphorus in Lake Lorraine generally decreased for the first 20 centimeters of soil core 1 and decreased through the entirety of soil core 2. However, phosphorus increased in the last 10 centimeters of soil core 1. The Dongting Lake study found that phosphorus decreased with depth in that lake which suggested an enrichment of phosphorus at the surface (Wang, 2016). Soil core 2 may have had the decrease with depth due to the reuptake of phosphorus by photosynthetic organisms. Soil core 2 was taken from a shallow part of the lake, meaning there is more sunlight for photosynthesis and so plant growth is stimulated. A similar process may be at work for the first 20 centimeters of soil core 1, but because of the lack of sunlight to that part of the lake due to its' depth not as much phosphorus taken up by photosynthetic organisms so the phosphorus levels are higher. The increase in the last 10 centimeters of soil core 1 is potential evidence of high levels of legacy phosphorus in Lake Lorraine.

Soil core 1 and 2 had differing correlations of phosphorus pentoxide and iron oxide. Soil core 1 had a significant positive correlation and soil core 2 had a significant negative correlation. Both soil core 1 and 2 had significant negative correlations between phosphorus pentoxide and calcium oxide. Both iron and calcium can bind to and release phosphorus meaning they can have a large influence on phosphorus-water interactions (Søndergaard, Jensen, & Jeppesen, 2003). This means that iron and calcium can help determine how much phosphorus is available for uptake by photosynthetic organisms. The negative correlations for calcium oxide and phosphorus pentoxide mean that phosphorus pentoxide decreases as calcium oxide increases. This could potentially mean that the calcium is binding to the phosphorus in both cores. The same is true for the iron oxide and phosphorus pentoxide found within soil core 2. For soil core 1, iron oxide and phosphorus pentoxide increased together. There is a connection between iron-bound phosphorus and phosphorus releases as iron-bound phosphorus is considered very mobile and can be released from the sediment and added to the water column (Søndergaard, Jensen, & Jeppesen, 2003). Iron and calcium bound phosphorus are typically found in greater amounts lower in the soil column and organic phosphorus was found in greater amounts at the surface (Bojakowska, 2016).

The Loss-on-Ignition tests provided evidence of high phosphorus cycling throughout Lake Lorraine sediments. The content of organic matter in a soil sample is important because it is a representation of how much phosphorus and other nutrients can be stored in and cycled through the sediment. With higher amounts or organic material, higher amounts of nutrients can be stored, and vice versa. The living organic matter rooted in these soils can then use the phosphorus and other nutrients for growth and development (Pagliari et al., 2017). As the organic material ages, the plant materials break down releasing these organic compounds, continuing the phosphorus cycle. Core 1, taken from the deepest part of the lake, has shown us that the shallowest 66% of the lake bed had an average of 46.45% organic matter, and the deepest third had a lower average percentage of OM at 24.91. Seeing that this sample was taken from the deepest point on the lake, logically, it has the lowest amount of direct sunlight reaching it. Knowing plants use photosynthesis to develop, less light would imply less productive plant growth. This being said, the deepest part of a lake should show the lowest amount of plant development. According to Mosaic Crop Nutrition, phosphorus is noted especially for its role in capturing and converting sunlight into useful plant compounds. With less sunlight, the rooted organisms in the soil need to draw more phosphorus from the soil to mitigate a decrease in available sunlight. With an increased amount of organic material in the shallow parts of sediment, the plants on the lake bed are able to draw the phosphorus they need from sediments and be over productive, compared to what they may have been with decreased amounts of phosphorus in combination with the low amount of sunlight. In shallow parts of the lake, areas getting more direct sunlight, less organic materials in the soils would be needed for productivity.

In Core 2, from one of the shallowest parts of the lake, the shallowest third of the sample showed 31.78% organic material, and the deeper 66% of the sample had an average of 62.9% organic material. Seeing that this sample comes from an area of high plant production and shallower depth, more sunlight is able to reach the organisms. As more sunlight is available, less nutrients would need to be used from shallower parts of the soil showing a lower amount of organic material, and the phosphorus could then be stored in deeper parts of the lake bed in higher amounts of organic material. Seeing that there is a smaller amount of organic material in the shallow section, and a larger amount in deeper sections, we can see that the living rooted plants on the lake bed have all the phosphorus they need to overproduce, and there is still a source of phosphorus beneath that not being reused; a possible source of legacy phosphorus.

In both cases, the content of organic material of the soil samples shows us that the lake bed is a storage source for high amounts of phosphorus and other excess nutrients. The overall water quality in the different sample areas of the lake was lessened as both held increased plant production and phosphorus cycling. This means the current phosphorus levels in the lake bed soils are continually increasing. With excess amounts of nutrients in the soils, plants are able to develop more rapidly and efficiently, leading to the increased amount of organic material, which when it dies off, leads to an increase in the amount of nutrients being released into the waters again and the cycle continues.

The results of our soil profiles may have been skewed as soil core 1 was given more time to dry than soil core 2 and the presence of water can cause a soil to look darker. One of the limitations with the PXRF and loss-on-ignition testing is that there were limited samples. We only had nine samples that we tested in three runs for each sample for the PXRF test. Having such a limited number of samples could have led to more error while more samples could have granted more confidence in our results. For the loss-on-ignition testing we were only able to test the nine samples themselves without any additional runs as the samples were destroyed by the testing. Another limitation was that we used 5 centimeter samples. Smaller samples, such as 2 centimeter samples, could have given us more accurate results.

Septic Systems and Modified DRASTIC Model:

Based on evidence from the maps, Lake Lorraine is at risk of receiving excess nutrients from agricultural runoff and faulty septic systems. Due to the soil composition, hydraulic conductivity, slope, land use, and depth to the water table there is a good possibility that nutrients from old septic systems and nitrogen from farming practices are contributing to excess nutrients in the lake, (Walker et al., 2003). An aspect to consider with the modified DRASTIC model is that it is not showing the direct risk to the lake but rather the risk to the water table. But once the nutrients are in the water table, this water flows underground towards the lake and can enter the water of the lake through the bed of the lake.

Within the watershed, 31% of the total area has septic systems that are at a moderate to high risk of leaking into the water table. Once a septic system leaks there is not much that can be done and it will eventually reach the water table and enter the water system. By combining these datasets with the modified DRASTIC model it was found that 18% of the watershed is at high risk for excess nutrients and 64% of the watershed is at moderate risk for excess nutrients. One of the factors that is attributed to this risk is the hydraulic conductivity of the area. Much of this watershed has a hydraulic conductivity that is conducive to drainage into the water table. This allows nutrients from septic systems to transport more readily. This increases the chance of nutrients from nitrates and septic systems entering the water table even greater. Another aspect of the area that creates the risk of excess nutrients is slope. The slope in this area is very flat which allows any surface water the chance to seep into the ground. With more water moving through the ground there is greater opportunity for more nutrients to be carried down into the water table and thus the whole water system. Land use was added to the model because it holds important implications to what kind of nutrients may be entering the ground. Much of the land within this watershed is used for agricultural purposes, just over 62%. Where there are farms there are fertilizers and with the variety of fertilizers that contain nitrogen, it is possible that this is also another source contributing to excess nutrients in the lake. So, adding this to the model is important to assess the risk posed to the water table.

The septic analysis is subjective and does not fully paint the picture of the situation for the risk analysis, but rather is used to provide a basic understanding of how older or broken systems may contribute to the excess nutrient load within the lake. The three different types of septic systems: mounds, holding tanks, and non-pressurized in-ground systems were described along with their year of implementation. The risk analysis utilizes these but does not take into consideration of whether or not the septic systems have leaked into the environment. The risk is fully subjective as to the knowledge of how the different systems operate and that these systems may leak with age. So, the weight of risk given to these systems may be not fully accurate, but accurate in the basic known signs of risk.

<u>Erosion</u>

The low risk areas outlined in figure 10 contain a low slope and also have a vegetative cover to slow down or stop erosion from taking place. Areas of moderate erosion were largely classified as agricultural areas with low to moderate slope. Agricultural areas are not uncommon in the Wisconsin landscape; however, finding an agricultural area that has a suitable cover crop over winter and, more importantly, spring runoff periods is an increasing challenge. If these areas contained a cover crop such as winter wheat, rye and oats, the classification of these areas would greatly differ and ultimately lower the erosion risk potential. Furthermore, no-till practices would also show a more viable and economic option for farmers rather than footing the extra cost of planting a cover crop. High risk areas were found to be primarily on the southern portion of the lake. These areas contain a mix of agriculture as well as residential. These areas contain high slopes as well as a lack of cover crops in most areas. There are also two prominent high risk strips located in the northern section. These correlate to sediment flow depicted in the shaded relief map draining into the lake. Note these do not show actual areas of erosion. These maps show which areas have been classified as high risk. Site visits and fieldwork are a better way to confirm these calculations and should be conducted in future studies to provide an accurate correlation coefficient between theoretical and actual values. The erosion risks potentially relate to the phosphorus levels in soil core 1 in that there is a high risk erosion area flowing from the north to the western end of the lake as shown by the results of the modified RUSLE and the relief map. This area of the lake is where we obtained soil core 1. This provides potential evidence for the high levels of phosphorus found in soil core 1.

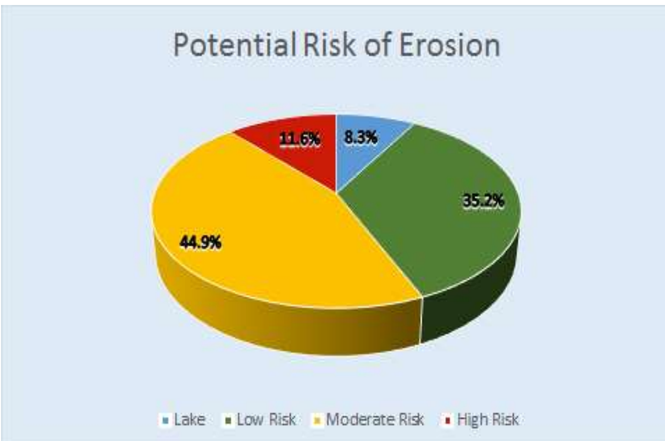



**Fig. 12:** The RUSLE model shows that more than half of the watershed is at a moderate or high risk of erosion, creating an easier path for nutrients to leach into the lake.

There are limitations within the cartographic models used for this analysis. We were limited to the number of parameters used within the mode, so that simplifies the results and reduces accuracy of the results. The model itself also has limitations. Within the model there are assumptions used that cause the parameters to be biased, and subjective. The weights and ratings are established based on our understanding of the area and accumulated knowledge. The size of the watershed also provided limitations due to the study. As the watershed is small, the precipitation, nitrate wells data, soil media, aquifer media, and vadose zone layers were unfit to add into the RUSLE and DRASTIC models because the results would be insignificant through such a small sample. This is not necessarily a problem, but leaves less room for certain interpretations to be made within different areas of the watershed as the results would not change significantly if those factors were added.

Due to the timeframe the study was performed under; not every aspect of the lake was able to be properly analyzed. Some of these aspects include the analysis of how 2,4-Dichlorophenoxyacetic acid, Aquathol Super K, and Rodeo Glyphosate, invasive species, surrounding agricultural use, and how surrounding homes fully impact the lake. It was impossible to analyze all of the factors that have a direct impact with the status of the lake. All of the practices done to analyze the current nutrient load and risk had to be done within a semester, and while there are always external factors that play a role on nutrient loading, they were simply too much to take on in the given timeframe.

Conclusion:

As lakes are aesthetically pleasing and a desired area for people to live, those who live around lakes have a duty to keep them as intact as possible for the greater good of the ecosystem and the global environment. It is with that regard that the results of studies like these should be taken into consideration while coming up with ways to improve lakes for use by humans and the other organisms within the environment. The fact that the surrounding practices around the lake have lead to the excess nutrient growth within it, shows that human activity should perhaps be altered to best take care of Lake Lorraine.

The chemicals 2,4-Dichlorophenoxyacetic acid, Aquathol Super K and Rodeo Glyphosate have been utilized in recent years to cut down the elodea, eurasian water milfoil, and white water lily. However, other options may be considered to best serve the lake's organisms and humans that live around it. These options include reducing the introduction of nutrients into the lake by altering farming practices, updating septic systems, and using weed-cutting devices to lesson herbicides within the lake.

Maintaining the nutrient load is one challenge to keeping the lake at a healthy status; it is the overall structure immediately surrounding the lake, and the lake's vegetation, that provide a buffer to excess nutrients and give the lakeshore its' stability. Cattails and other lakeshore vegetation create an issue in terms of what is best for the lake and how humans may want to shape the lake for their own use. It has been studied that riparian zones are very important to keeping out pollutants, capturing nutrients, and acting as erosion preventing structure (WDNR, 2017b;Valkamaa et.al, 2008). These studies illustrate the importance of these zones and give reasons as to why they should be protected as much as possible on lakeshores. For that reason, when it comes to vegetation removal, it may be best to solely target invasives within the lake and leave the native vegetation to play its role. Additionally, keeping natural vegetation helps maintain a healthy habitat for the fish and other wildlife. Good fishing habitat is needed for maintaining the fishing industry and the ability to maintain recreational use of the lake.

We found that the lake most likely is afflicted by legacy phosphorus due to evidence found from our PXRF and Loss-on-Ignition testing as well as the results of the modified RUSLE. Lake Lorraine is also at risk for excess nutrients with 18% of the watershed having a “high risk” of excess nutrients and 64% of the watershed having a “moderate risk” of excess nutrients. This is due to old septic systems and farming practices in the area. The natural geography of the area compounds this issue. A direction for future study would be to look at the effect of wave action on shoreline erosion. Another direction would to obtain soil cores from more areas of the lake and conduct PXRF and loss-on-ignition tests to see a comparison with our data. Water cores should also be looked at for phosphorus levels in the water column. A fourth direction would be to look at seasonal variations in phosphorus levels. The area of “high risk” erosion flowing from the north end of the watershed to the west end of the lake should also be looked at further detail.

A combination of anthropogenic practices and natural geography of Lake Lorraine have made it what it is today. Septic systems should be updated as they are one of the causes of excess nutrients in the lake. Riparian buffers should also be in place to help mitigate the runoff from surrounding areas and native vegetation such as cattails should left alone to play its natural role while invasives should continue to be removed.  No wake laws should also be enforced to lessen erosion on the lakeshore.

## **Acknowledgements**

We would like to take the time to thank all of the those who helped us throughout the semester in order to produce sufficient and meaningful results. To begin, we would like to thank Dr. Romero for guiding us through the class and providing us with resources and deadlines to produce good results in a timely manner. Next, we would like to thank Shannon Haydin of Walworth County’s Land Use and Resource Management for providing us with many aspects of Walworth County’s online data and answering any questions we had in regards to Lake Lorraine and Walworth County. Furthermore, we would like to thank Don Huntington as he graciously showed us around the lake on his pontoon and allowed us to gain a better understanding of the lake’s status and possible areas to be improved. Finally, we would like to thank both Dr. Jacobs and Dr. Splinter for the guidance of completing soil analysis and running GIS models, respectively. Without the help of all of these kind individuals, we could not have completed the

project as completely as we have, and we are extremely grateful for all of the help we have received.

## **Bibliography**


Bojakowska, I. (2016). Phosphorus in lake sediments of Poland – Results of monitoring research. *Limnological Review, 16*(1), 15-26. https://doi.org/10.2478/limre-2016-0002

Garrison, P. J., LaLiberte, G. D., & Ewart, B. P. (2010). The importance of water level changes and shoreline development in the eutrophication of a shallow, seepage lake. *Proceedings of the Academy of Natural Sciences of Philadelphia*, *160*, 113-126. https://doi:10.1635/053.160.0112

Imanishi, Y., Atsushi, B., Komatani, S., Wada, S. I., & Tsuji, K. (2010). Experimental parameters for XRF analysis of soils. *International Centre for Diffraction Data,* 248-255. Retrieved from http://www.icdd.com/resources/

Laflen, J.M., L.J. Lane, and G.R. Foster. (1991). WEPP—a next generation of erosion prediction technology. *Journal of Soil Water Conservation 46*(1): 34–38.

Mikulyuk, A., Sharma, S., Van Egeren, S., Erdmann, E., Nault, M. E., & Hauxwell, J. (2011). The relative role of environmental, spatial, and land-use patterns in explaining aquatic macrophyte community composition. *Canadian Journal of Fisheries and Aquatic Sciences*, *60,* 1778-1789. https://doi:10.1139/F2011-095

Munsell Color Notation & Color Test: Dimensions of Color. (2011). Retrieved from http://munsell.com/about-munsell-color/how-color-notation-works/

Ostendorp, W., Iseli, C., Krauss, M., Krumscheid-Plankert, P., Moret, J., Rollier, M., & Schanz, F. (1995). Lake shore deterioration, reed management and bank restoration in some Central European lakes. *Ecological Engineering, 5,* 51-75.

Pagliari, P., Kaiser, D.E., Rosen, C.J., & Lamb, J.A. (2017). The nature of phosphorus in soils. Retrieved from https://www.extension.umn.edu/

Purdue University. (2009). *Standard Test Methods for Loss on Ignition (LOI) of Solid Combustion Residues.* Retrieved Oct. 15, 2017 ftp://ftp.ecn.purdue.edu/olek/PTanikela/To%20Prof.%20Olek/ASTM%20standards/LOI%20using%20TGA%20D7348.pdf

Søndergaard, M., Jensen, J.P., & Jeppesen, E. (2001). Retention and internal loading of phosphorus in shallow, eutrophic lakes. *The Scientific World, 1,* 427-442. http://doi:10.1100/tsw.2001.72

Søndergaard, M., Jensen, J. P., & Jeppesen, E. (2003). Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia, 506*(1), 135–145.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at https://websoilsurvey.nrcs.usda.gov/. Accessed [10/15/2017]

Stauffer, R.E. (1985). Relationships between phosphorus loading and trophic state in calcareous lakes of southeast Wisconsin. *Limnology Oceanography, 30(l),* 123-145. https://doi:10.4319/lo.1985.30.1.0123

United States Census Bureau. (2017). *Population Data*. Retrieved from https://www.census.gov/topics/population/data.html

United States Department of Agriculture: Agricultural Research Service. (2016). *Revised Universal Soil Loss Equation 2 - Overview of RUSLE2.* Retrieved from https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/rusle2/revised-universal-soil-loss-equation-2-overview-of-rusle2/

USDA. (n.d.). The Color of Soil | NRCS Soils. Retrieved December 5, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054286

United States Geological Survey. (2017). Topographic Maps. U.S. Department of the Interior. Available online at https://www.usgs.gov/products/maps/topo-maps/. Accessed [10/20/2017]

Valkamaa, E., Lyytinena, S., & Korichevab, J. (2008). The impact of reed management on wildlife: A meta-analytical review of European studies. *Biological Conservation, 141,* 364 – 374. https://doi:10.1016/j.biocon.2007.11.006

Vereş, D. Ș. (2002). A comparative study between loss on ignition and total carbon analysis on minerogenic sediments. *Studia UBB Geologia, 47*(1), 171-182.

Walker, R. L., Cotton C., & Payne, K., (2003). A GIS Inventory of On-Site Septic Systems Adjacent to the Coastal Waters of McIntosh County, Georgia. *The Marine Extension Service,* 1-44

Walworth County Government. (2017). *OneView Mapping Application.* Retrieved from https://gisinfo.co.walworth.wi.us/oneview/

Wang, L., & Liang, T. (2015). Distribution Characteristics of Phosphorus in the Sediments and Overlying Water of Poyang Lake. *PLoS ONE, 10*(5), 1-12. https://doi.org/10.1371/journal.pone.0125859

Wang, L., & Liang, T. (2016). Distribution patterns and dynamics of phosphorus forms in the overlying water and sediment of Dongting Lake. *Journal of Great Lakes Research, 42*(3), 565–570. https://doi.org/10.1016/j.jglr.2016.03.013

Welch, E. B., & Cooke, G. D. (1995). Internal phosphorus loading in shallow lakes: importance and control. Lake and Reservoir Management, 11(3), 273-281.

Wisconsin Department of Natural Resources. (2011). *Lake Lorraine, Whitewater Creek Watershed (LR14).* Retrieved Oct. 30, 2017. http://dnr.wi.gov/water/waterDetail.aspx?key=11774

Wisconsin Department of Natural Resources. (2017a). *Impaired Waters Detail - Lake Lorraine.* Retrieved Oct. 16, 2017 from http://dnr.wi.gov/water/impairedDetail.aspx?key=11774

Wisconsin Department of Natural Resources. (2017b). *Safeguarding our shorelands: Research on shoreland buffers.* Retrieved Dec. 6, 2017 from http://dnr.wi.gov/topic/ShorelandZoning/Research/ShorelandBuffers.html

Wisconsin Department of Natural Resources. (2017c). *Trophic State Index Graph: Lake Lorraine - Deep Hole, Walworth County* Retrieved Oct. 14, 2017 from http://dnr.wi.gov/lakes/clmn/reports/tsigraph.aspx?stationid=653255