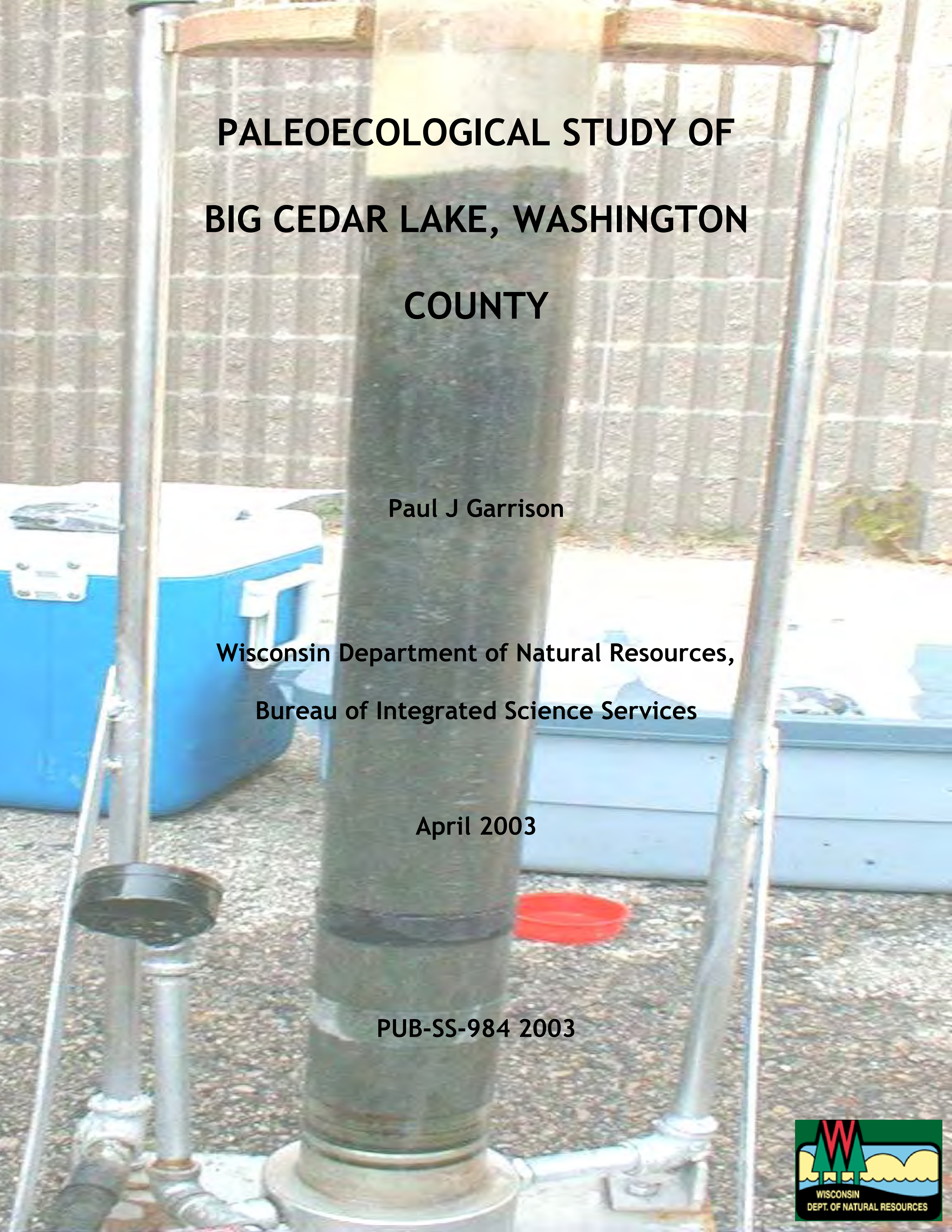

PALEOECOLOGICAL STUDY OF BIG CEDAR LAKE, WASHINGTON COUNTY

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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, one can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

Two sediment cores was collected from Big Cedar Lake on 3 November 1998. One core was in the deep area of the south basin in a water depth of 100 feet and the other core was taken in the deep area of the north basin in 37 feet of water. The core from the south basin was 44 cm in length and the core from the north basin was also 44 cm in length. Both cores were sectioned into 1 cm intervals. The cores were dated by the ^{210}Pb method and the CRS model used to estimate dates and the sedimentation rate. The cores were analyzed for diatoms to assess changes in nutrient levels during the last 150 years and geochemical variables in order to determine the causes of changes in the water quality.

Site Description

Prior to the arrival of Europeans during the 1830s the landscape around Big Cedar Lake was mostly forested with scattered wetlands. Early settlers removed many of the trees and used the land for subsistence farming. Later in the 19th century, especially after the development of the moldboard plow, a larger part of the lake's watershed was plowed. The original land surveys were done in this township during 1834-36. Land grants had already been granted around these lakes although no structures were shown in the survey (Figure 1). Throughout the last half of the 19th century farming became increasingly efficient with the improvement of equipment. During the twentieth century farming practices became increasingly mechanized which enabled the farming of more land. In many other areas of the state this resulted in an increase in the sedimentation rate of lakes as well as increased productivity. During this time the number of homes surrounding Big Cedar Lake likely increased. In 1975 the Big Cedar Lake Protection and Rehabilitation District was formed which enabled the obtaining of state grants to develop a lake management plan. Several land acquisition grants were obtained which allowed the District to purchase farmland and take over 150 acres of farmland out of production.

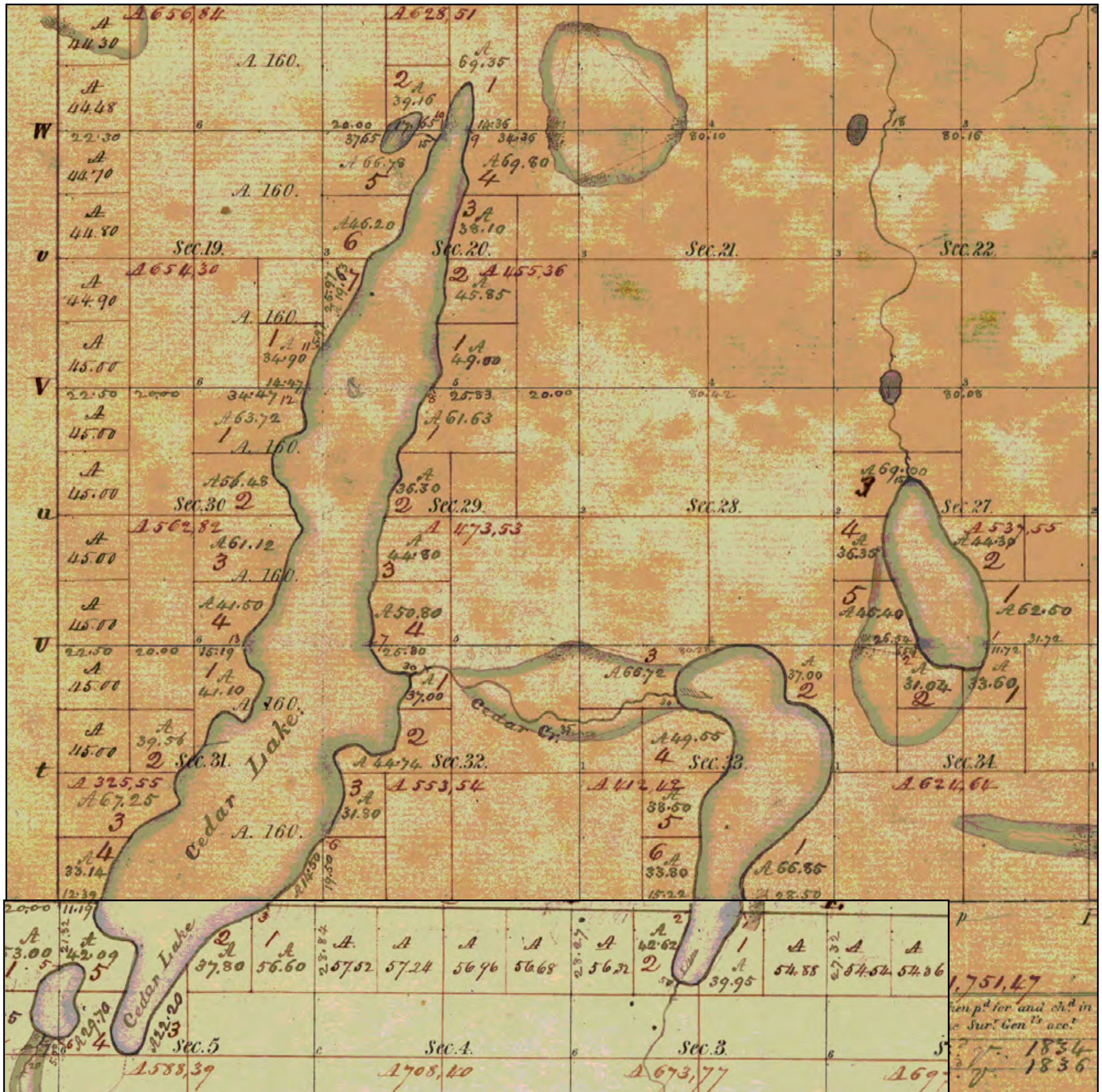

Figure 1. Map from original land survey performed in 1834-36.

Results and Discussion

Dating

In order to determine when the various sediment layers were deposited, the samples were analyzed for lead-210 (^{210}Pb). Lead-210 is a naturally occurring radionuclide. It is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why is sometimes is found in high levels in basements) it moves into the atmosphere where it decays to lead-210. The ^{210}Pb is deposited on the lake during precipitation and with dust particles. In the lake sediments it slowly decays. The half-life of ^{210}Pb is 22.26 years (time it takes to lose one half of the concentration of ^{210}Pb) which means that it can be detected for about 130-150 years. This makes ^{210}Pb a good choice to determine the age of the sediment since European settlement began in the mid-1800's. Dates and the sedimentation rates were determined using the CRS model (Appleby and Oldfield, 1978).

There can be problems with this dating technique. For example, when sediment has moved after it was deposited, there have been large changes in sediment deposition over the last 150 years, and errors associated with lab analysis with sediments that are over 100 years old. For these reasons the accuracy of the ^{210}Pb dates is verified by other methods. These methods usually involve measuring parameters that are known to have been deposited at a certain time and comparing stratigraphic changes in the core in Big Cedar Lake with other lakes in the region.

Cesium-137 (Cs^{137}) can be used to identify the period of maximum atmospheric nuclear testing (Krishnaswami and Lal, 1978). The peak testing occurred by the USSR in 1963 and thus the ^{137}Cs peak in the sediment core should represent a date of 1963. Another sediment marker that can be used in Big Cedar Lake is arsenic. Sodium arsenite was used for aquatic plant control during the 1950-60's before its use was banned. The peak application of sodium arsenite in Big Cedar Lake was in 1963 (Lueschow, 1972). Therefore, the peak arsenic concentration should indicate this date. Figure 2 shows the peak concentrations of ^{137}Cs and arsenic. In the core from the south basin, the peaks of cesium and arsenic are offset by 1 cm. In the north basin, the peaks occur at the same depth. Both of these elements can move somewhat after their deposition so the fact they are offset is not a concern. The depth of these peaks is very close to the date of 1963 calculated by the ^{210}Pb model indicating that the model results are very good.

Sedimentation Rate

The mean sedimentation rate for the last 150 years was 0.015 g cm^{-2} yr^{-1} in the south basin and 0.008 g cm^{-2} yr^{-1} in the north basin. These rates are some of the lowest rate found in Wisconsin lakes (Figure 3). The higher rate in the south basin in not unexpected since the greatest rate in a lake typically occurs in the deepest area because of sediment focussing.

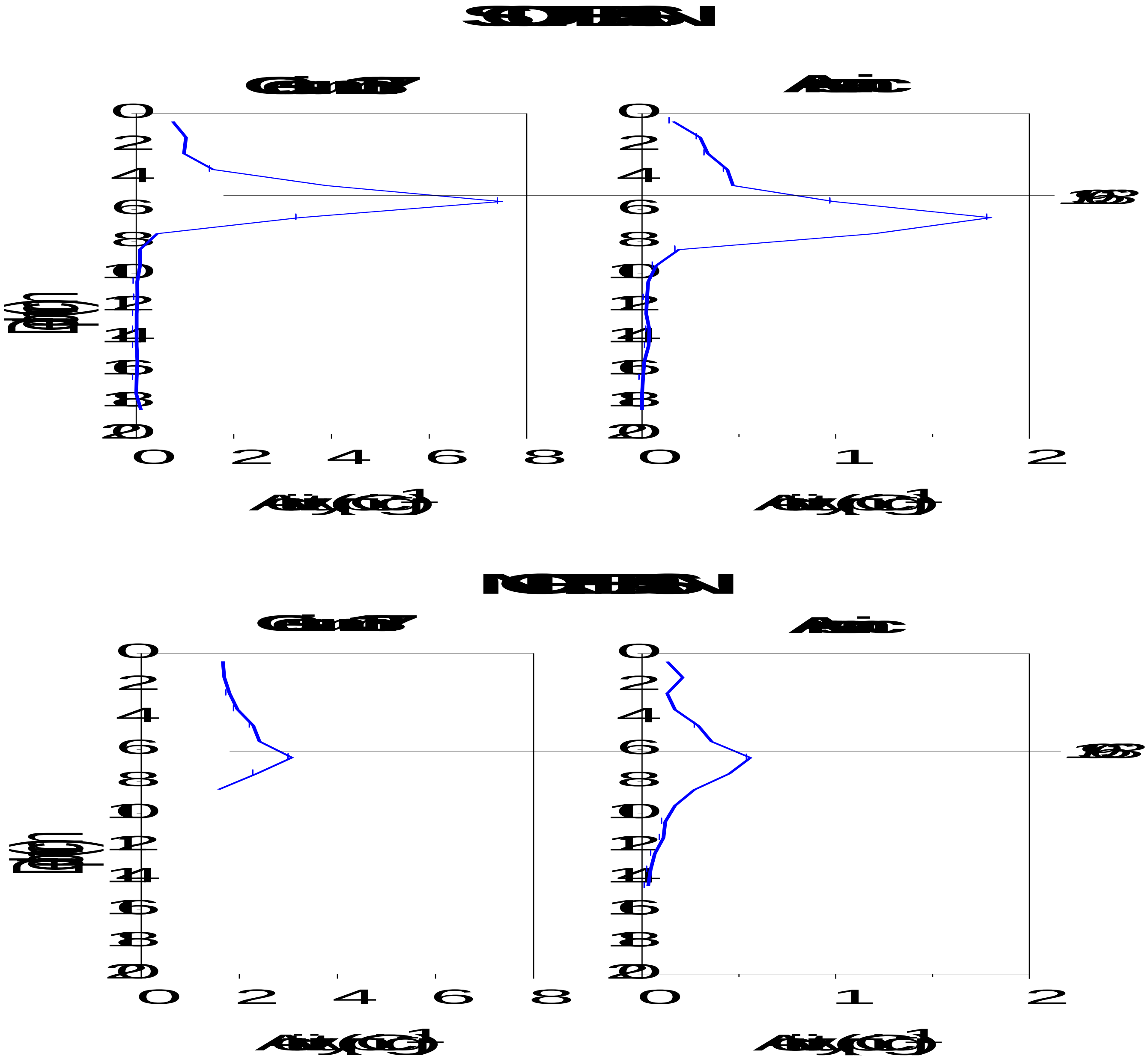

Figure 2. Profiles of cesium-137 and arsenic. Cesium-137 is a byproduct of atmospheric nuclear testing while arsenic was used for aquatic plant control in the 1950-60s. The peak deposition of both of these chemicals in Big Cedar Lake was 1963.

In the south basin, the peak sedimentation rate occurred during the 1880s (Figure 4). Since this high rate was for a short time it likely represents an episodic event, perhaps associated with early landclearing for farming. A secondary peak occurred during the 1930s. This increased rate encompassed a period of about 10 years and may have been associated with shoreline home construction or agricultural activities. Since 1940 the sedimentation rate has been relatively low, near historical levels. There has been a small increase since the mid-1970s, but the increase is not very large.

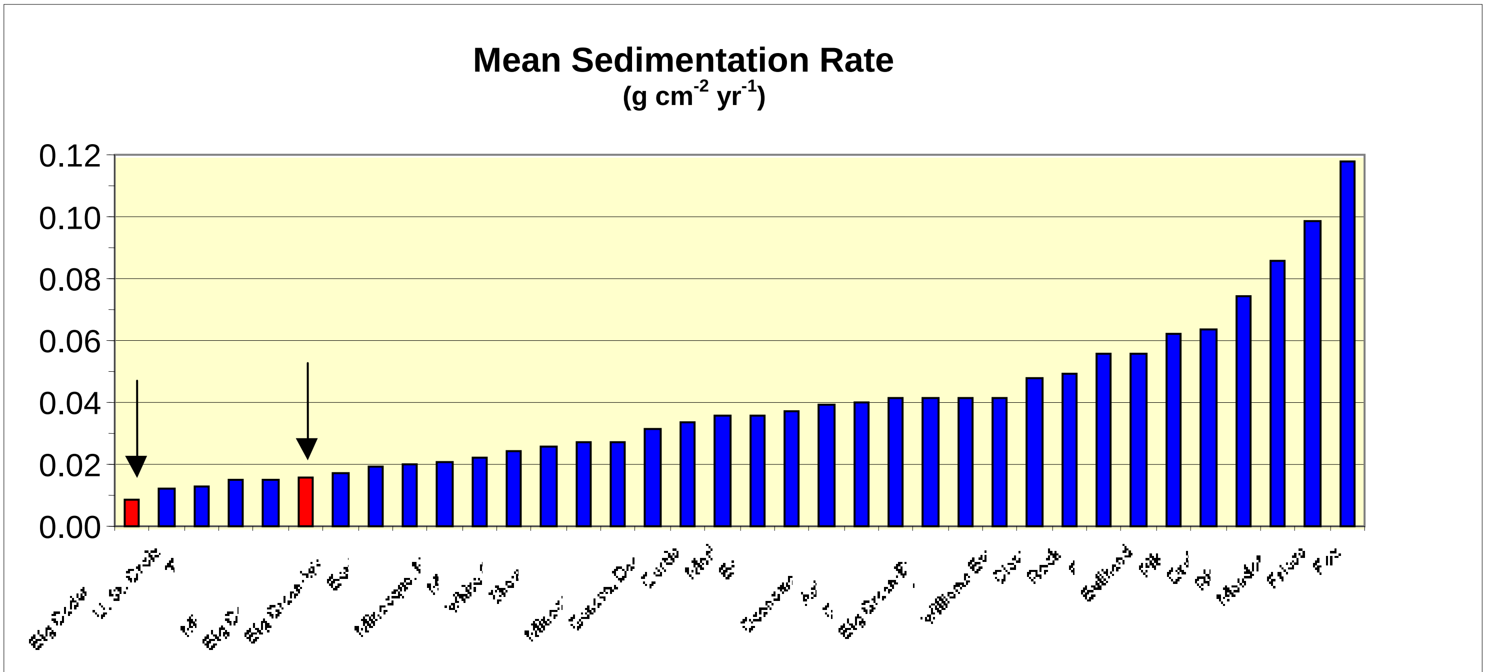

Figure 3. Mean sedimentation rate for the last 150 years for 31 Wisconsin lakes. The arrows indicate the cores from the north basin (left) and the south basin (right).

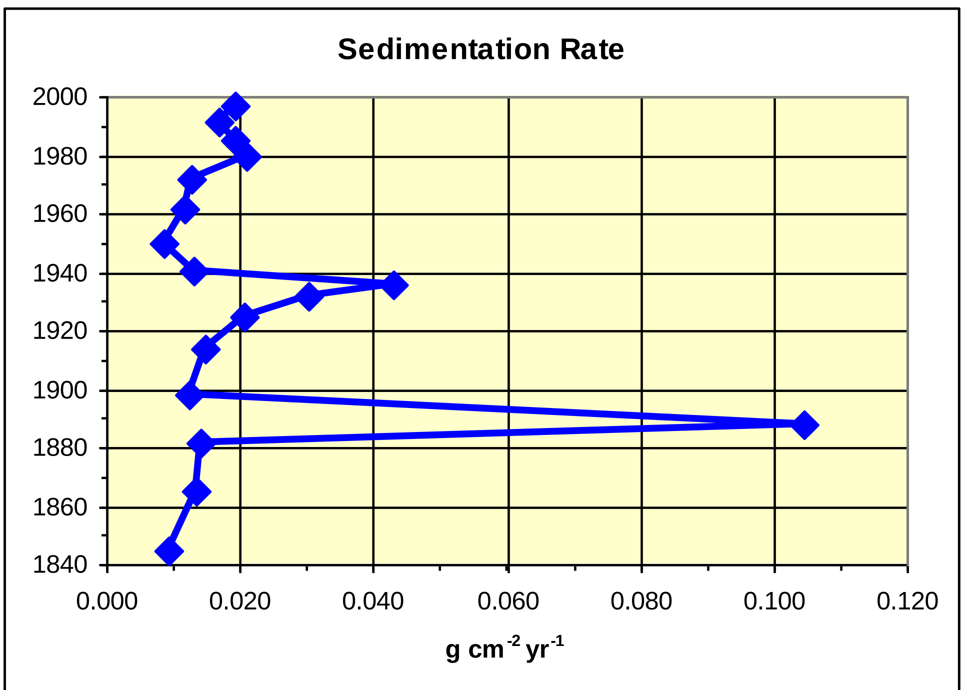

Figure 4. Sedimentation rate for the south basin.

Geochemistry

Geochemical variables are analyzed in order to estimate changes in the delivery of soil and nutrients from the watershed. The chemical aluminum (Al) is usually found in soil particles, especially clays. Changes in Al are an indication of changes in soil erosional rates throughout the lake's history. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. Calcium carbonate is often the most common chemical in hardwater lakes like Big Cedar Lake. These lakes are also known as marl lakes because they precipitate calcium carbonate, which is also known as marl. Marl is very common in Big Cedar Lake and is the reason for the light gray color of the sediment throughout much of the lake. Organic matter is deposited in the lake as a result of algal and aquatic plant production in the lake. Increases in organic matter are an indication of increased productivity of the lake.

In the core from the south basin, aluminum concentrations first began to increase around 1840 (Figure 5). This reflects the initial farming activities near the lakeshore with the arrival of European settlers. The greatest aluminum concentrations occurred between the period 1880-1950. This was the period of the greatest soil erosion around the lake. Soil erosional rates have steadily declined since 1950 reflecting improved agricultural practices during the last 50 years as well as the removal of farming operations from around the lake during the last 25 years.

There was a significant reduction in the calcium carbonate in the core around 1870. This reduction has been found in many hardwater lakes and is associated with early agricultural activity (Engstrom et al., 1985; Garrison, 2000a,b; Garrison and Wakeman, 2000). As more land is cleared for farming, the soil erosion materials from around the lake dilute the calcium carbonate.

The peak phosphorus concentrations occurred between the period 1880-1920. This peak is likely a result of the early agricultural activity around the lake. During this time period the nitrogen levels did not increase above historical levels. The highest nitrogen levels occurred around 1940 when phosphorus also was high. This elevated deposition of nutrients likely is the result of the use of synthetic fertilizers for farming and lawns. Commercial fertilizer use increased tremendously during the last 50 years in order to improve agricultural production as well as use on lawns. The reduction of both phosphorus and nitrogen, especially since 1980, probably reflects the removal of land from agricultural production around the lake. The increase in phosphorus and nitrogen in the surface sample is an artifact of collecting the core in the fall. During the summer both of these nutrients are released from the deep-water sediments when the overlying waters are devoid of oxygen. During fall turnover these nutrients are returned to the sediments resulted in elevated concentrations in the surface sediments.

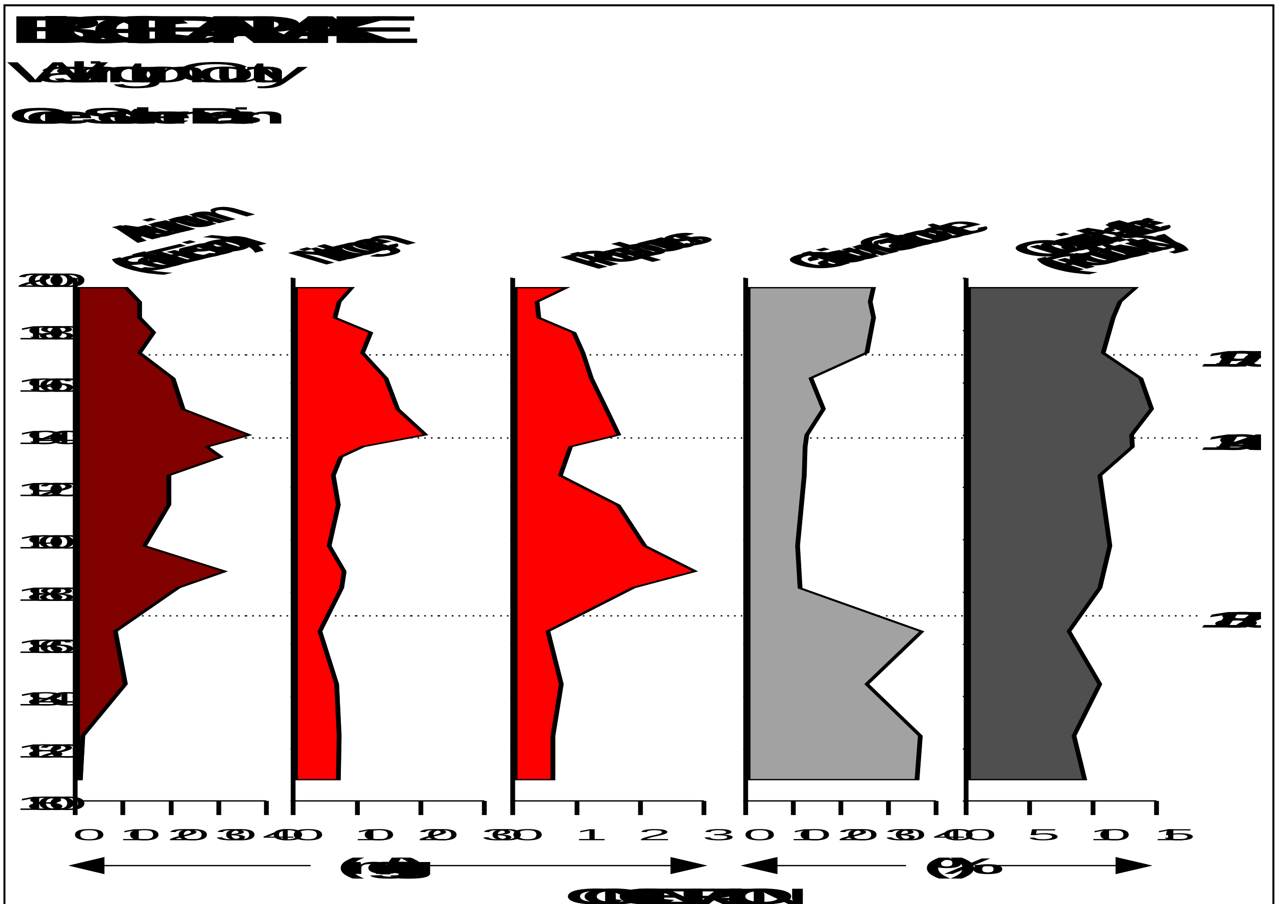

Figure 5. Profiles of selected chemical variables in the core from the south basin. The greatest soil erosion occurred during the period 1880-1950. The rate has been reduced since 1970.

The peak in organic matter occurred during the period 1940-70. This likely reflects increased algal and plant productivity in the lake with increased use of commercial fertilizers and other watershed activities such as shoreline development. With the reduction in the deposition of nutrients, the lake's productivity appears to have declined somewhat. The increase at the top of the core likely reflects the deposition of algae and plants produced in the lake the previous year. During the winter this material would degrade, thus reducing the organic matter production.

Diatom Community

Aquatic organisms are good indicators of water chemistry 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. They are a type of alga which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live under a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 6 shows photographs of two diatom species that were common in the sediment cores.

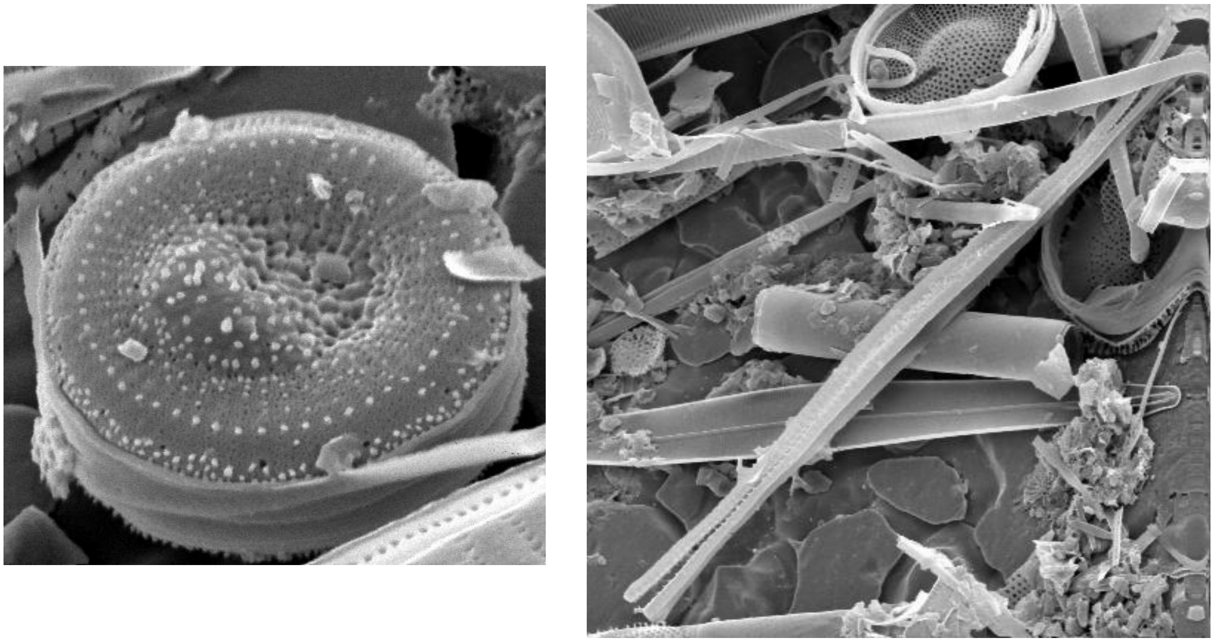

Figure 6. Electron micrographs of the diatoms *Cyclotella michiganiana* (left) and *Fragilaria crotonensis* (right) which were found in the cores from Big Cedar Lake.

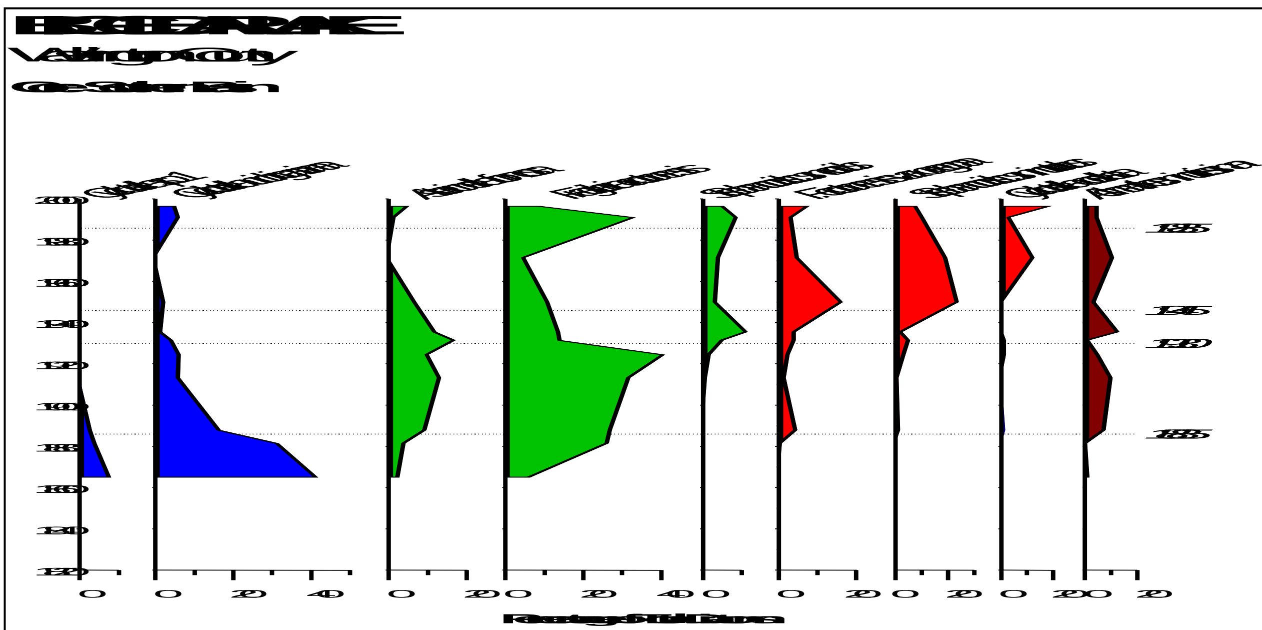

Figure 7. Diatom diagram showing selected common taxa. Diatoms in blue are indicative of low nutrients, green-moderate nutrients, red-high nutrients.

The diatom *Cyclotella michiganiana* (Figure 7) dominated the bottom of the core. Since this diatom grows in the metalimnion, it indicates good water clarity and low nutrient levels (Garrison & Wakeman, 2000). The other common diatom at the bottom of the core was *Cyclotella* sp. 1. This diatom has been found in other marl lakes in southern Wisconsin. This diatom also disappeared from these lakes prior to 1900. Both of these species were often important components of the diatom community in southern Wisconsin lakes prior to European settlement (Garrison, unpublished data). The two *Cyclotella* species decline in the late 1800s while the diatoms *Asterionella formosa* and *Fragilaria crotonensis* increase. The latter two species are indicative of increased, although moderate nutrient levels (Ennis et al., 1983, Engstrom et al., 1985, Christie & Smol, 1993, Stager et al., 1997). Unlike *C. michiganiana*, *A. formosa* and *F. crotonensis* inhabit the surface waters of the lake and do not need as good of water clarity for survival. The increase in nutrient levels after 1880 occurred while soil erosion was increasing (aluminum, Figure 5) and was the result of agricultural practices. This shift from a diatom community dominated by the *Cyclotella* species to one dominated by *A. formosa* and *F. crotonensis*, typically happened during the later part of the nineteenth century of other southern Wisconsin lakes (Garrison, 2000a,b; Garrison & Wakeman, 2000). These two diatoms, which indicate moderate nutrient levels, were the dominant component of the diatom community until 1930.

By 1945 the dominant component of the diatom community was *F. crotonensis* var. *oregona* and *Stephanodiscus minutulus* (Figure 7). These species are an indication of further increases in phosphorus in the lake since these diatoms are found in lakes with elevated nutrient levels (Bradbury, 1975; Carney, 1982; Fritz et al., 1993; Garrison and Wakeman, 2000). *S. minutulus* continued to be present in elevated levels until after 1980 when it declined. This is an indication that nutrient levels in the lake declined around this time. The increase of *F. crotonensis* as well as *S. medius* and *C. michiganiana* since 1990 indicates that phosphorus levels have declined.

Achnanthidium minutissima typically grows attached to aquatic plants. Increases in this diatom are an indication of an increase in density or coverage of plant beds. *A. minutissima* was found in low levels at the bottom of the core. However, around 1885 the abundance increased. This occurred at the same time that the rest of the diatom community indicated an increase in nutrients in the lake. The plant community has remained at elevated levels compared with pre-settlement times through the present time. The increase in plant beds with early European settlement has been found in nearly all lakes in Wisconsin where sediment cores have been analyzed (Garrison, 2000a,b; Garrison and Wakeman, 2000). It appears that the littoral zone responds very early to the increased input of nutrients from the watershed.

Diatom assemblages historically have been used as indicators of trophic changes in a qualitative way (Bradbury, 1975; Anderson et al., 1990; Carney, 1982). In recent years, ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages. These methods are based on multivariate ordination and weighted averaging regression and calibration (Birks et al., 1990). Ecological preferences of diatom species are determined by relating modern limnological variables to surface sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

In the core from the south basin the diatom community was used to estimate summer phosphorus concentrations throughout the core. Phosphorus concentrations were at their lowest at the bottom of the core. Historical P levels are estimated to be about 13 µg L^{-1} (Figure 8). Phosphorus levels began to increase around 1920 and reached their peak values during the period 1945 to 1970. Since the mid-1970s phosphorus values have declined until they are near pre-settlement levels at the top of the core. The increase in summer phosphorus levels during the middle of the twentieth century corresponds to increased levels of nitrogen and phosphorus deposition (Figure 5). Although soil erosion was declining during this period the use of synthetic fertilizers on lawns and agriculture resulted in an increase of nutrients entering the lake from the watershed. Following the formation of the Big Cedar Lake Protection and Rehabilitation District and the effort to reduce nutrient input by removing farms from the watershed as well as efforts to reduce nutrient input from shoreline development, there was a dramatic decrease in phosphorus levels in the lake.

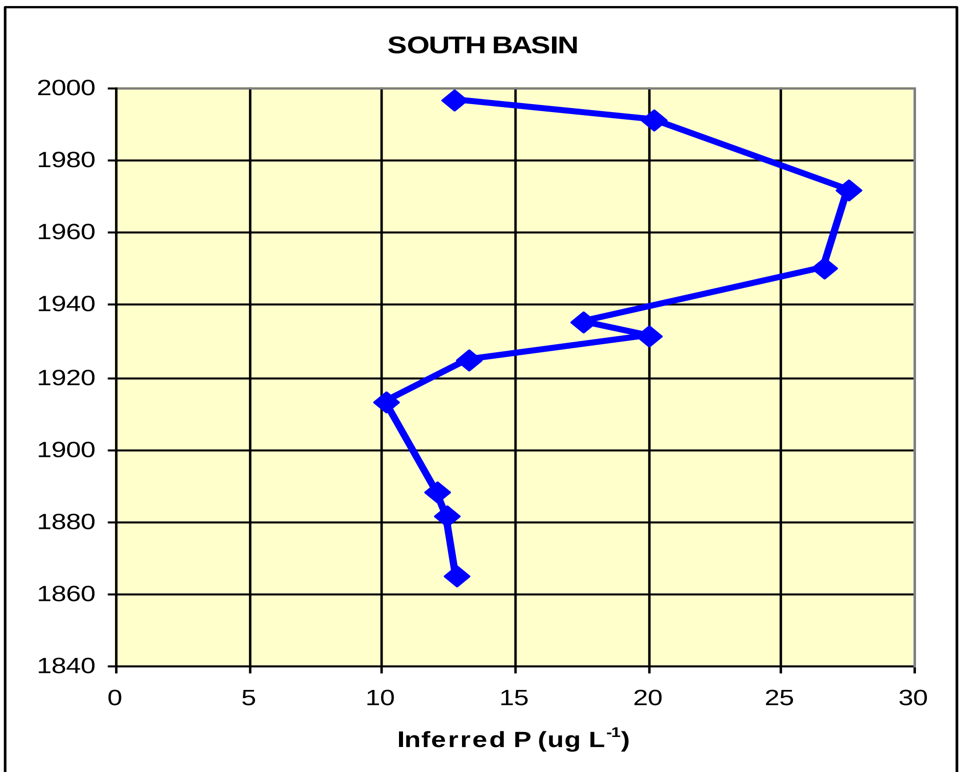

Figure 8. Estimated summer phosphorus concentrations based upon the diatom community.

North Basin

The north basin is smaller and shallower than the south basin. At least in part because of this, this part of the lake has experienced a different water quality history. The sedimentation rate has steadily increased during the last century and the highest rate occurred at the top of the core (Figure 9). This increase in sedimentation was the result of soil erosion (aluminum) from the watershed as well as

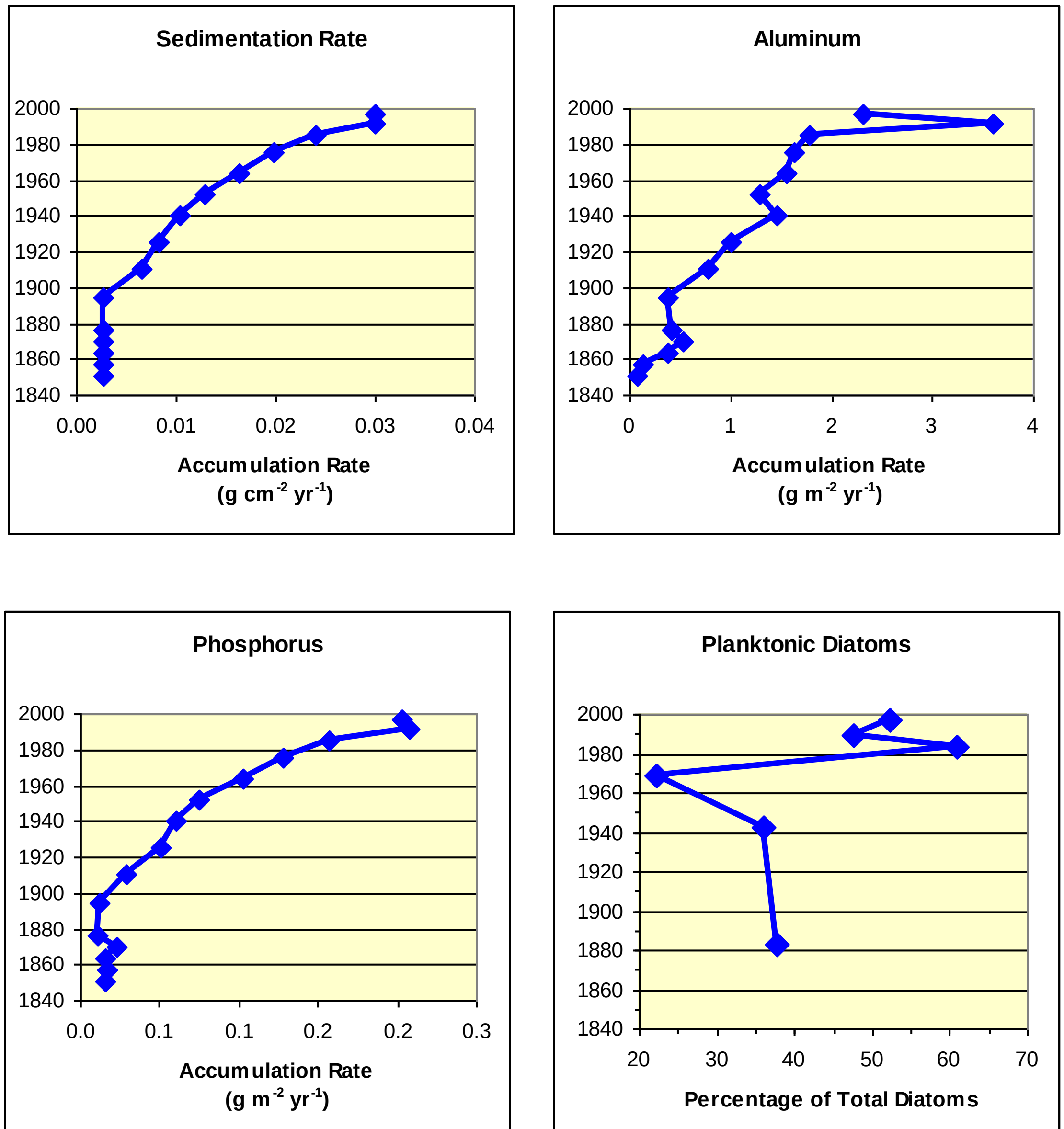

Figure 9. Selected profiles of variables from the core in the north basin. All of these variables indicate declining water quality in this basin, especially during the last 100 years.

increased productivity in this basin. There was a small increase in soil erosion with early farming around 1870, but the greatest increase occurred after 1900. Although soil erosion appears to have declined in the last few years, it still remains elevated. Phosphorus deposition likewise has increased since 1900. The accumulation rate at the present time is ten times greater than it was prior to the arrival of European settlers (Figure 9). The increase in the delivery of phosphorus to the lake is reflected in the diatom community. Planktonic diatoms, which inhabit the open water of the lake, typically become more common with higher nutrient levels (Bradbury & Winter, 1976; Battarbee, 1978). There was a large increase in these diatoms starting around 1980 in the north basin (Figure 9). This is good evidence that the increase in phosphorus loading during the twentieth century has been manifested in greater algal levels in the last 20 years. Prior to this time, much of the increased phosphorus was incorporated in attached plants and their associated algae. Unlike the south basin, the northern part of the lake has not exhibited a decline in phosphorus levels since 1980.

Summary

- The sediment cores from the north and south basins of Big Cedar Lake reflect changes that have occurred in the lake for the last 150 years.
- The south basin has been affected less than the north basin by watershed activities. This likely is because of it is somewhat larger in size but also is much deeper. These factors result in this basin having more water and thus it is able to dilute the nutrients more.
- In the south basin, the sedimentation rate has not significantly increased since the arrival of Europeans during the 1830s, although there have been episodes of increased rates. In contrast, in the north basin sedimentation rates have continually increased during the last 100 years and currently are at their highest rates.
- While the highest soil erosional rates in the north basin occurred in recent times, in the south basin the peak rates were during the period 1880-1950.
- Phosphorus in the surface waters of the south basin began to dramatically increase after 1920. The peak values occurred during the period 1950-70 and were nearly twice as high as pre-settlement levels.
- The work of the Big Cedar Lake Protection and Rehabilitation District has been very effective in reducing the phosphorus levels in the south basin. Current levels are close those experienced in the lake 150 years ago.
- Although phosphorus levels are similar to historical concentrations in the south basin, there are more aquatic plants in the lake now compared with pre-settlement. This is true in both basins.
- Unlike the south basin, the north basin has not experienced a reduction in phosphorus levels in the water.

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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.

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.

Aluminum – A chemical that is generally found only in soils. Changes in its deposition is an indication of the watershed

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