The Good, The Bad, and the Hypereutrophic: A Historical Sedimentary and Geochemical Analysis of Two Connected Suburban Lakes in Scott County, MN

Hermann, Nicholas W. (herm3407@stthomas.edu), Theissen, Kevin M., Chatmas, Emily S.
University of St. Thomas Department of Geology, 2115 Summit Ave, St. Paul, MN 55105

PRIOR LAKE - SPRING LAKE
WATERSHED DISTRICT

ABSTRACT

The Prior Lake-Spring Lake system in Scott County, MN, consists of three connected suburban lakes near the Twin Cities: Spring Lake, Upper Prior Lake (UPL), and Lower Prior Lake (LPL). These lakes are vital to residents and nearby businesses for fishing and aesthetics. Spring Lake is hypereutrophic with phosphorus levels averaging 125.2 µg/L between 1996-2006, more than triple the targeted water quality standards. As a result of increased primary productivity, lower dissolved oxygen in Spring Lake has caused periods of anoxia in the last few decades. UPL has been eutrophic since 1998, with phosphorus exceeding the state standard of 60 µg/L. LPL is considered mesotrophic to eutrophic, with current phosphorus levels averaging 30 µg/L since 2003. In this study, we used geochemical methods (x-ray fluorescence (XRF), loss on ignition (LOI), Pb-210 age dating) and sediment microscopy to characterize sediments from a multi-core transect from Spring Lake and a deepwater core in LPL to examine historical changes in sedimentation and nutrient levels in both lake basins. Additionally, this allowed us to compare the histories of the two ends of the system that currently are very different in trophic status.

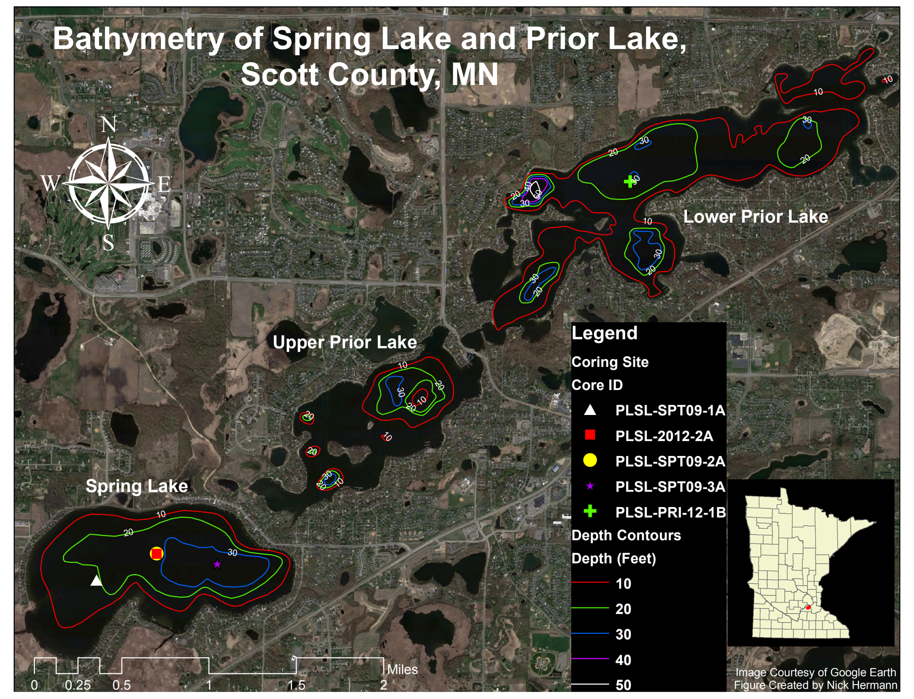
Spring Lake has undergone a drastic shift in geochemistry since European settlement. Not only was there an increase in heavy metals, there was also a significant change in lake ecology as indicated by changes in the biogenic fraction, including a shift in the diatom community. Spring Lake has crossed an environmental threshold in the last decade, as indicated by laminations highly concentrated with centric diatoms and calcite, the result of increased biological productivity and the onset of deepwater anoxia. In contrast, our results indicate that LPL has been the more stable of the two lakes, showing little evidence of the extreme changes that have occurred in Spring Lake. However, there was a change in the dominant species in the diatom community in the uppermost portion of the core, and we believe this may be the early signal of a shift towards a less desirable condition.

METHODS

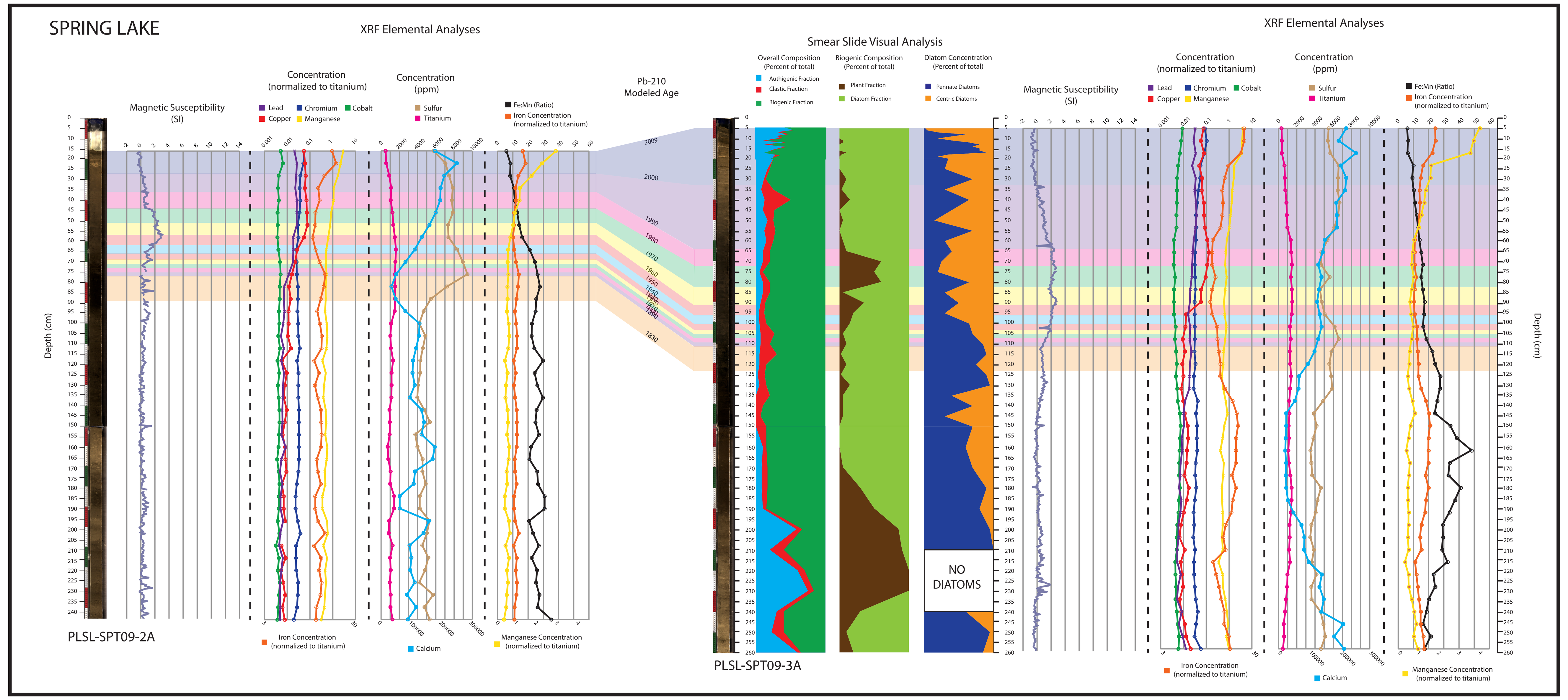
I used x-ray fluorescence (XRF), loss on ignition (LOI), magnetic susceptibility, sediment microscopy, and Pb-210 age dating. I used a previously dated core from Spring Lake (PLSL-SPT09-2A) and magnetic susceptibility data from both the deepwater (PLSL-SPT09-3A) and medium-depth cores to correlate ages in the deepwater core. XRF results for redox sensitive elements (Pb, Fe, Mn, Co, Cu, Cr) were normalized to the concentration of titanium in an attempt to correct for the influence of weathering.

RESEARCH GOALS

1) Examine the geochemical and ecological histories of Lower Prior Lake
2) Correlate ages between multiple Spring Lake cores to understand the basin-wide trends in relation to nutrient levels
3) Compare ecological and geochemical histories of two ends of the PLSL System by studying Spring and Lower Prior Lake

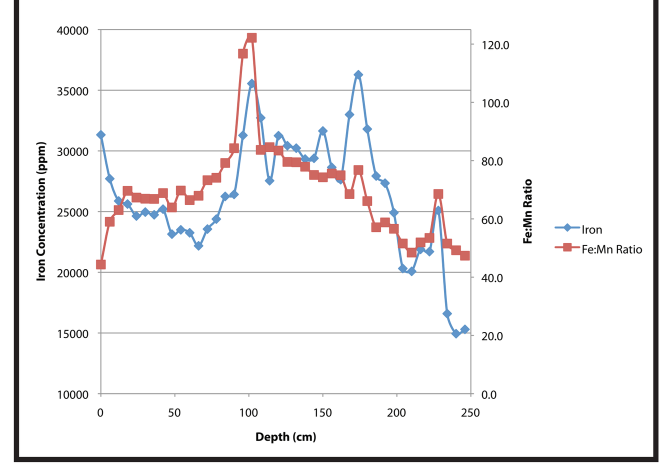


▲ Figure 1 (Above): Bathymetry of the PLSL System and coring locations



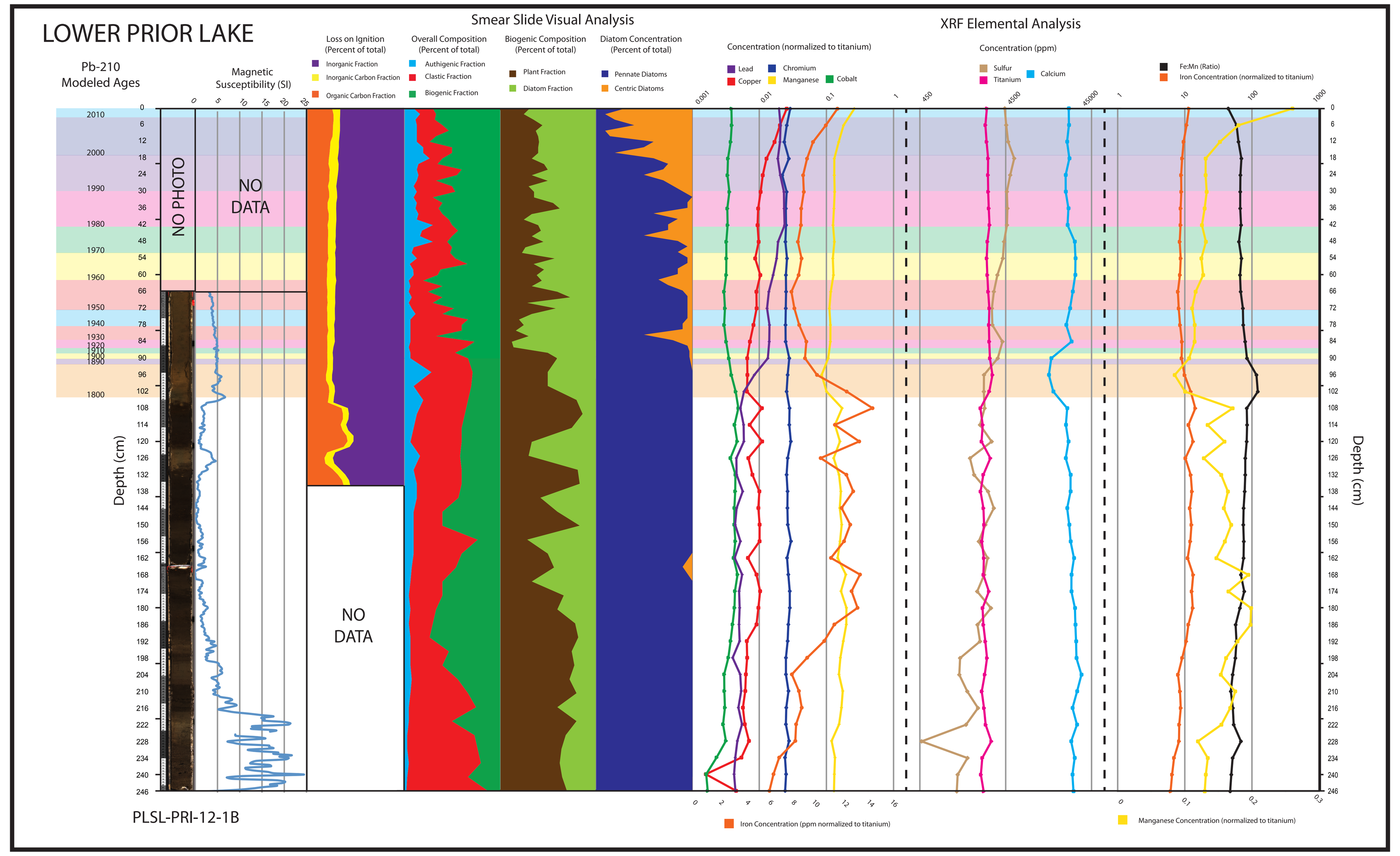
◀ Figure 2 (Top Center): Geochemical and biological data for two cores from Spring Lake. The core on the left was Pb-210 age dated, and decadal ages were interpolated between two known age dates surrounding the decadal year. Age correlation based on magnetic susceptibility was used to identify ages in the deeper core on the right. Each core was analyzed using XRF elemental analysis at 6cm intervals. Smear slide analysis was used in the deep core to determine the general component percentages of the sediment, as well as more specifically examining the biologic content within the sediment.

Figure 4: LPL Iron Concentration vs. Fe:Mn Ratio



◀ Figure 4 (Left): Graph of iron and Fe:Mn ratio for Lower Prior Lake. There is a clear inverse relationship between the two variables in the top 18 cm of the core, but for the majority of the record, Fe:Mn was directly related to iron concentration. Not shown is a plot of Fe:Mn vs iron concentration for the top 18 cm. A linear trend line was used to determine the relationship, and the r^2 value was 0.952, meaning the relationship was significant.

▼ Figure 3 (Below): Geochemical and biological data for the core from Lower Prior Lake. This core was Pb-210 age dated and decadal ages were interpolated between two known age dates surrounding the decadal year. In addition to smear slide analysis and XRF, loss on ignition (LOI) was conducted at 1cm resolution until 66cm, and at 2cm resolution until 136cm.



INTERPRETATIONS: SPRING LAKE

Spring Lake has historically held at least a small population of centric-type diatoms, specifically of the genus *Stephanodiscus*. *Stephanodiscus* has been well studied in Minnesota lakes in different eco-regions, and it was found that *Stephanodiscus* was present in areas that had clear agricultural runoff, urban inputs, and municipal waste disposal (Ramstack et al, 2003). In this case, agricultural input is the main source of nutrient input from surrounding farm areas and previous farming directly around the lakes. Smear slide analysis shows a general range of 50-80% centric diatoms that prevail from the 1930s to present in the deeper core. Lead concentration as determined by XRF rises in the intermediate and deep cores around the historical time of human settlement in the early to late 1800s, and these results bear the same trend as ICP analysis for lead accumulation run in 2010 on the intermediate core (Czeck, 2010). Sedimentation rates have clearly increased over time at both sites in the lake, presumably as the result of increased nutrient loading, causing higher precipitation of ions in solution, increased deposition of biogenic material, and higher clastic input from farming and construction around the lakes. Using the concentrations of iron and manganese, we calculated the Fe:Mn ratio and compared it to the concentration of iron. In both the intermediate and deep cores, there has been a five times decrease in the Fe:Mn ratio since the mid to late 1800s, consistent with the time of human settlement. Fe:Mn ratios can represent the onset of reducing conditions, marked generally by an increase at the start of reducing conditions and a decrease as anoxia becomes permanent (Swain, 1984; Tracey et al, 1996). When iron decreases, the ratio is expected to decrease unless more manganese is also being precipitated. However, if iron is increasing and the ratio is decreasing, this means a significant amount of manganese is being precipitated, which is more common in reducing environments. We have seen a marked stability or increase in iron since the 1950s in both cores (especially in the last two decades), yet the Fe:Mn ratio continues to decrease. We interpret the indirect relationship between iron and the Fe:Mn ratio to be indicative of more anoxic conditions in the lake. Coinciding with the changes in Fe:Mn and iron concentration, another redox sensitive element, copper, makes a significant jump in concentration by an order of magnitude (20 ppm to 100+ppm) over only a decade (1950-1960) in the deep core. There is also an increase in copper in the intermediate core, but it takes place to a lesser extent and over a longer timescale. Finally, the most visible line of evidence in these cores is the varves that have been produced within the last 20 years. We hypothesized that decreasing oxygen levels reduce the number of organisms available to disturb the top of the sediment column, allowing both greater preservation of diatom shells and a higher concentration of calcite. In fact, the amount of calcite in the both cores has been rising since the 1940s and 1950s, also coinciding with a doubling of calcium from roughly125,000 to 250,000ppm since the 1940s.

INTERPRETATIONS: LOWER PRIOR LAKE

In contrast to Spring Lake, Lower Prior Lake (LPL) has been considerably more stable in terms of ecology and geochemistry. Most of the elements determined by XRF do not vary much at all prior to the last decade or so, with the exception of lead which quadruples from 10 to 40ppm during the time of Euro-American settlement in the 1800s. Lead begins to rise again after WW2 in the 1950s, and gradually does so until 1980, where lead concentration remains mostly stable through the present. LOI results show that the carbon content and inorganic content remain almost constant throughout the last 210 years. The only hints of ecological changes are seen in the smear slide results. Regarding the total biogenic fraction, macrophyte fragments make up 50-70% prior to the early 1900s, whereas from 1910 to present, macrophytes only make up 20-50% of the total fraction. Concerning the diatom fraction, it is clear that pennate diatoms constituted 90-100% of the diatom species until 1910. At this time, centric *Stephanodiscus* diatoms begin to show up in the record, and since the late 1980s, the population has skyrocketed from roughly 20% to 90% of the total diatom fraction. Clearly, LPL was not as nutrient rich as Spring Lake was until very recently. After the 1980s farming crisis, agriculture ramped up in the area and undoubtedly used a lot of fertilizers, most likely feeding the increasing *Stephanodiscus* diatoms. Finally, the Fe:Mn ratio comparison to iron concentration is illustrated in Figure 4, and this shows a strong inverse relationship between the two representing more anoxic conditions. I believe that a shifting redox state as shown by an increase in higher deposition of redox sensitive metals, such as copper and manganese, combined with higher nutrient levels potentially indicate the beginnings of a change to a more eutrophic to hypereutrophic state in the coming decades unless phosphorus input to the lake is decreased.

CONCLUSIONS

1) Sedimentation into both lakes has increased substantially, presumably by human influence
2) Spring Lake historically has been a much more nutrient rich lake than Lower Prior Lake
3) Spring Lake has shifted both in terms of ecology and geochemistry. Ecologically, Spring Lake is now dominated by *Stephanodiscus* diatoms. Geochemically, sediments in Spring Lake are now more calcitic and contain higher amounts of copper, manganese, calcium, and lead than most (Ca) or all (Cu, Mn, Pb) of the geochemical record
4) Agricultural runoff has played a large role in the nutrient levels in both lakes
5) Lower Prior Lake may be showing signs of becoming more anoxic in the deepest parts of the lake as a result of increased productivity
6) Prevention of hypereutrophic conditions in Lower Prior Lake seem very feasible if phosphorus load is decreased, whereas Spring Lake may be more naturally a nutrient sink for runoff regardless of decreasing the phosphorus load

ACKNOWLEDGEMENTS

I would like to thank everyone who helped me with this project, including Erik Smith, Alex Blel, Libby Tousignant, Will Hobbs, Kelly McGregor, Kyle Zimmer, Daniel Engstrom, and Mike Kinney. I would also like to thank the St. Croix Research Station, the Prior/Spring Lake Watershed District, the University of Minnesota Limnological Research Center, and the University of St. Thomas Geology Department.

SOURCES

Czeck, B., 2010. "Reports." Prior Lake Spring Lake Watershed District. N.p., 2010. Web. 19 Sep 2012. <http://www.plslwd.org/reports.php>.

Ramstack, J. M., S. C. Fritz, D. R. Engstrom, and S. A. Heiskary. "The Application of a Diatom-based Transfer Function to Evaluate Regional Water-quality Trends in Minnesota since 1970." Journal of Paleolimnology. Kluwer Academic Publishers, 6 July 2002. Web. 30 Oct. 2012. <http://www.nrcresearchpress.com/doi/abs/10.1139/f04-015#.UJNa4l7n2p0>.

Swain, E.B., 1894, The paucity of blue-green algae in meromictic Brownie Lake: iron limitation or heavy metal toxicity [Ph.D. dissertation]: University of Minnesota.

Tracey, B., Lee, N., and Card, V., 1996, Sediment indicators of meromixis: comparison of laminations, diatoms, and sediment chemistry in Brownie Lake, Minneapolis, USA: Journal of Paleolimnology, v 15, p 129-132.