Bone Lake Phosphorus Loading: Preliminary Analysis of Suspected Sources

Katie Dennis ‘17, Zach Beckman ‘17
ESCI 430 Capstone Project

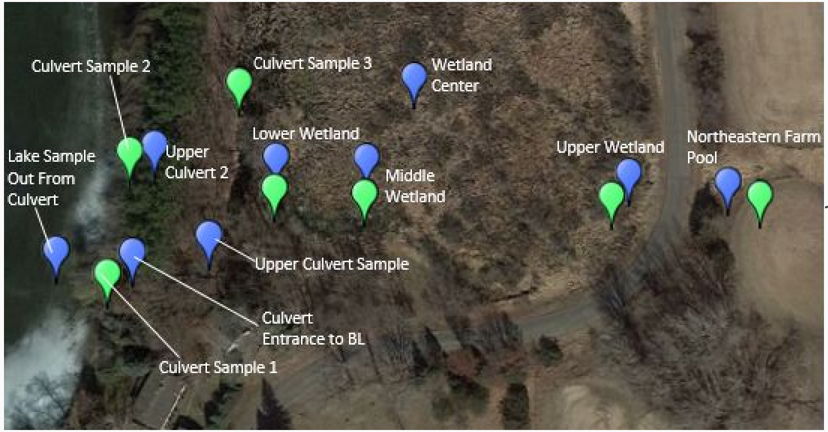
Our Research Questions:

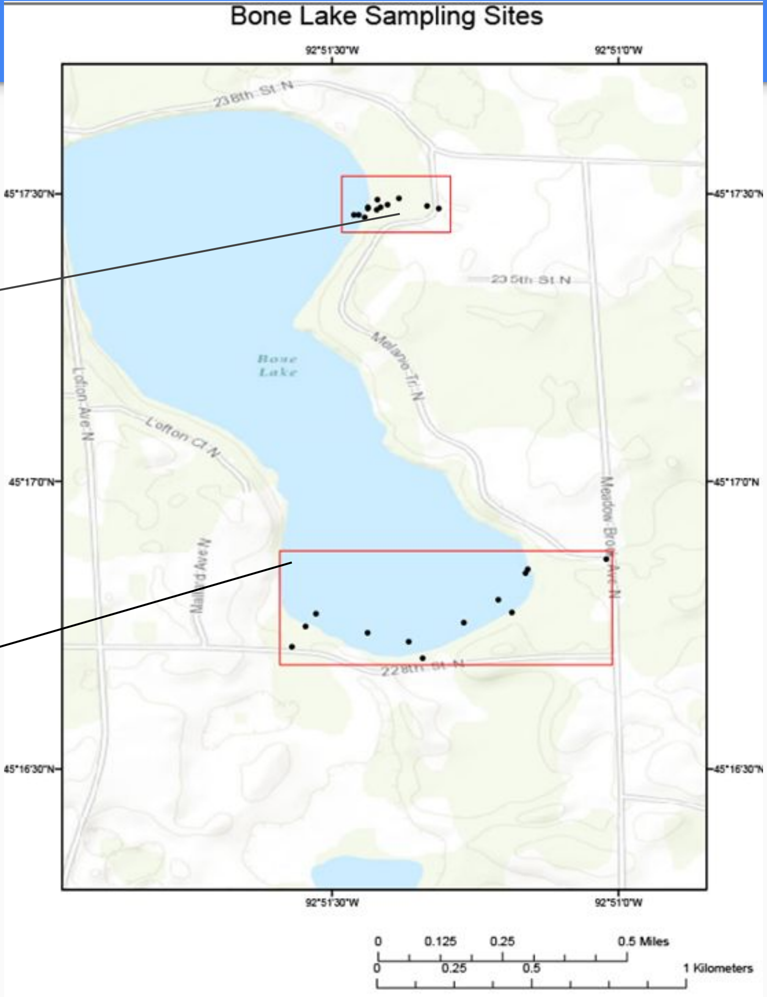
- What are the main source(s) of nutrient pollution into Southern Bone Lake (site 1)?

-Is the southern farm wetland a significant P load?

- Is the northeastern wetland (site 2) a cause for concern with respect to P loading?

Overview: Our Sites





“Inflow 1”

“Inflow 2”

“Inflow 3”

Sampling Techniques

Southern Bone Lake:

- Feb. 11th- April 25th
- 43 water samples collected
- 11 sediment samples collected

Northeastern Wetland:

- March 27th- April 25th
- 20 water samples collected
- 7 sediment samples collected

Summation of Methods: Analysis of Our Samples

Sediment:

Bray:

- NH_4F, HCl
- Stronger digestion
- Ammonium Molybdate analysis in spectrophotometer

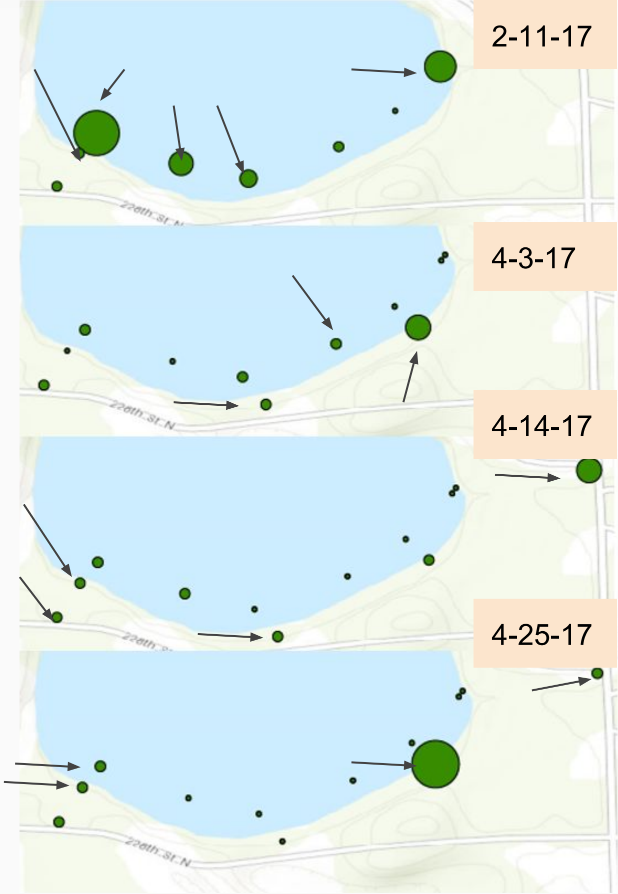
EPA Hot Block Digestion, Meixner Analysis

- Samples digested in H_2O_2, HNO_3, 36xN HCL and diluted to 50 mL (Diluted by approximate factor of 3.1)
- Meixner analysis: ammonium molybdate makes blue color proportional to P in sample

Water:

- HANNA
  Low Range aqueous P Analyzer, Ammonium Molybdate, undiluted.

Southern Bone Lake | **Water P: HANNA Low Range** | Northern Wetland

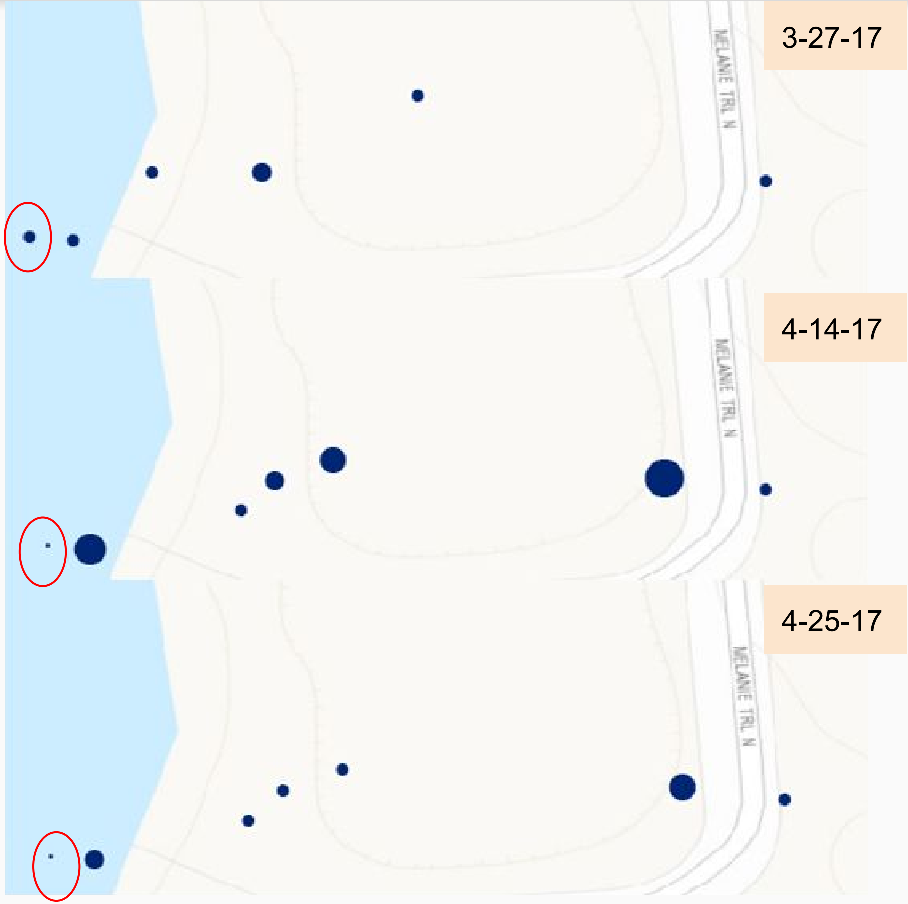


Total P (mg/L)

- 0.000000
- 0.000001 - 0.150000
- 0.150001 - 0.200000
- 0.200001 - 0.250000
- 0.250001 - 0.300000
- 0.300001 - 0.370000

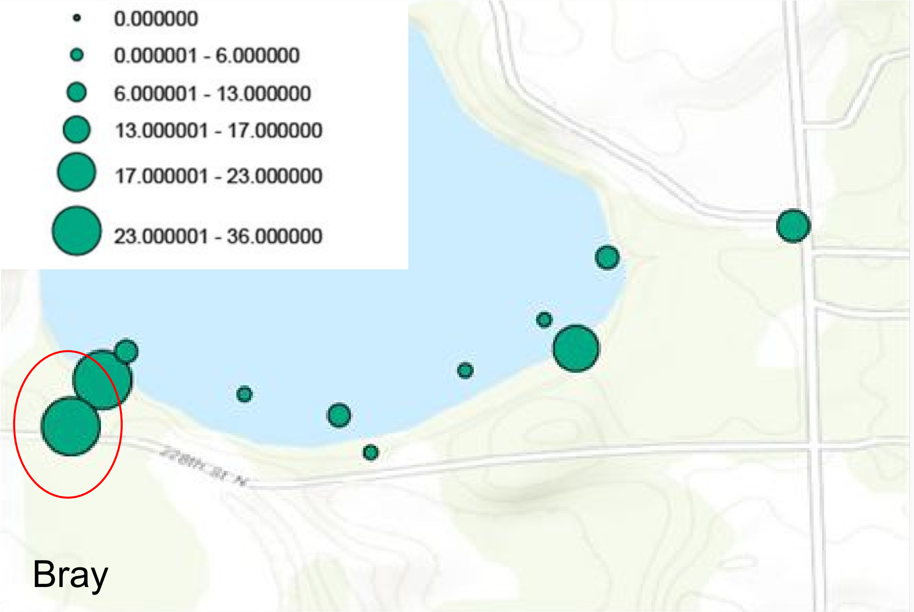
Total P (mg/L)

- 0.000000
- 0.000001 - 0.500000
- 0.500001 - 1.000000
- 1.000001 - 1.500000
- 1.500001 - 2.000000
- 2.000001 - 2.500000

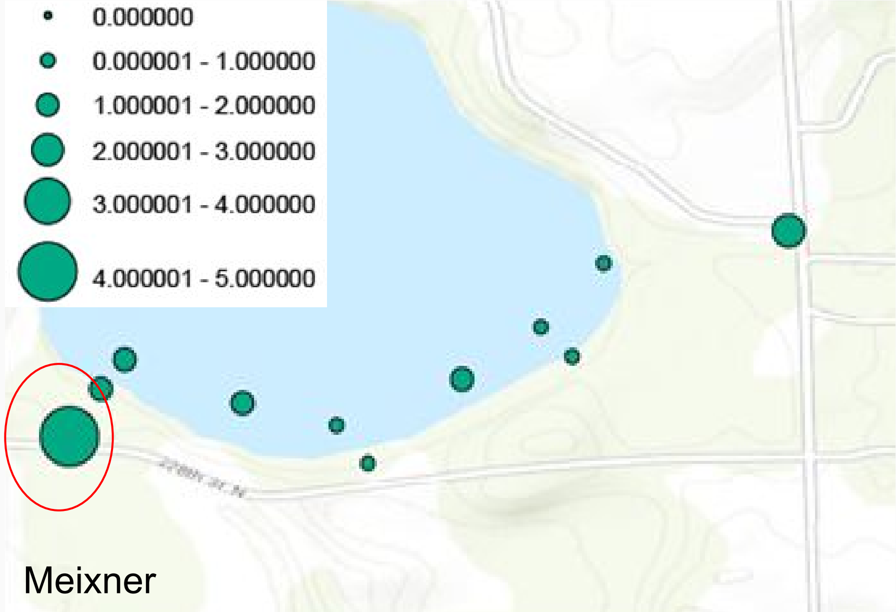


Analysis of Southern BL- Bray and Meixner Comparison

P (ppm)



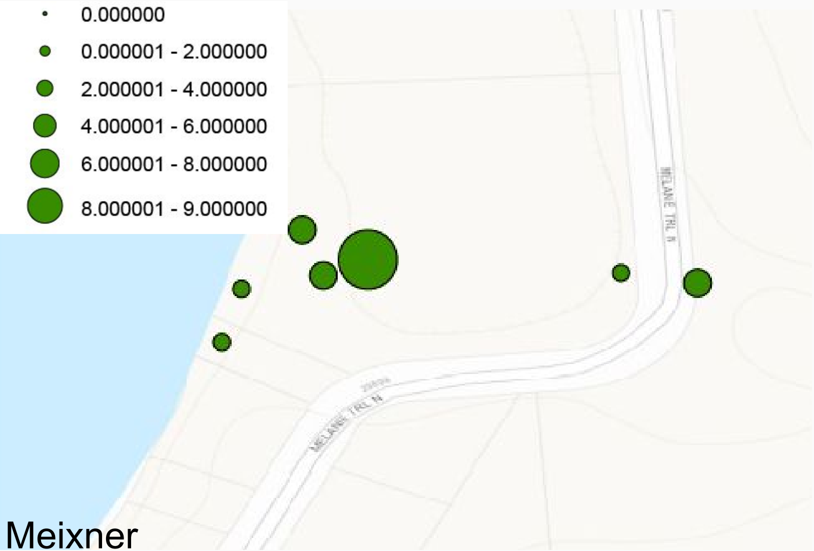
P (ppm)



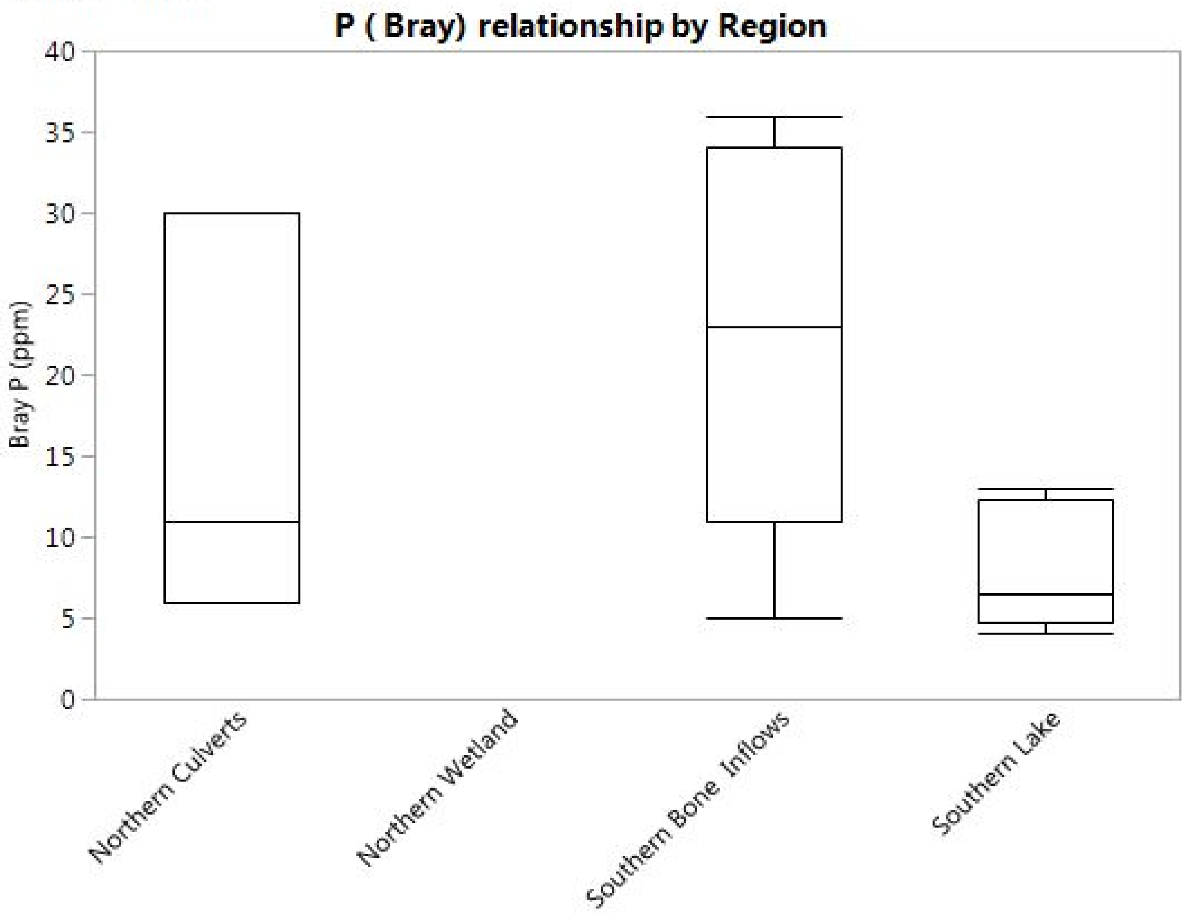
Analysis of Northern Wetland- Bray and Meixner Comparison

P (ppm)

P (ppm)



Bray P in Sediments by Region

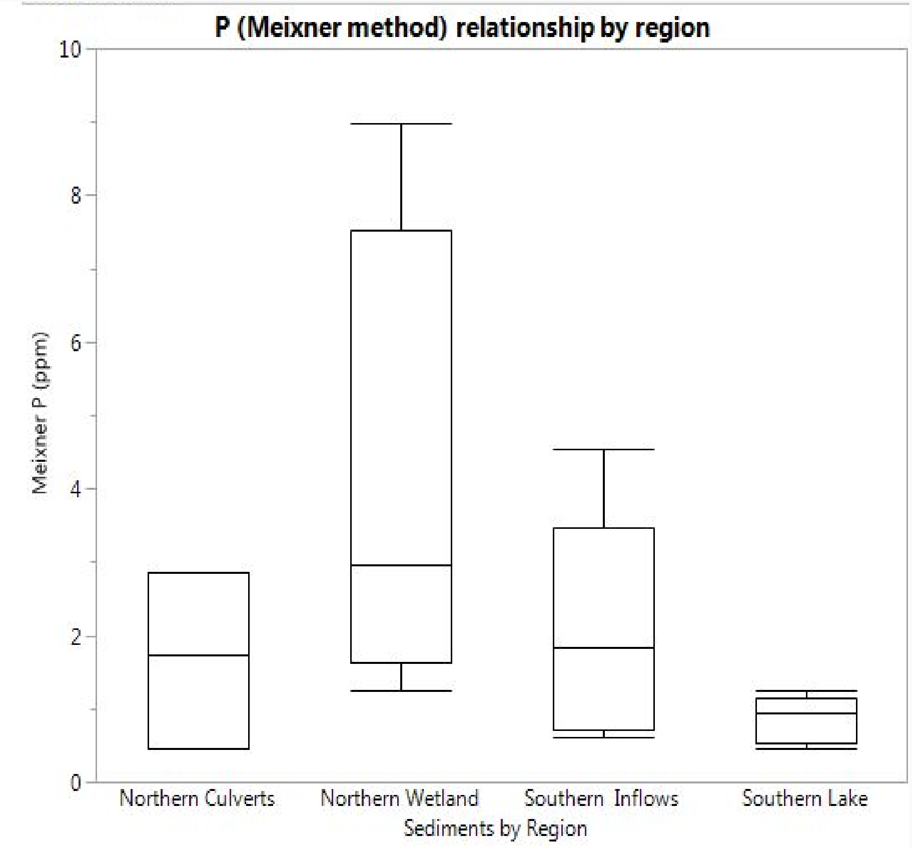


- Both southern and northern culvert inflows have larger P loads in sediments

- Southern lake has lower P in Sediment
- **Larger sediment values indicate P buildup due to constant nutrient loading over time**

Note: Data Gap due to turnaround time of Bray data analysis on NW samples from U of M. Samples will be sent at a later date, if requested.

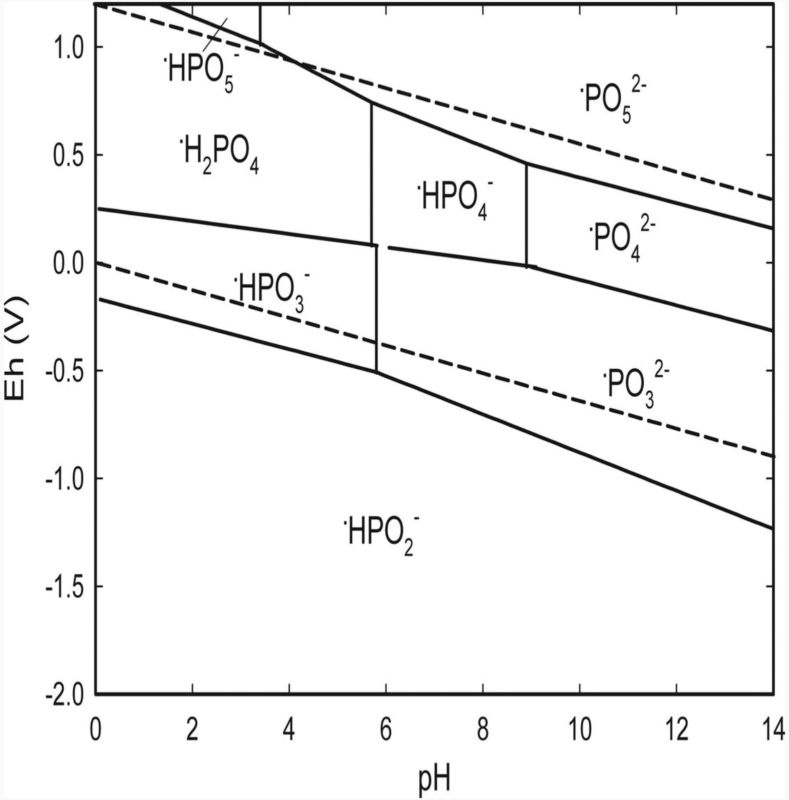
EPA-Meixner P in Sediment by Region



- Similar Trends (Barring Data Gap)
- Highest observed load in wetland sediments
- Both southern and northern culvert inflows have larger P loads in sediments
- Southern lake has lower P in sediment
- **Larger sediment P values indicate buildup due to constant nutrient loading over time**

P Release mechanisms in wetlands:

- Current peat loads + vegetation in wetlands create anoxic conditions
- Anoxia leads to lower pH
- Lower pH leads to new redox gradients
- New redox gradient leads to desorption of P from iron rich sediments
- Increase in temperature during summer months increases rates of P release
- P release from wetland allowed to flow into Bone



Bone Lake Phosphorus Loading from Suspected Sources:

Analysis of Northern and Southern Wetland Sediments

Katie Dennis ‘17 and Zach Beckman ‘17

University of St. Thomas, Environmental Science Department

Supervisors: T. Hickson (PhD) and K. Theissen (PhD)

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Executive Summary:

The Comfort Lake Forest Lake Watershed District (CLFLWD) has been investigating several likely causes of nutrient pollution into Bone Lake. They commissioned the University of St. Thomas to investigate two separate locations, one on the northeastern corner of Bone Lake and the other on the southern shore. These sites were chosen based off of community concern and historical land management practices. We investigated the two site locations and found there to be sufficient evidence that these sites contribute to phosphorus (P) loading into the Bone Lake water column.

Water sample results identified 16 of the 43 samples taken from southern Bone Lake to be considered impaired, as they are above the lake's eutrophication standard. 17 of the 20 samples from the northeastern wetland were above this set standard as well. Sediment analysis measured a maximum phosphorous load of 36 mg/L. If less than 1/10 of the P available in the sediments is released into the lake, Bone Lake will demonstrate increasingly eutrophic conditions.

Based off of our findings, we suggest further monitoring of these sites by the CLFLWD, and implementation of best management practices in areas of concern. The majority of our investigation focused on sediment analysis, therefore additional attention must be paid to the overall flow of nutrients in the water column and erosional rates of agricultural land into the wetlands. Long term studies should take into account inflows of P from the wetlands, with special attention given to the health of Bone Lake.

Introduction:

Phosphorus (P), a limiting nutrient in freshwater systems, is essential for plant growth and survival. In a lake, the scarcity of P is due to an attraction to soil particles and organic matter. Any unattached, or “free” P is quickly removed by algae and other aquatic plants (Department of Environmental Quality, 2017). Conversely, when P levels become excessive, eutrophication occurs along with extensive plant growth and algal blooms. Excessive algae growth can cause hypoxic or anoxic conditions, harm water quality, and affect food resources and available habitat for other aquatic species (EPA, 2017). This often happens as a result of nutrient loading, a common issue with many lakes. Farming by-products such as animal manure, excess fertilizer, and soil erosion make agriculture one of the largest sources of P pollution in the country (EPA, 2017).

This study evaluates the main source(s) of nutrient pollution into Bone Lake, located within the Comfort Lake and Forest Lake Watershed District (CLFLWD) in Scandia, MN (Figure 1). Previous studies of Bone Lake found P levels to be higher than the lake’s eutrophication standard of 0.04 mg/L. Currently, the average yearly nutrient load with respect to P is 0.062 mg/L, which designates the lake as semi-eutrophic (CLFLWD, 2014-15).

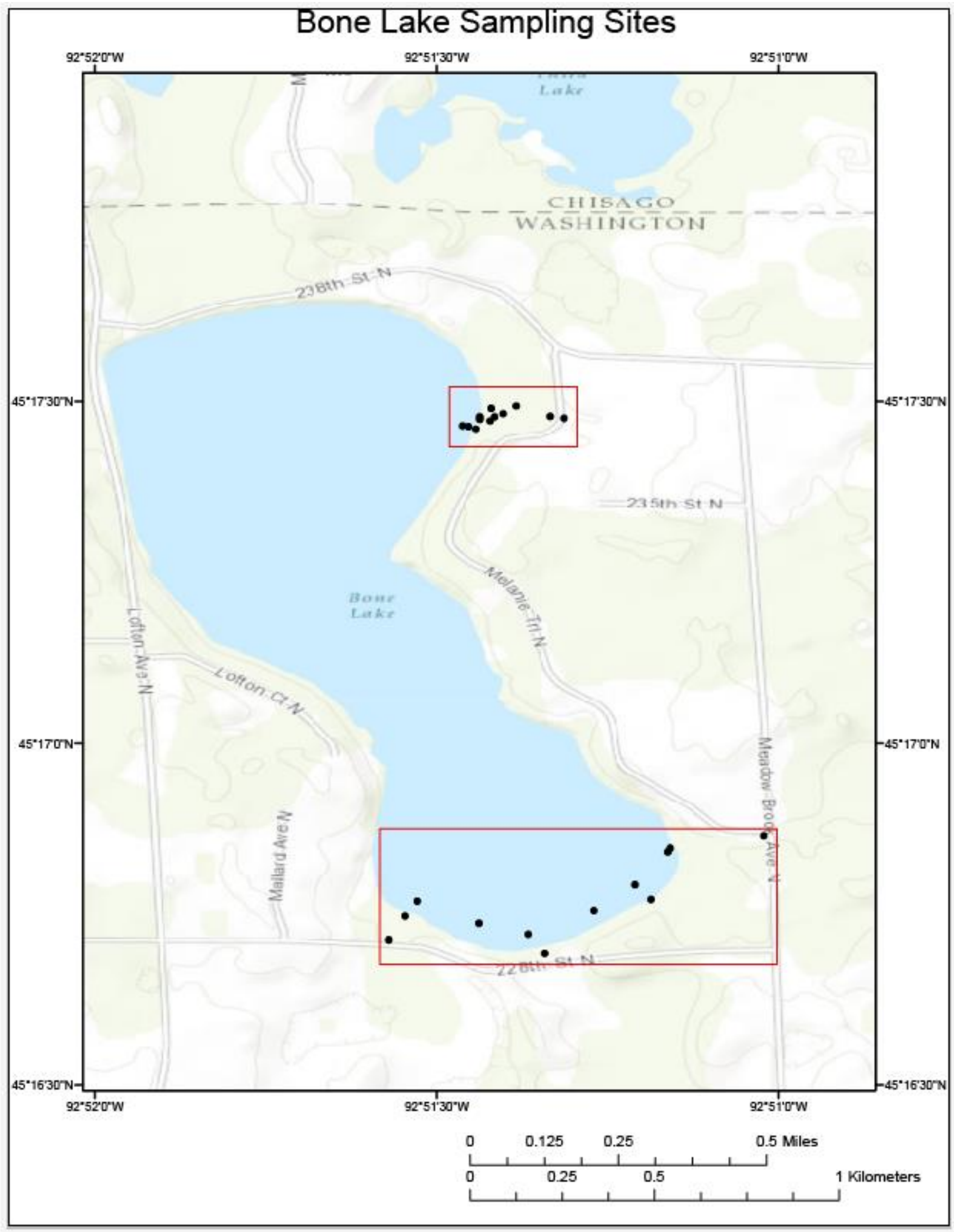

Figure 1: Bone Lake sampling sites. The southern box encompasses samples taken from the southern shore of Bone Lake and from inflows into the lake. The northern box encompasses samples taken from the northeastern wetland, northeastern Bone Lake, and the culvert that flows through the wetland and into Bone Lake. See Figures 2 and 3 for a description of each site.

Our first sampling site and largest suspected source of pollution for the southern portion of the lake is a farm which is located adjacent to the lake shore (Figure 2). The southern half of Bone Lake's P levels make up 20% of the lake's annual P load (Mike Kinney, oral commun(s), February, 2017). The working hypothesis of the CLFLWD is that current land use practices on the farm could not contribute to this large influx of nutrient loading, as the owner is known to practice rotational grazing. This agricultural method is known to decrease soil erosion potential, require less pesticide and fertilizer use, and reduce the amount of barnyard runoff (Undersander, 2002).

For this reason, we suspect that previous landowners could be responsible for the nutrient loading into southern Bone Lake. The prior use of the land for row crops likely contributed to nutrient accumulation in the wetland that is located on the farm's property. This buildup of P over time is referred to as "legacy P." Legacy P release in sediments can occur over 5-30 year periods due to changing of redox gradients and erosional soil movement (Richardson et al., 1985). The resulting internal P released has been shown to increase base P loads by up to 300 mg/L over a 10 year period (Sharpley et al. 2013). These types of nutrient loads have been shown to quickly impact littoral lake shore environments (Mardsen, 1989).

Our second sampling site included a wetland on the northeastern corner of the lake that has been subject to heavy erosion from an adjacent agricultural field for approximately 40 years (Mike Kinney, oral commun(s), February 2017). This location has been monitored in the past, but water and sediment samples had not been taken prior to this project at the location where the wetland enters the lake (Emmons & Oliver et al., 2015). The wetland is located next to a road (Melanie Trail), where a culvert flows from the southeastern side of the wetland property into the lake (Figure 3). The culvert flows to Bone Lake from cropland that has been the source of sediment and nutrient loading into the wetland. The results generated from analyzing the wetland water and sediment samples will be beneficial for the CLFLWD, as the district plans to convert the field from row crop to perennial grass and they would like to know if further restoration should be done to the wetland (Mike Kinney, personal communication, March 13th, 2017).

By analyzing samples taken from each location using chemical and geochemical methods, we determined where the largest concentrations of P were located in Bone Lake and their proximity to wetlands or property inflows.

Methods:

Southern Bone Lake Sampling:

Water and sediment samples were collected from the southern littoral shoreline of Bone Lake and the four inflows from the farmer's property into the lake. 43 water samples and 11 sediment samples were collected from February 11th to April 25th of 2017. Figure 2 shows water and sediment sampling sites for Southern Bone Lake and the farm property adjacent to it. Water samples were collected using an ice auger on February 11th and YSI multiprobe data for dissolved oxygen (D.O), conductivity, pH, and oxidation reduction potential (ORP) was recorded (Appendix, Table 2). All other water sampling was done after the ice was off of Bone Lake and no further YSI measurements were taken. Sediment samples were collected using a bucket auger when the ice was off of the lake. GPS locations were taken at each site and sampling coordinates remained the same throughout the project, with the exception of taking the last batch of samples a few meters closer to the shore on April 25th.

Figure 2: Water and sediment sampling sites for Southern Bone Lake. Blue and green markers depict where sediment and water samples were taken along the shoreline of the lake. Purple markers (A-D) depict the four inflows from the farmland into the lake (I1-I4). Sediment and water samples were taken from each purple marker location, with the exception of I4L where only water samples were taken. White markers depict culvert locations where water and sediment samples were taken. The red W marker shows the location of the farmer's wetland, and the F marker shows where the farmland is located.

Northeastern Wetland Sampling:

We collected 20 water samples and 7 sediment samples between March 27th and April 25th of 2017. Water samples were collected once before and two times after the ice melted on the wetland. Culvert sediment samples 1, 2 and 3 (Figure 3) were collected using a bucket auger while ice was still on the wetland. All other samples were taken after the ice was off of the wetland. GPS locations were taken at each sampling site. Figure 3 depicts locations of soil and water sampling for the northeastern wetland on site.

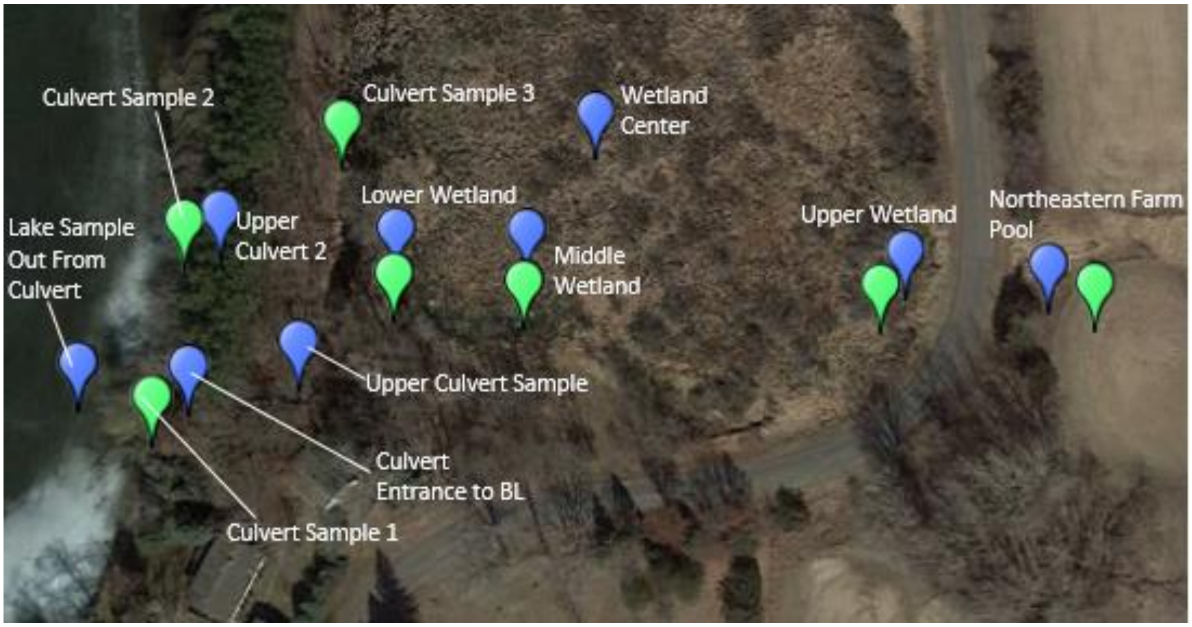

Figure 3: Sampling locations for the northeastern wetland, northeastern Bone Lake, and the culvert that runs through the wetland into Bone Lake. Blue markers depict water samples and green depict sediment samples. Sample names correspond to the exact GPS location where each sample was taken (Appendix, Table 3).

Water samples taken from each site were filtered for organic matter at 0.45µm and analyzed for Total Phosphorous (TP) utilizing a HANNA Low Range Phosphorous Colorimeter. The HANNA method utilizes ammonium molybdate for aqueous samples and gives a TP reading in mg/L. Environmentally available P was measured in soil and sediment samples using two separate methods, Bray P Analysis and Meixner Colorimetry Analysis. All samples analyzed by the Meixner method were subjected to an acid digestion following protocol from a modification on the EPA's 3050B method that requires a hot block digestion at 120℃ for 35 minutes and at 95℃ for 2.5 hours. Because this method specified that the samples not boil, we adjusted the temperature of the digestion to 90℃ throughout. During the hot block digestion, environmentally available P was desorbed from sediments using HNO3, 36xN HCl, and H2O2 (Dowdell and Thompson, 2014). Digested samples were diluted to 50mL, which is a factor of 3:1 in comparison to Bray.

Post digested sediments were analyzed using the Meixner Colorimetry method (Singer and Janitzky, 2017). Ammonium molybdate was added to each sample, which produces a blue color proportionate to the concentration of P present in each. These samples were run against a calibrated standards curve (4 standards, $R^2 = 0.9987$). Based on this curve, we utilized Beer-Lambert law that correlated absorbance (660nm) and concentration of P in mg/L (Singer and Janitzky, 2017).

For method comparison, sediments were sent to the University of Minnesota Soil, Water, and Climate lab for Bray Phosphate Analysis. The Bray method utilizes ammonium fluoride and hydrochloric acid for release of total P from sediment into solution (Bray et al, 1945). This solution was then analyzed with both spectrometry and colorimetry for accuracy through comparison. All sediment samples taken from southern Bone Lake were sent to the lab along with culvert samples 1, 2 and 3 from the northeastern wetland location. Sampling difficulties relating to ice cover on the northeastern wetland and turnaround time of the lab resulted in a lack of analysis using the Bray method for the northeastern wetland samples. If requested, the remaining sediment samples can be outsourced at a later date. The resulting P data from this project was synthesized into separate spatial GIS diagrams showing the extent of nutrient loading per region.

Results:

Water sample Results Southern Bone Lake:

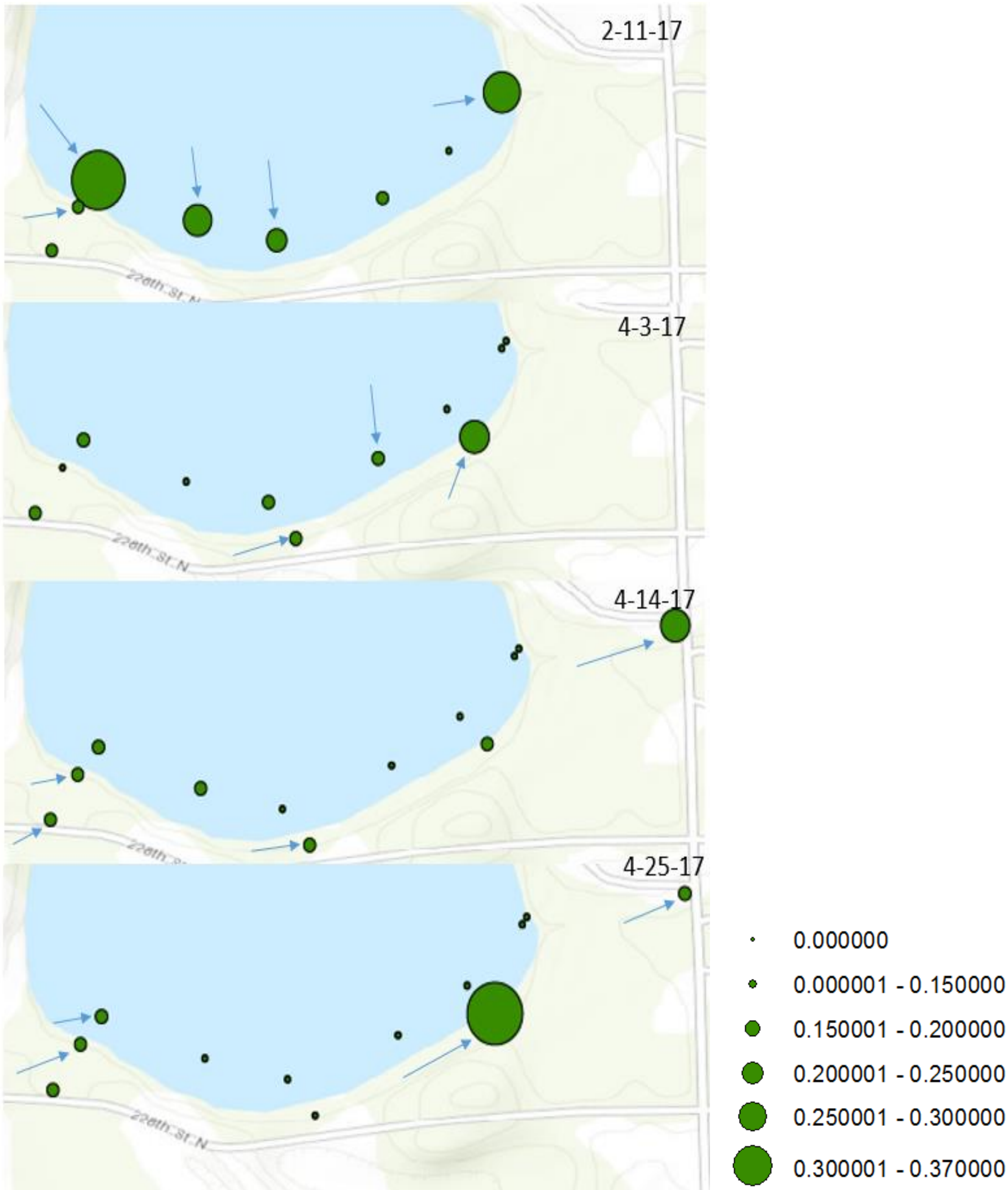

Figure 4: HANNA low range total P measurements for Southern Bone Lake corresponding to the location where each water sample was taken. Sampling dates range from February 11th to April 25 (top right of each image). Blue arrows depict samples that exceed the lake's eutrophication standard of 0.04 mg/L. The legend attached to the image displays a TP range (mg/L) between 0 and 0.37 and marker size increases with increased concentration.

Water Sample Results Northeastern Wetland:

Figure 5: HANNA low range total P measurements for the northeastern wetland corresponding to the location where each water sample was taken. Sampling dates range from March 27th to April 25 (top right of each image). The legend attached to the image displays a TP range (mg/L) between 0 and 2.5 and marker size increases with increased concentration.

Southern Bone Lake Sediment Analysis: Bray and Meixner Methods

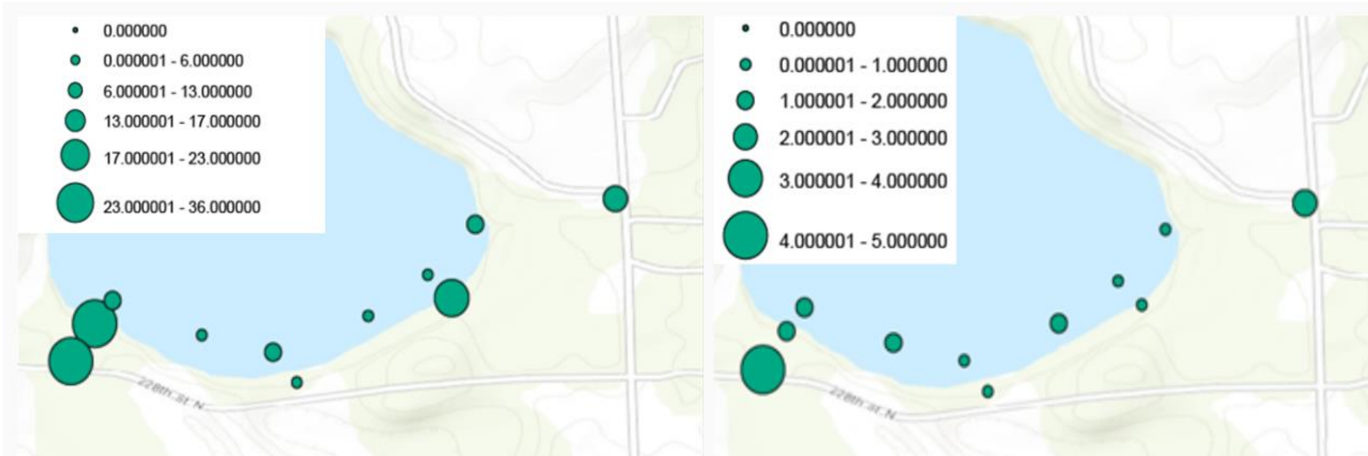

Figure 6: A comparison of Bray sediment analysis (Left) and Meixner sediment analysis (Right). The legend for the Bray analysis ranges between 0 and 36 mg/L of environmentally available P and marker size increases with increased concentration. The legend for the Meixner sediment ranges between 0 and 5 mg/L of environmentally available P and marker size increases with increased concentration.

Northeastern Wetland Sediment Analysis: Bray and Meixner Methods

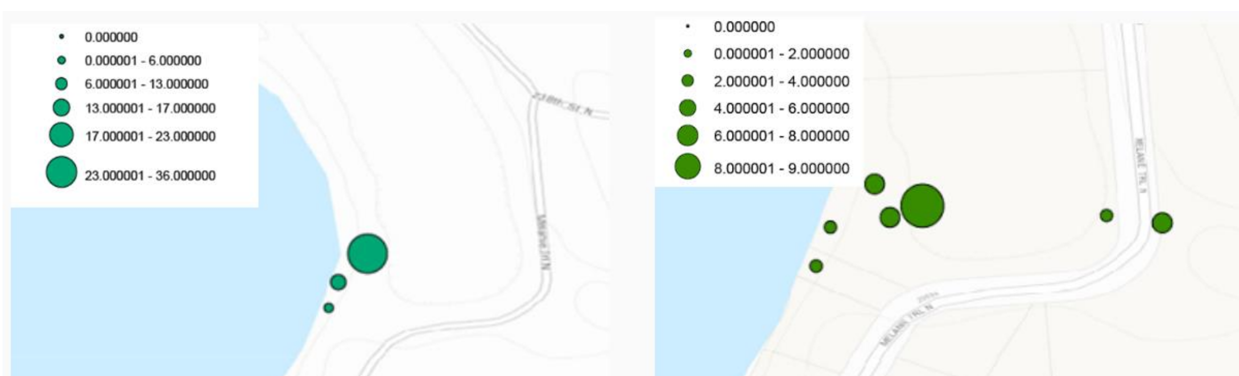

Figure 7: A comparison of Bray sediment analysis (Left) and Meixner sediment analysis (Right). The legend for the Bray analysis ranges between 0 and 36 mg/L of environmentally available P and marker size increases with increased concentration. The legend for the Meixner sediment ranges between 0 and 9 mg/L of environmentally available P and marker size increases with increased concentration.

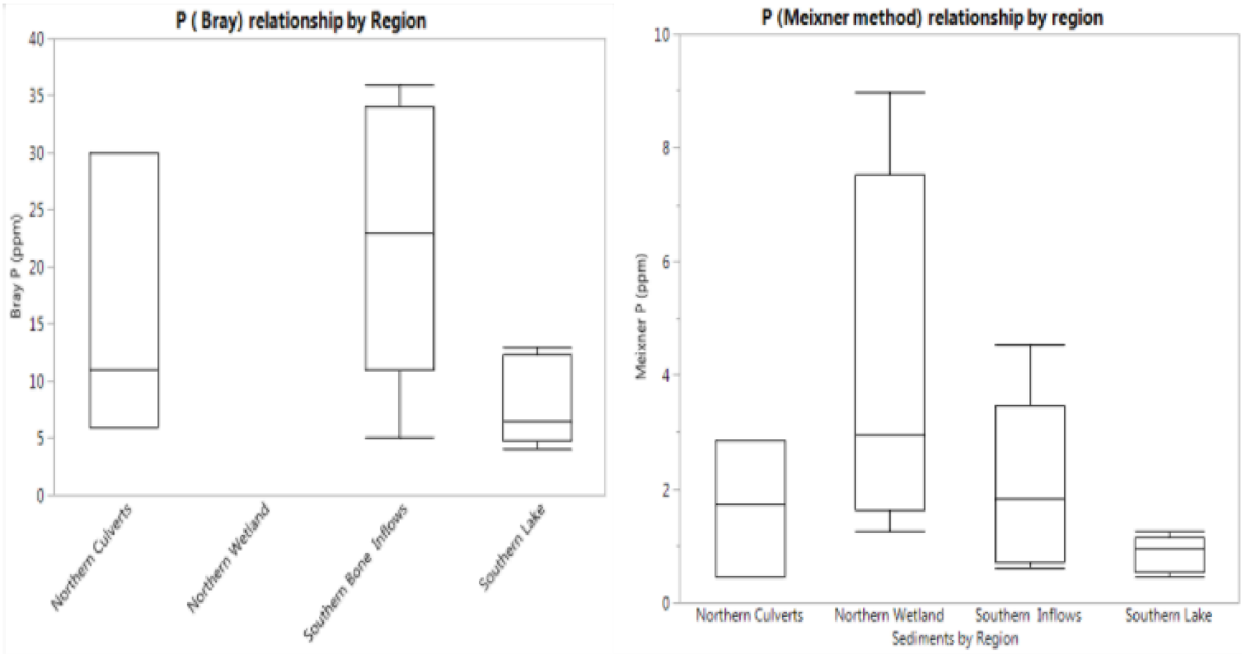

Figure 8: Box and Whisker plot of Bray sediment P and Meixner sediment P. Highest values for maximum, minimum, and mean are all located in areas other than the lake shore sediments. The significant data gap in Bray is due to sampling difficulties during winter months, along with analysis turn-around time from the university of MN soil and climate lab.

Discussion:

Data Trends: Water Samples Taken From Southern Bone Lake and the Northeastern Wetland

Referring to Figure 4, water samples taken on the 11th of February had the highest TP values for the southern shore of Bone Lake. This is especially true for samples located at BL1 and BL 6. After the 11th of February all other sampling values for BL1 were 0 mg/L. For the BL6 location, samples taken during April were at least two times lower in value than what was taken in February. One trend that could explain this change over time for the BL1 location is the dissolved oxygen measurement taken on the first sampling date when ice was still on the lake. BL1 had a D.O. level of 15.0%, or 2.17 mg/L (Appendix, Table 2). All other samples taken on this date were above 8 mg/L. In shallow lakes, research points to oxygen availability mediating the release of P from sediments. (Hupfer et al. 2008). Having a low dissolved oxygen level in the water column can create gradients favorable to P release by increasing acidic conditions.

Another difference that could account for changes in P between February 11th and other sampling dates is that there was ice cover on the lake during this time. The temperature on this date was above average as well, reaching almost 50°F. At this point, a possible explanation for the elevated P values could be that melting was beginning to occur and decomposed organic material was being released from the snow and ice. Other sampling occurred after ice was off the lake entirely, so no other comparisons can be made regarding P concentrations and snowmelt for this project, but are viable studies to conduct in future sampling.

After February 11th, sampling values were less variable for the southern shore. Regarding inflow values, dates April 3rd and April 25th at sample location I3 had higher TP values than the other samples. These values were 0.23 and 0.36 mg/L, respectively. One possible explanation for elevated trends in the data could be due to the popularity of the site for residential dumping of yard waste. The stream directly south of this location has been historically subject to local residents disposing of organic matter, which flows toward the lake and to the I3 location (Mike Kinney, oral commun. 2017).

Regarding April 14th data, location I4R had the highest value for the data set at 0.23 mg/L. This location, referred to as the Meadowbrook tributary in the 2015 Bone Lake Diagnostic Report, is considered a hotspot, as it contributes a larger fraction of its P load relative to its fraction of total flow into the lake. Meadowbrook represented 19% of total flow, but 43% of the TP load (Emmons & Olivier, 2015). Although we were only able to sample this location twice during our study, both times the P value for the location exceeded the lake's eutrophication standard of 0.04 mg/L, labeling it impaired. These findings, coupled with findings of the Bone Lake diagnostic report, suggest that the I4R location be subject to more extensive monitoring and that best management practices be implemented.

Location I4R was not the only sample location that exceeded the lake's eutrophication standard of 0.04 mg/L. Sixteen of the water samples demonstrated P levels above this value, necessitating action (Figure 4). Here, because almost half of the samples that were gathered displayed P values that would be considered impaired, it is crucial that continued monitoring happen at southern Bone Lake locations and that sample data be taken for a longer period of time.

Similar to the Meadowbrook location that flows into southern Bone Lake, another hotspot mentioned in the Bone Lake Diagnostic Report was Melanie Trail, which is our northeastern wetland location. This area is expressed as one of concern as it represents 1% of total flow into the lake, but 11% of the TP load for 2015 (Emmons & Olivier, 2015). Referring to Figure 5, P readings taken at this location on April 14th and 25th were highest at the upper portion of the wetland and again where the culvert enters into Bone Lake. This trend could be problematic if runoff from the cropland is not being absorbed by the wetland, but water samples were only gathered three times over the period of one month, so strong extrapolations cannot be made at this point. All samples except the samples in northern Bone Lake that were farther from the culvert exceeded the eutrophication standards of the lake. Due to this finding, we suggest that the location where the culvert enters northern Bone Lake be monitored in the future. One positive finding is that the P value farther out into the lake does not exceed this standard, but this finding could also be due to dissolution of P into the water column.

Regarding the water sampling data, it should be noted that Bone Lake is stratified, but could display semi-meromictic conditions (Kevin Theissen, oral commun(s), 2017). This would result in seasonal turnover during the summer stagnancy during the winter, which could result in variability during our sampling times while the lake was experiencing turnover. For southern Bone Lake, while there is no clear trend between all 4 sampling dates, our points of discussion are worth concern and should be addressed with further and more extensive sampling over a longer time period. Regarding the northeastern wetland, we recommend that the location where the culvert enters Bone Lake be monitored, as does the upper wetland location, especially after changes are made to the row crop that is located adjacent to the upper wetland and to Melanie Trail.

Data Trends: Sediment P in southern Bone Lake and the Northeastern Wetland:

Figure 6 shows the relationship between two different methods of measuring environmentally available P in sediments in the southern half of Bone Lake. Both the Bray and Meixner methods of analysis show a greater inflow of environmentally available P at the I1R location of Bone Lake. This location is a culvert that flows from the farm's wetland into the lake (Figure 2). Further, this trend between the two different methods suggests a relationship between sediment legacy P release and this location. Here, the Bray P concentration was 32 mg/L, which is twice the value of any of the Bone Lake shore line samples. The Meixner concentration at this location was 4.5 mg/L, which is more than three times greater than any of the shoreline samples. These values provide evidence that the wetland located on the farm property is contributing to P release into southern Bone Lake through the inflow 1 location. This idea is further exemplified by looking at the BL6 location on the southern shore of Bone Lake, which had the highest sediment P value for the lake at 13 mg/L.

Regarding the Bray method of analysis, inflows 3 and 4R had high levels of P in the sediment. Inflow 3 displayed a P value of 23 mg/L, while I4R displayed a reading of 17 mg/L. As discussed previously, the location where the 14R inflow hits Bone Lake receives high P loading relative to flow, and is therefore an area of concern. BL1, the location where the culvert enters the lake, displayed the second highest P value for the southern shore at 12 mg/L, illustrating that best management practices need to be considered for this location. BL4, the location close in proximity to where I2 enters the lake had the 3rd highest sediment P value for the lake's shore at 8 mg/L. For the Bray method, the locations on the southern shore that are closest in proximity to where all four inflows enter the lake have higher sediment P values than the samples that aren't located next to inflows into the lake. Due to this finding, it is recommended that the farm wetland south of the lake that is attributing high levels of P buildup in its sediments be monitored and managed so that southern Bone Lake does not experience future higher levels of loading at these locations.

Figure 7 displays sediment values for the northeastern wetland. Although more sediment data was analyzed using the Meixner method, both methods of analysis show that sediment P increases toward the wetland and away from the lake. The Meixner results show the highest value (8.98 mg/L) occurring at the middle wetland location. This is expected, as wetlands sequester high amounts of P in their sediments (Richardson et al. 1983). This finding provides support for the continuing functionality of the Northern Wetland removing P from Bone Lake, as sediment P levels are highest in the wetland itself. Here, agricultural runoff from the row crop adjacent to the wetland is being retained, thus minimizing the amount of nutrient loading that occurs in northern Bone Lake.

Figure 8 shows the comparison of maximum, minimum, and mean values for P in sediment by Bray and by Meixner-EPA. P concentration is shown in the center of the north and south wetlands, as well as their respective culvert outflows, to have higher means, minimums, and maximum values for sediment P than the sediment P in the lake. This increase in P from lake to wetland center is a trend that occurs in both the southern and northern portion of the lake, suggesting similar mechanisms of P loading from agricultural sources. The cause is likely a historically constant flow of nutrient-enriched water from the wetlands into their culverts for decades. The constant loading of P into the lake over this time scale would focus the flow of nutrient-rich water and eroded outwash from the wetland in a very concentrated gradient from the culvert to the lake, a trend that is present in the spatial data shown in figure 6. Interestingly, these trends are opposite of trends seen in the water column, in that sediment samples show greater P concentration than P in the sampled water.

Sediment Results in Context:

With the current eutrophication standard of Bone lake set at 0.04 mg/L for water (CLFLWD, 2014-2015), the sediment data presents a significant concern. The lowest observed P are at levels dramatically higher than this set standard (BL2 at 0.4 mg/L). If even 1/10th of the sediment P in the lowest tested sample is released into the lake, then that internal load alone will be enough to classify the water as impaired. In Bone Lake, seasonal variance in temperature and anoxic conditions create redox gradients that favor P release from the sediments. Further, there is a large implied load of aqueous P flowing seasonally from the farm and northern wetland that is responsible for the buildup in P sediments. Constant flow of desorbed P in the water column and nutrient rich eroded outwash from the wetland over time could be resorbed into sediment rich in minerals such as iron and calcium. The result would be a high P buildup in the sediments nearest their inflows to Bone Lake, a trend present in the data (Figures 6, 7). Concern has been expressed by citizens of Bone Lake about the farm and wetlands contributing to the eutrophication of the lake.

Based off of high sediment P values, quantified P in the water column above the lake's eutrophication standard, and the agricultural nature of the land surrounding Bone Lake, the concern expressed by the residents of Bone Lake is valid, and worth further study.

Bone Lake Phosphorus Release Mechanisms:

Phosphorous release methods in lake beds are variable and are reliant on individual lake conditions. In general, the amount of iron(III) minerals, microorganisms, plant life, anthropic sources of loading, oxygen availability, temperature, and pH all have significant effects on the release, sedimentation, or adsorption of P in shallow lakes (Sondergaard et al, 2003). Bone Lake is a designated shallow lake, and demonstrates recurring eutrophic conditions, resulting in observed lower dissolved oxygen content throughout the lake (CLFLWD, 2015). This allows for P to be released from the sediment into the water column of the lake seasonally and exacerbates anoxic conditions in the lake due to higher temperatures in summer months.

Typically, these anoxic conditions are often coupled with a shift to lower pH resulting in acidic conditions. Such conditions desorb loosely bound P in iron rich sediments into the water column, and allow for the newly release P to be bioavailable for algae, plant life, and other microorganisms. The lake's current eutrophic conditions may lead to a positive feedback loop for constant desorption of P from saturated sediment near the wetland into the lake's water column over time.

The resulting mechanisms of seasonal turnover, lake temperature variation, pH, and oxygen access in Bone Lake provide reasons for the high levels of observed P in the water column seasonally over the past 3 years (EPA, 2014, EPA, 2015), and may contribute more to the loading of Bone Lake than previously thought.

Future Study and Management Recommendations

While wetlands serve as large sinks for runoff nutrients (Richardson, 1985), it is important to note that rates of P capture can be affected if nutrient input is great enough. Further study should be undertaken to understand the true scope of both the southern and northern wetland effectiveness of P retention so to reduce the amount of nutrient loading into Bone Lake. Bone Lake's grade is a C as of 2015 (CLFLWD, 2015) and the lake may benefit from several management strategies to achieve the watershed's goal of a B grade by 2020. This could be done by studying sediment erosion rates, quantifying overland runoff P, and gaining landowner permission for sediment sampling in the southern farm wetland in the future.

Principally, reduction in P based fertilizers applied to agricultural areas has been shown to decrease seasonal loads significantly into lakes (Foster Creek Conservation District, 2009). This is the easiest achievable goal with the least suspected cost and effort based off of the possibility of remediation gains. We believe that increased community awareness and communication of agricultural impacts on the local watershed is key to reducing Bone Lake's nutrient loading. Community outreach could be beneficial for residential areas as well, as fertilizer use on lakeshore properties contributes to direct nutrient loading into the lake.

Should continuing studies show proof of P-enriched runoff flowing to Bone Lake through wetland and culvert contacts, a possible next step could be to assess the feasibility and cost-benefit analysis of buffer strip creation near the boundaries between agricultural land and corresponding wetlands. Buffer strips would allow for a first line of defense against P loading due to agricultural methods and overland runoff towards the lake, and would function as a strong intermediate step over time. Care should be taken in monitoring buffer strips, as like wetlands, their P retention rates can be impacted and re-release of P into groundwater can occur (Osbourne et al, 1993). Similar to buffer strips, another remediation strategy to reduced nutrient loading into Bone Lake could be the implementation of conservation tillage on agricultural land. This practice reduces erosion rates and allows for water infiltration into agricultural soils, reducing agricultural runoff. Conservation tilling also protects the land's top soil and increases crop yield, thus benefiting property owners as well (Janssen, & Hill, 2017).

After monitoring both wetland locations, if high P loading is still occurring in Bone Lake then intensive wetland remediation might be necessary. The current data trends suggest that the wetlands on both the south and the north portion of Bone Lake are doing a reasonable job sequestering P in their sediments, and are at this point fairly functional. However, if further studies suggest a declining state of effectiveness, this process could be undertaken by CLFLWD. Wetland remediation has already occurred within the watershed. The three wetlands adjacent to Moody Lake, located north of Bone Lake, began restoration in 2016. The overall gain of the Moody Lake Wetland Remediation project is an expected reduction of 445lb/yr. of P, which accounts for approximately 80% of the total internal P/yr. reduction needed to restore Moody Lake to acceptable levels of health (EOR et al. 2015, PCA 2010). The restoration process cost approximately $536,605 and while Bone Lake has fewer (if any) sites requiring this extensive remediation, the project would be expensive in both money and time. However, if the wetlands show signs of extensive degradation, the project would be considered the best option for Bone Lake's P load reduction, in addition to restoring its aquatic ecology and environment back to a long term healthy and functional state.

Appendix Data:

Table 1- Water and Sediment Sample Data: Southern Bone Lake

SAMPLE NAME	LOCATION LAT	LOCATION LON	H2O FEB11 (mg/L)	H2O APRIL3 (mg/L)	H2O APRIL14 (mg/L)	H2O APRIL25 (mg/L)	BRAY (mg/L)	MEIXNER (mg/L)
BL 1	45.28067	-92.8527	0.27	0	0	0	13	0.558421851
BL2	45.27988	-92.8535	0	0	0	0	4	0.453717754
BL3	45.27924	-92.8545	0.01	0.07	0	0	5	1.256449165
BL4	45.27867	-92.8561	0.18	0.015	0	0	8	0.846737481
BL5	45.27894	-92.8573	0.24	0	0.03	0	5	1.104704097
BL6	45.27948	-92.8588	0.36	0.03	0.03	0.15	12	1.04400607
I1L	45.27912	-92.8591	0.14	0	0.08	0.11	36	1.848254932
I1R	45.27853	-92.8595	0.02	0.025	0.08	0.01	32	4.53414264
I2	45.2782	-92.8557	NA	0.07	0.07	0	5	0.831562974
I3	45.27952	-92.8531	NA	0.23	0.04	0.36	23	0.603945372
I4L	45.280768	-92.852636	NA	0	0	0	NA	NA
I4R	45.281069	-92.850348	NA	NA	0.23	0.07	17	2.394537178

Table 2- YSI Multiprobe Data from February 11th for locations BL1-BL6

Sample #	D.O (%)	D.O (mg/L)	Conductivity	pH	ORP
BL1	15	2.17	282.2	6.69	67.7
BL2	80.3	11.63	163.3	7.36	84.5
BL3	79.9	11.61	162	7.43	68
BL4	82	11.87	164.4	7.52	101.2
BL5	91.1	13.29	159.1	7.65	112.3
BL6	55	8.05	177.1	7.16	77.5

Table 3- Water and Sediment Sample Data: Northeastern Wetland

SAMPLE NAME	LOCATION LAT	LOCATION LON	H2O MARCH27 (mg/L)	H2O APRIL14 (mg/L)	H2O APRIL25 (mg/L)	BRAY (mg/L)	MEIXNER (mg/L)
Lake Sample Out From	45.2911	-92.858	0.03	0	0	NA	NA

Culvert							
Upper Culvert Sample	45.2912	-92.857	NA	0.14	0.07	NA	NA
Culvert Entrance to BL	45.2911	-92.858	0.2	1.65	0.87	NA	NA
Upper Wetland	45.2913	-92.856	NA	2.24	1.23	NA	1.256449
Middle Wetland	45.2914	-92.857	NA	1.26	0.49	NA	8.980273
Lower Wetland	45.2913	-92.857	0.97	0.65	0.09	NA	2.758725
Northeastern Farm Pool	45.2913	-92.855	0.42	0.15	0.37	NA	3.153263
Wetland Center	45.2916	-92.8564	0.14	NA	NA	NA	NA
Upper Culvert 2	45.2913	-92.8573	0.06	NA	NA	NA	NA
Culvert Sample 1	45.291	-92.857	NA	NA	NA	6	0.4522
Culvert Sample 2	45.2912	-92.857	NA	NA	NA	11	1.726859
Culvert Sample 3	45.2915	-92.857	NA	NA	NA	30	2.864947

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