WHAT GREEN LAKE'S SEDIMENTS TELL US ABOUT ITS HISTORY

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INTRODUCTION

Questions often arise concerning how a lake's water quality has changed through time as a result of *watershed* disturbances. In most cases there is little or no reliable long-term data. Questions often asked are if the condition of the lake has changed, when did this occur, what were the causes, and what were the historical condition of the lake? *Paleoecology* offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include *diatom* frustules, cell walls of certain algal species, and subfossils from aquatic plants. The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. Using the fossil remains found in the sediment, we can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

Figure 1. Typical sediment core from the lake.

In 1999, sediment cores were extracted from 4 sites throughout Green Lake. The main sites were in the eastern and western basins (Figure 2). Samples from these sites were used for sediment dating, inputs of important chemical variables, and reconstruct the nutrient history of the lake during the last 150 years.

This summary sheet briefly describes the results from the sediment cores, which document changes in the water quality of Green Lake during the last 150 years.

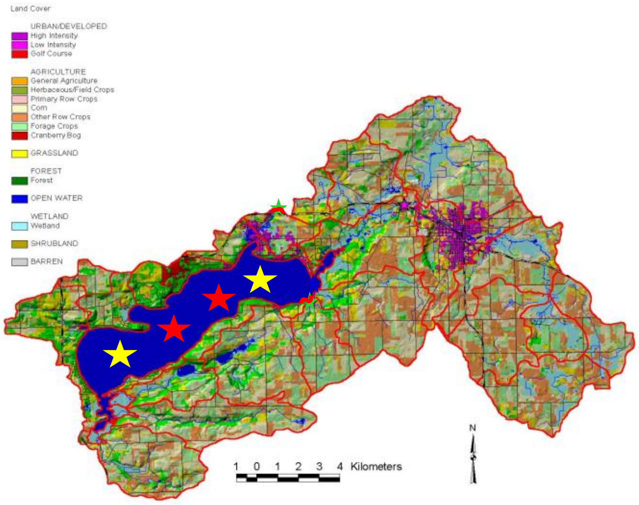

Figure 2. Green Lake and its watershed. Stars are the core sampling sites. The 2 sites are either end are the main sites.

GREEN LAKE WATERSHED HISTORY

Winnebago Indians prior to the arrival of the first European settlers in 1835 inhabited the area around Green Lake. The landscape was much different then. The land was entirely prairie with oak openings. There were few large trees. The Indians called the lake “Daycholah” while Europeans named the lake for its emerald green color. Early settlement occurred on the southern side of the lake but the town of Dartford (now Green Lake) was platted in 1847 at the lake’s outlet. Through the years more settlers arrived and the area became popular for tourists. Many hotels were constructed and agricultural activity increased in the watershed. Today the village of Green Lake and the city of Ripon are located in the watershed. Landuse in most of the watershed is in agriculture but the lakeshore consists of homes.

SEDIMENTATION RATES

Sediment dating allows for the estimation of when certain things happened in the lake and its watershed. It also gives an estimation of how much sediment is accumulated over time. This is done using radionuclides that are deposited in the sediments.

The mean *sedimentation rate* over the last 150 years in the western basin was much lower at 0.017 g cm^{-2} yr^{-1} compared with 0.036 g cm^{-2} yr^{-1} in the eastern basin (Figure 3). The rate in the western basin is one of the lowest compared with other Wisconsin lakes. The higher rate in the eastern basin is because most of the tributaries enter the lake here, including the major tributary, Silver Creek. These tributaries bring in a great deal of sediment from the watershed.

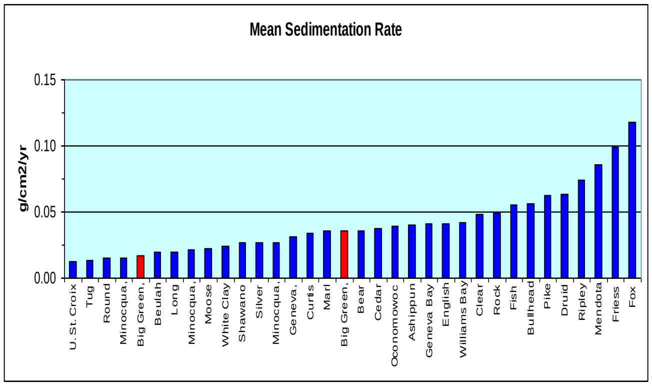

Figure 3. Mean sedimentation rates for selected Wisconsin lakes.

More important than the mean sedimentation rate is how the rate has changed during the last century. The present sedimentation rate in the eastern basin is similar to the historical rate (Table 1). In the western basin, the present rate is double the historic rate. This is increased rate is an indication that changes have occurred in the watershed during the last century.

Table 1. *Sedimentation rates in g cm^{-2} yr^{-1}*

	WESTERN	EASTERN
RECENT	0.023	0.045
HISTORICAL	0.011	0.044

SEDIMENT CHEMISTRY

By examining what chemicals have been deposited in the sediments, we can infer what changes have occurred in the watershed. For example, *titanium* is found in association with soil particles and thus is an indication of changes in soil erosional rates in the watershed. Since iron and manganese are released from the bottom sediments when the overlying waters lack dissolved oxygen, changes in their levels are an indication of changes in the oxygen content of the bottom waters. *Phosphorus* and *nitrogen* are pollutants of major concern in lakes. In high concentrations they lead to increased plant growth and algal blooms.

In both the eastern and western basins, titanium

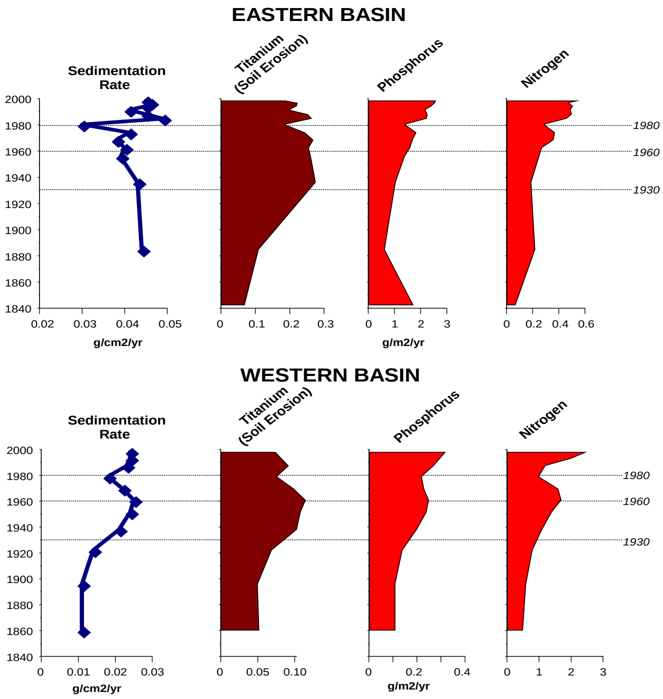

Figure 4. Profiles of important chemicals

significantly increased after 1930 (Figure 4). This is an indication of increased soil erosion in the watershed. This likely is the result of the increased mechanization of agriculture with the development of tractors and other farm equipment, which allowed more land to be cultivated. In the eastern basin during this time the sedimentation rate did not increase but it did in the western basin. In Green Lake, much of the sediment that is deposited is not from soil erosion but is *marl*. This is typical in a hard water lake like Green Lake. After 1960, titanium generally declined. This likely indicates improved cropping practices that reduced soil erosion in the watershed.

Nutrient inputs (phosphorus, nitrogen) increased after 1930 in the western basin but the increase occurred later in the eastern basin. In both basins, the greatest deposition of nutrients has occurred in the last decade. It appears that the major input of nutrients is not from soil erosion since titanium deposition has declined during this period.

Changes in the deposition of chemical variables that have occurred since European settlement are also evident in changes in sediment enrichment factors (SEF). If the present deposition rate is higher than the historical rate, the SEF will be greater than 0. The higher the factor, the greater the deposition at the present time compared with historical levels. SEFs for titanium (soil erosion) and phosphorus are higher in the eastern basin compared with the western basin (Table 2). Again, this reflects the fact that the most of the lake's tributaries enter the eastern basin. Most alarming is the increase in nutrients. There has been a doubling of phosphorus in the western basin while phosphorus deposition has increased much more in the eastern basin.

Table 2. ***Sediment enrichment factors. The higher the value the greater the increase of a chemical in recent times compared with historical levels.***

	WESTERN	EASTERN
TITANIUM	**0.6**	**2.0**
PHOSPHORUS	**1.0**	**6.3**
NITROGEN	**3.9**	**2.9**

Even though soil erosion has been decreasing in the last few decades, nutrient levels have been increasing. So what is the major source of the increase? Figure 5 shows profiles of titanium (soil erosion) and uranium. While titanium declined after 1960, uranium has steadily increased since 1950. Uranium (or cadmium) is often found as a contaminant in commercial fertilizers. This is a result of where the phosphate material is mined. Therefore increases in uranium are an indication of an increase in the use of fertilizers. In general, fertilizers have been more widely used since World War II. After the war, many factories that produced ammunition were converted to making fertilizer. It appears that in Green Lake, a significant source of nutrients during the last 50 years has been fertilizer runoff from agricultural fields and shoreline homes.

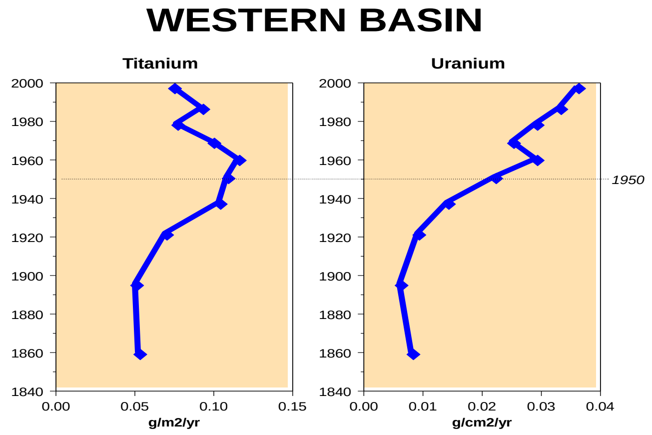

Figure 5. Profiles of titanium (soil erosion) and uranium (commercial fertilizer).

When bottom waters lose dissolved oxygen, *manganese* is released from the sediments. The decline in the ratio of iron to manganese (Fe:Mn) is an indication of declining oxygen in the deep waters

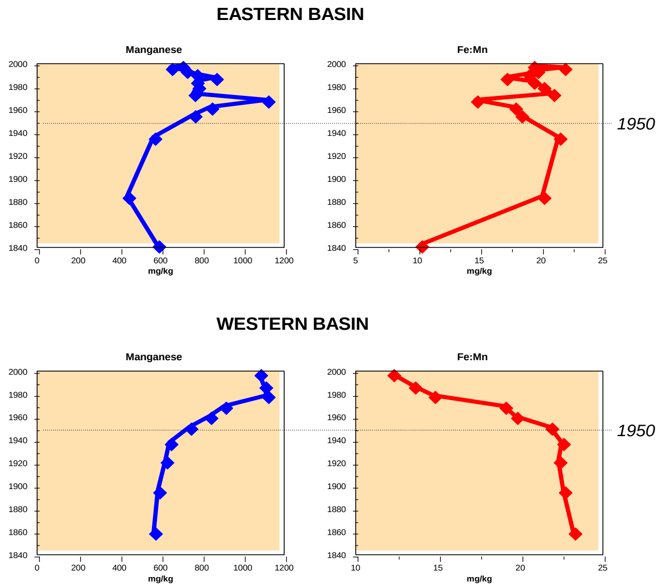

Figure 6. Profiles of manganese and Fe:Mn. A decline in the Fe:Mn indicates a loss of oxygen in the bottom waters of the lake.

of the lake. In the eastern basin there has not been a decline in the Fe:Mn ratio during the last 150 years.

In the deeper western basin, the Fe:Mn ratio has declined since 1950 (Figure 6). This corresponds with increase in phosphorus deposition. This implies that the increased phosphorus has resulted in increased productivity in the lake and the increased decaying organic matter is depleting oxygen at a faster rate than happened prior to 1950. This does not mean that the bottom waters of the western basin are completely devoid of oxygen, just that the level of oxygen is lower at the present time compared to pre-1950.

INDICATOR ORGANISMS

Aquatic organisms are good indicators of a lake's water quality because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis is *diatoms*. These are a type of algae which possess siliceous cell walls which enables them to be highly resistant to degradation and are usually abundant, diverse, and well-preserved in sediments. They are especially useful as they are ecologically diverse. Diatom species have unique features as shown in Figure 7, which enable them to be readily identified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. The diatom community indicates that the lake's water quality during the 1800's was very good. Phosphorus levels were somewhat lower in the western basin compared with the eastern basin (Figure 8). Phosphorus levels remained low until about 1930 when they began to slightly increase in the western basin until the levels were similar throughout the entire lake basin. In the eastern half of the lake, phosphorus levels quickly increased after 1950. This is the same time period when phosphorus deposition levels also increased in response to increased use of commercial fertilizers in the watershed. In the eastern part of the lake, phosphorus levels declined slightly from the period 1970-1990. However, in the western basin, phosphorus levels continued to increase during these two decades. Throughout the lake basin, the highest levels of phosphorus during the last 150 years occurred during the 1990's. There is some evidence that phosphorus levels have started to decline slightly during the last 5 years. However, current levels are considerably higher than they were historically.

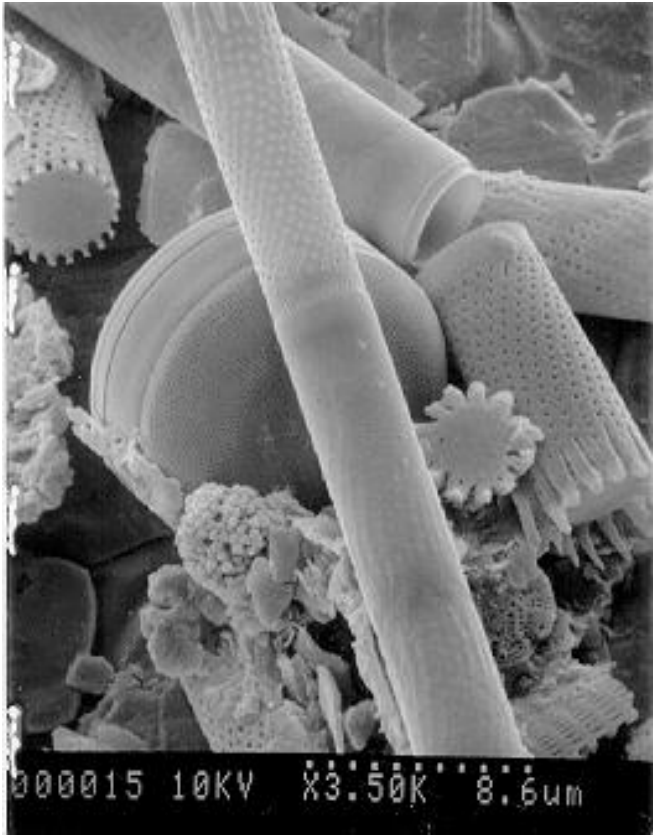

Figure 7. Picture of typical diatoms found in Green Lake.

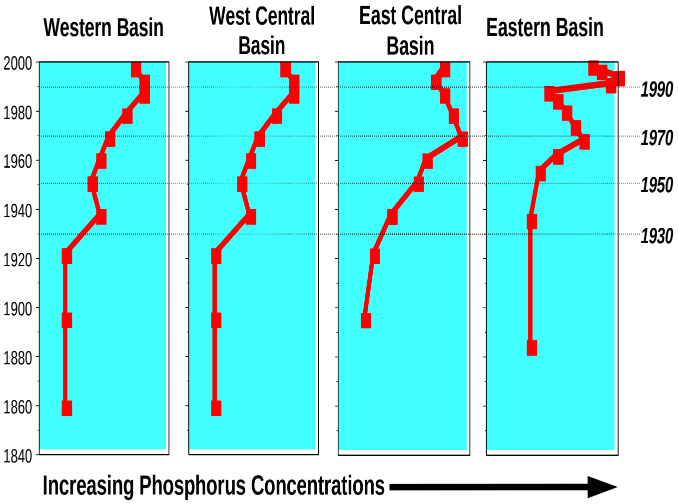

Figure 8. Profiles of diatom inferred phosphorus levels in the lake during the last 150 years.

SUMMARY

- **Historically, phosphorus levels were highest in the eastern portion of the lake. This was because most of the tributaries enter the lake there.**
- **Soil erosion in the watershed increased significantly beginning around 1930. This was the result of increased mechanization of agriculture.**
- **Following World War II, the use of commercial fertilizers increased resulting in increased delivery of phosphorus to the lake. This increased phosphorus happened despite a reduction in soil erosion in the watershed.**
- **The lake soon responded to increased phosphorus loading by experiencing an increase in algal levels. This was most apparent in the eastern part of the lake.**
- **The highest phosphorus levels during the last 150 years occurred during the 1990's.**

GLOSSARY

Diatoms – Type of algae that possesses shells made of silica. This allows them to remain in the sediments for many years. Many diatoms live under unique environmental conditions including varying nutrient levels.

Manganese – A chemical that is released from the sediments when there is little dissolved oxygen in the bottom waters. Changes in its concentration indicate changes in the oxygen content of the bottom waters.

Marl – A type of sediment made of calcium carbonate that is deposited in hardwater lakes found in central and southern Wisconsin. Its color is often light gray.

Nitrogen - A major nutrient responsible for plant fertilization. While it is often not as important as phosphorus for plant growth, when present in excessive levels can help cause algal blooms.

Paleoecology – The study of a lake's history using fossils preserved in the sediments.

Phosphorus – A major nutrient responsible for plant fertilization. It is usually the nutrient that causes excessive algal growth.

Sediment dating – The use of scientific techniques to determine the age of a sediment slice.

Sedimentation rate – The rate at which sediment is deposited at the bottom of the lake.

Titanium – A chemical that is generally found only in soils. Changes in its deposition is an indication of the watershed soil erosion rate.

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