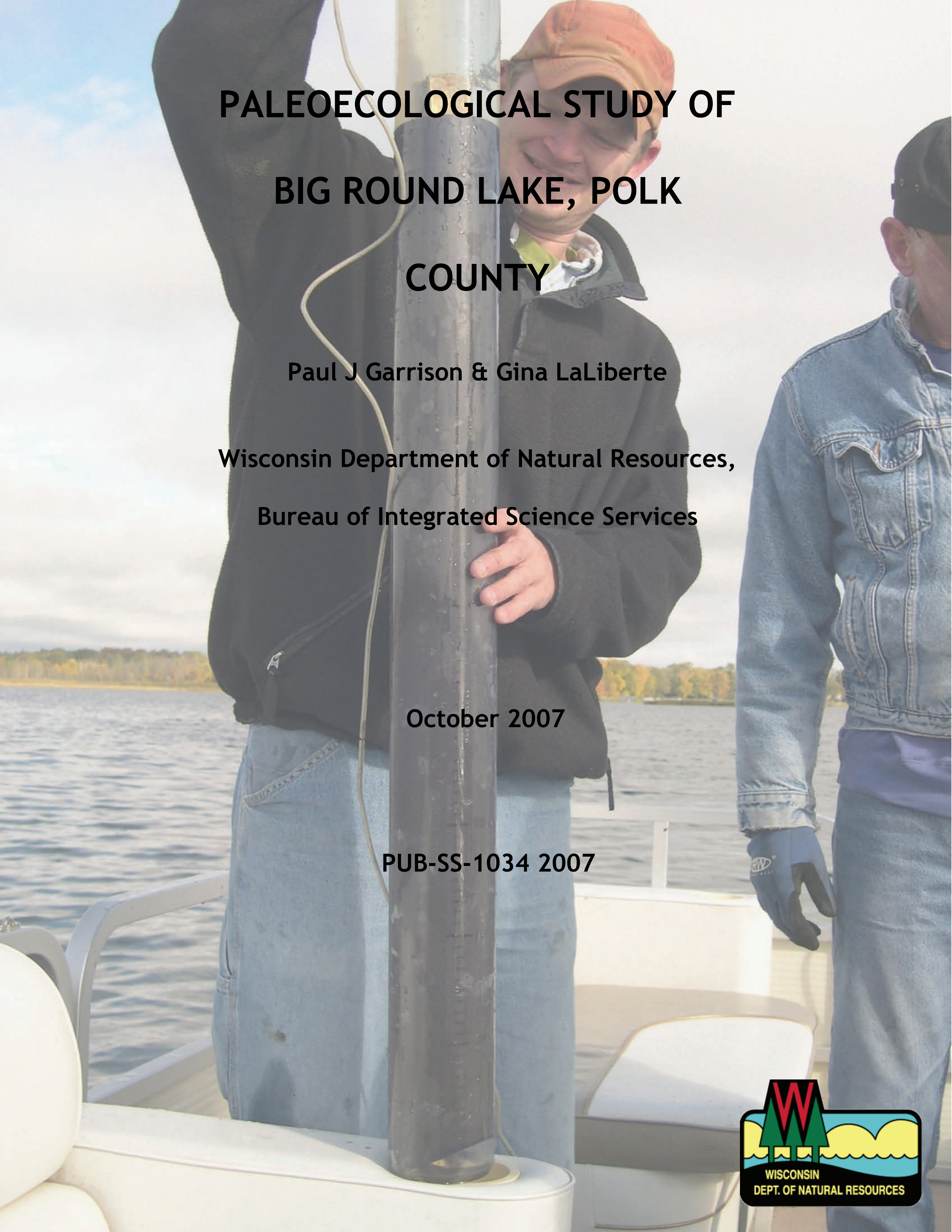

PALEOECOLOGICAL STUDY OF BIG ROUND LAKE, POLK COUNTY

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October 2007

PUB-SS-1034 2007

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.

Big Round Lake is a 1015 acre lake located in Polk County. The maximum depth is about 17 feet with a mean depth of 10 feet. A sediment core was collected from the lake on 28 September 2006. The core was collected with a piston core with a plastic tube having an inside diameter of 8.8 cm. The core was collected from the deep area of the lake (Figure 1). The location of the coring site was 45° 31.555' north, 92° 18.277' west in a water depth of 15 feet. The core was sectioned into 2 cm intervals for the entire core (82 cm). The core was dated by the ^{210}Pb method and the CRS model used to estimate dates and sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and changes in the macrophyte community and geochemical elements were examined to determine the causes of changes in the water quality. Algal fossils, e.g. selected blue green and green algae, were analyzed in the core to assess changes in nutrients.

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. After it enters the lake and it is 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 settle-

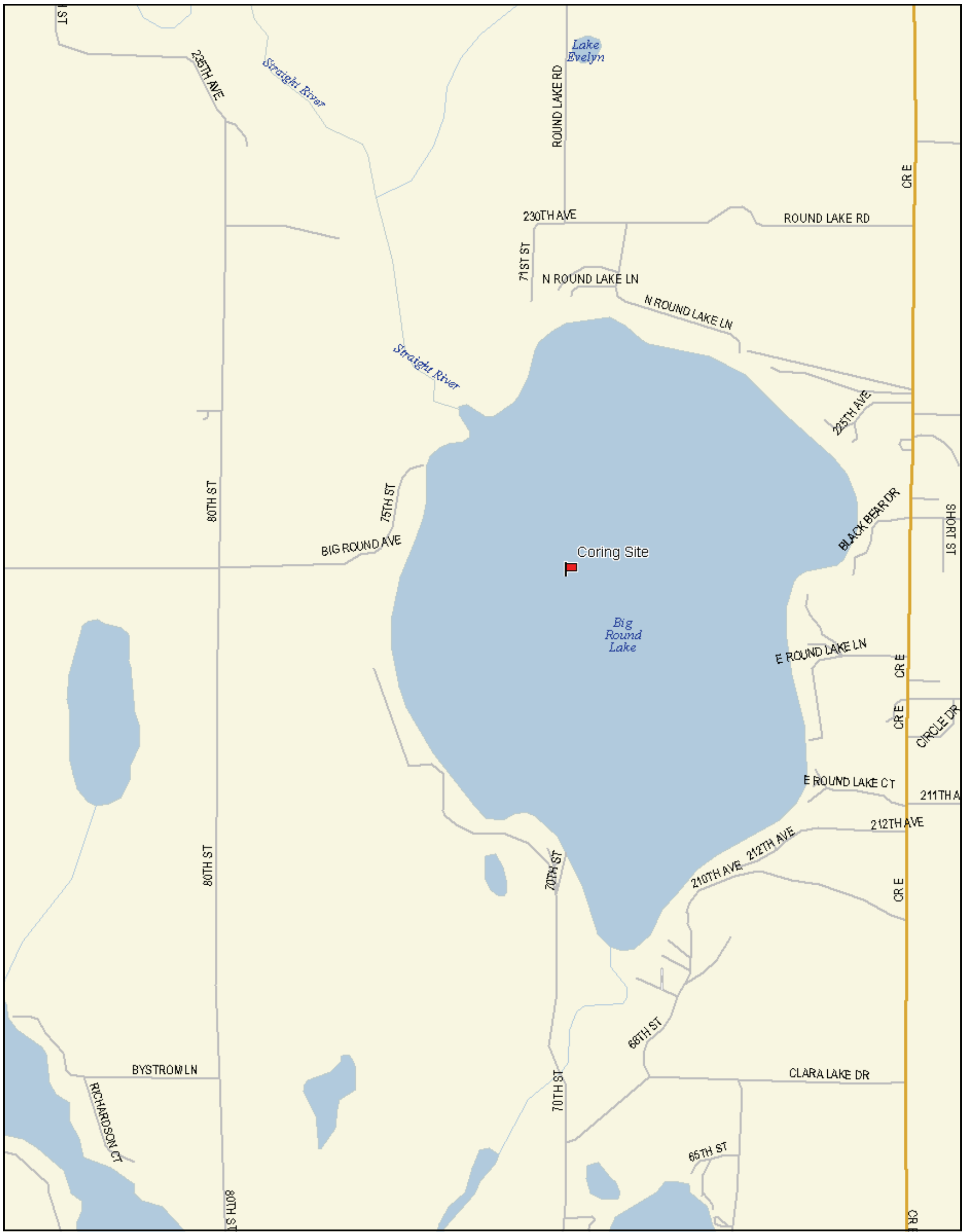

Figure 1. Map of Big Round Lake showing the coring site. The water depth at the site was 15 feet.

ment began in the mid-1800s. Sediment age for the various depths of sediment were determined by constant rate of supply (CRS) model (Appleby and Oldfield, 1978). Bulk sediment accumulation rates (g cm^{-2} yr^{-1}) were calculated from output of the CRS model. Accumulation rates of geochemical variables were computed for each sediment depth by multiplying the bulk sediment accumulation rate (g cm^{-2} yr^{-1}) by the corresponding concentration (mg g^{-1}) of each constituent in the bulk sediment.

Sedimentation Rate

The mean mass sedimentation rate for the last 180 years was 0.009 cm^{-2} yr^{-1}. This is one of the lowest rates that has been measured in 43 Wisconsin lakes (Figure 2). The average linear rate for the same time period is 0.20 cm yr^{-1} which equates to less than 0.1 inch of sediment per year.

To account for sediment compaction and to interpret past patterns of sediment accumulation, dry sediment accumulation rates were calculated. The sedimentation rate during the last half of the nineteenth century declined (Figure 3). It is unclear why this would have occurred. Following the installation of the dam around 1917 the rate began to increase which continued until around 1940. During the last 65 years the rate has been fairly constant with the exception of around 1960 when an episodic event resulted in a temporary increase in the sedimentation rate. Although the present sedimentation rate is higher than it was 100 years ago, the increase is smaller than typically seen in other Wisconsin lakes.

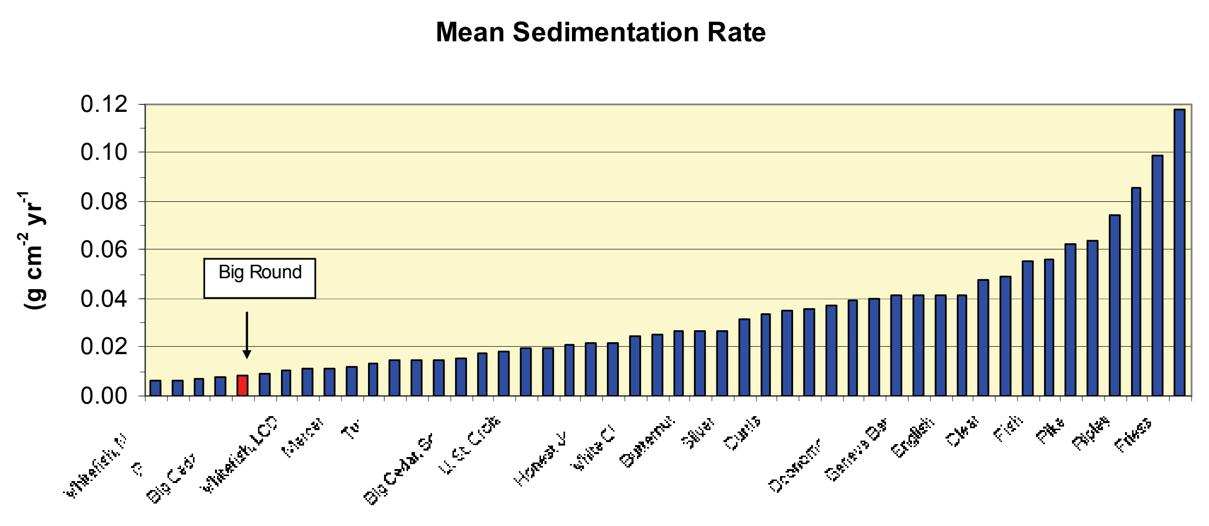

Figure 2. Mean sedimentation rate for the last 180 years for 43 Wisconsin lakes. The arrow indicates Big Round Lake.

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 1). The chemicals aluminum (Al) and titanium are surrogates of detrital aluminosilicate materials and thus changes in their profiles are an indication of changes in soil erosion. Zinc (Zn) is associated with urban runoff because it is a component of tires and galvanized roofs and downspouts. Zinc profiles may also reflect emissions from smelting of lead-zinc ores (Dean 2002). Potassium (K) is found in both soils as well as synthetic fertilizers. Therefore its profile will reflect

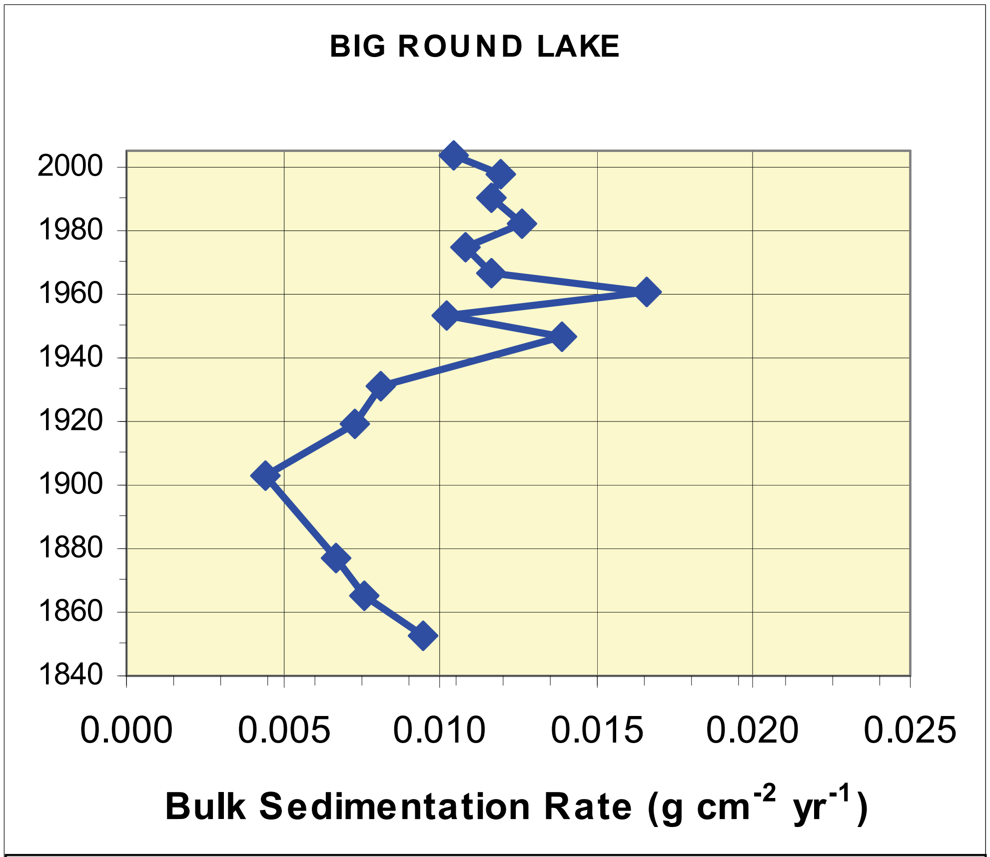

Figure 3. Sediment accumulation rate for Big Round Lake since 1850. While the rate since 1940 is higher than the previous 100 years, the increase is less than experienced in many other lakes.

changes both from soil erosion and the addition of commercial fertilizers in the watershed. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. General lake productivity is reflected in the profiles of organic matter. The organic matter determination includes a number of elements, especially carbon.

Table 1. Selected chemical indicators of watershed or in lake processes.

Process	**Chemical Variable**
Soil erosion	aluminum, potassium, titanium
Synthetic fertilizer	potassium
Urban	zinc, copper
Ore smelting	zinc, cadmium, copper
Nutrients	phosphorus, nitrogen
Lake productivity	Organic matter

The accumulation rate of selected geochemical elements was calculated by combining the elemental concentrations with the sedimentation rate. The accumulation rate gives an indication of how the deposition of the elements change through time. This provides an indication of what watershed and inlake processes have occurred that consequently affected the lake ecosystem.

The accumulation rate of aluminum and potassium, which indicate soil erosion, prior to 1940 was relatively low (Figure 4). Both increased after 1940 and some of the highest rates occur at the very upper part of the core. This indicates that soil erosion has increased in the last 70 years and erosional rates continue at an elevated rate, compared with historical levels. The increase in soil erosion is smaller than has been measured in many other Wisconsin lakes.

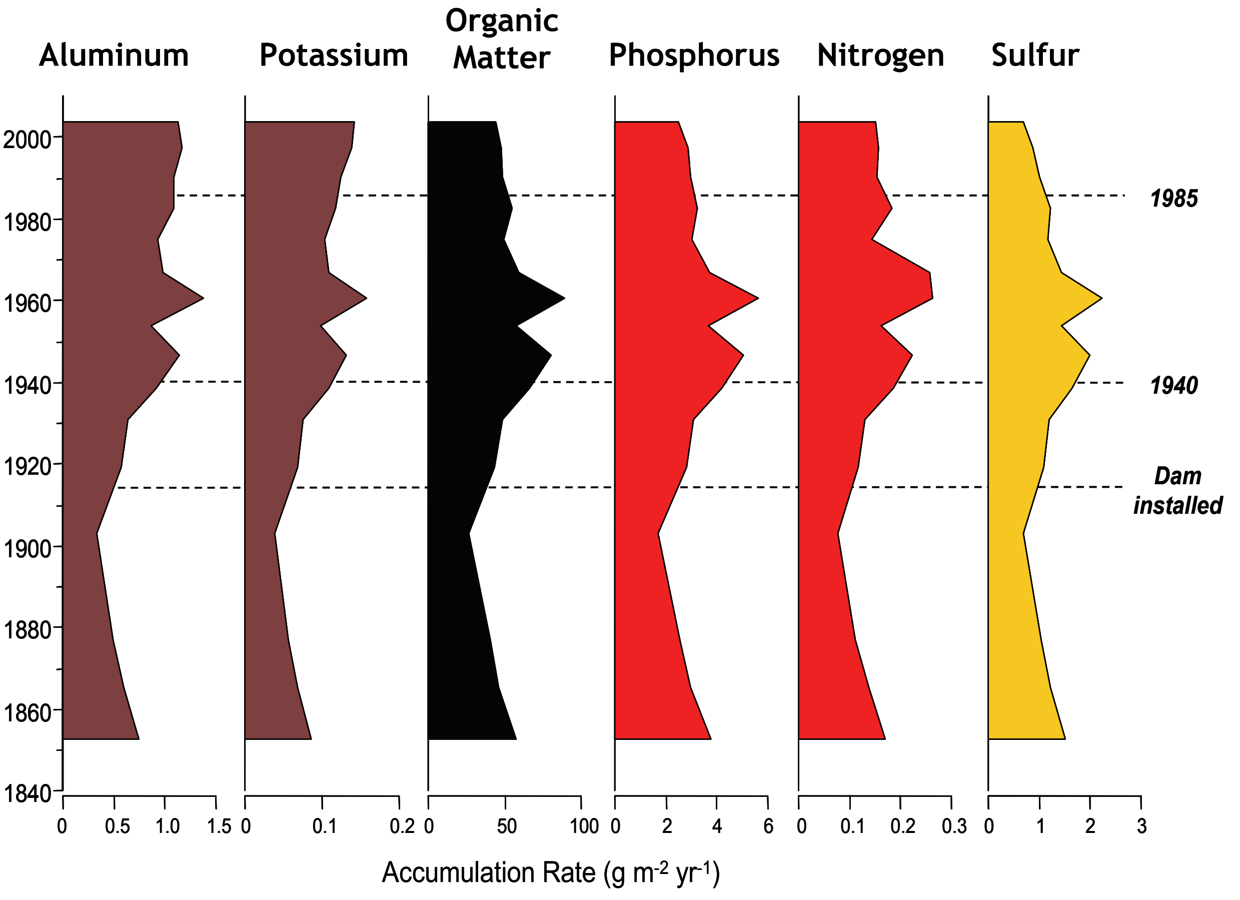

Figure 4. Profiles of the accumulation rate of selected geochemical elements. Aluminum profiles are indicative of soil erosional rates in the watershed. Potassium profiles are indicative of both soil erosion and use of synthetic fertilizers. Organic matter reflects the productivity of the lake. Nitrogen and phosphorus profiles reflect changes in nutrient deposition rates.

The peak in deposition of organic matter occurred during the period between 1940 and mid-1960s (Figure 4). The phosphorus and nitrogen accumulation rates have generally been higher since 1940 compared to earlier times (Figure 4). The phosphorus and nitrogen profiles are very similar to the organic matter profile which indicates that these nutrients are closely associated with organic matter. Since the nutrient accumulation rates decline in the upper part of the core unlike the erosional indicators, it appears that soil delivered from the watershed is not a major nutrient source.

The profile of sulfur shows a similar trend as nitrogen and phosphorus (Figure 4). This likely reflects that much of the sulfur is combined with organic matter, much like nitrogen and phosphorus. The decline in the ratio at the upper part of the core is an indication that mercury levels in fish may be declining. The microbial cycling of sulfur exerts a strong control on mercury methylation in lakes (Fitzgerald and Lamborg 2004). With the reduction in sulfur concentrations it would be expected that mercury methylation would decline. A study of on two lakes in Isle Royale found that mercury levels in northern pike have declined in recent years in response to a reduction in sulfur deposition as a result of reduced emissions (Drevnick et al, in press).

Selected geochemical elements were normalized to aluminum (Al) to discern anthropogenic inputs apart from mineral sediment. This analysis helps determine trends that impact the lake apart from the input of soil from the watershed.

The elemental profiles normalized to Al indicate that anthropogenic influences both from the immediate watershed as well as long-range atmospheric transport have had an impact on the sediments of Big Round Lake. Since both aluminum and potassium (K) are found in soil particles, it would be expected that the ratio of these elements would be similar throughout the core if soil particles were the only source of potassium. This was the case from the 1850 until 1940 (Figure 5). During the period 1940-1985 the ratio declined slightly. During the last 20 years the ratio increased, indicating a preferential increase in potassium deposition. This likely is the result of the addition of synthetic fertilizer to lawns surrounding the lake.

The ratio of both of the nutrients, phosphorus and nitrogen, to aluminum decline during the last century (Figure 5). This further emphasizes that deposition of these nutrients to the sediments is not controlled by erosional processes in the lake's watershed. Especially since these ratios decline during the last 50 years when the deposition of soil erosional indicators is increasing (Figure 4). The exception to this trend is during the early 1960s when there was a short lived increase in the P:Al (Figure 5). Apparently there was an episodic event which delivered phosphorus to the lake. An episodic input of sediment occurred at the same time (Figure 3).

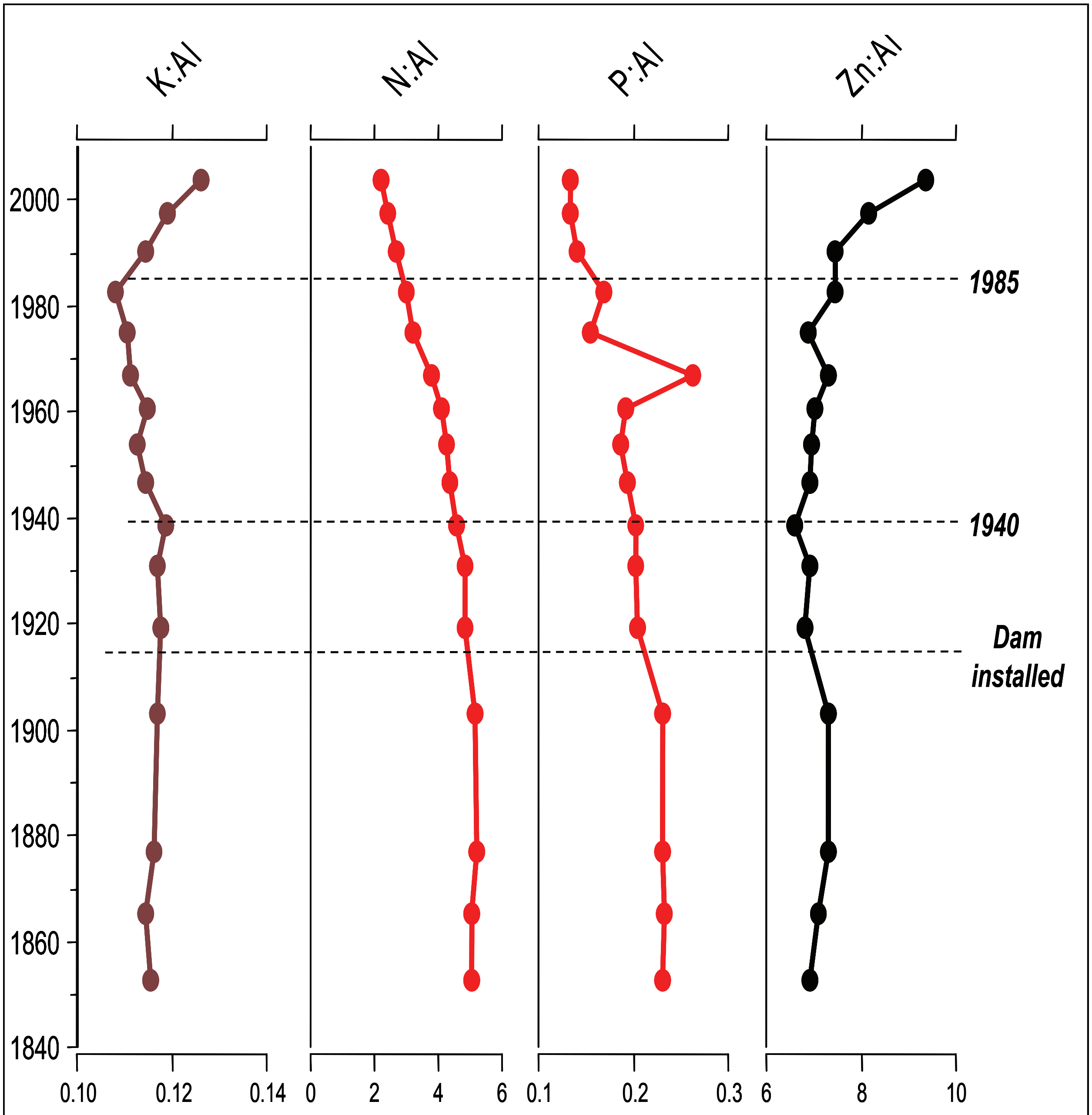

Figure 5. Profiles of selected elemental profiles normalized to aluminum. The elements are normalized to Al to reflect changes in deposition that are not related to erosional inputs from the watershed. The increase in K:Al near the top of the core reflects increased application of fertilizers on the lake shore while the increase in Zn:Al reflects atmospheric deposition of Zn from regional smelting of lead-zine ores.

The Zn:Al profile is relatively constant until after 1985. While zinc is an important component in runoff from suburban development, in this case it likely reflects long range atmospheric input. Smelting of lead-zinc ores occurs in the region. Other byproducts of regional smelting operations, e.g. cadmium and lead, also show an increased deposition in recent years. Other paleolimnological studies in the region have noted similar profiles as seen in Big Round Lake (Garrison and Fitzgerald 2005).

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.

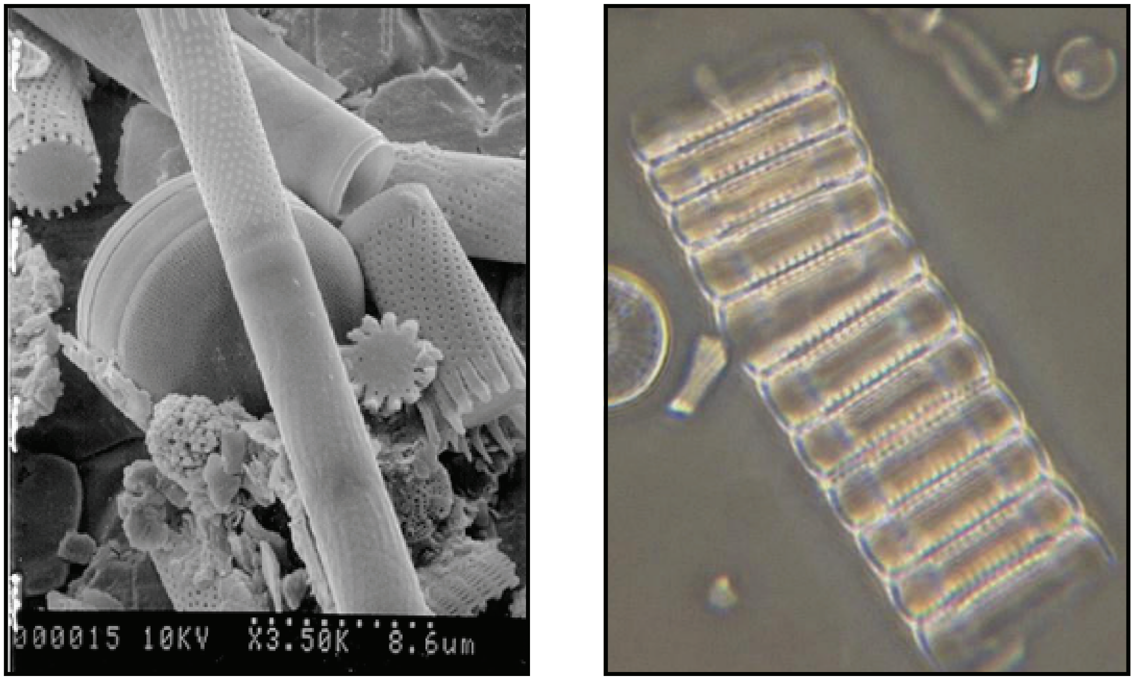

Figure 6. Micrographs of the diatoms *Aulacoseira* (left), *Pseudostaurosira brevistrata* (right). The *Aulacoseira* pictured is typically found floating in the open water while *P. brevistrata* grows attached to substrates such as aquatic plants.

The diatom community is composed of nearly equal parts species that occupy the open water of the lake and those that grow attached to substrates, e.g. plants (weeds). This community is typical of a productive shallow lake. In a shallow lake, it would be expected that diatoms that grow in the open water of the lake would be uncommon. Throughout the core, the general composition of the diatom community has changed little (Figure 7). The most common planktonic diatom is *Aulacoseira ambigua*, a common diatom found throughout the Upper Midwest. This diatom is generally found under low to moderate phosphorus levels. A similar diatom, *A. granulata*, is found throughout the core. This diatom indicates higher phosphorus levels. This indicates that the lake naturally has moderate phosphorus levels.

A significant component of the diatom community are taxa of the group Fragilariaceae. Although

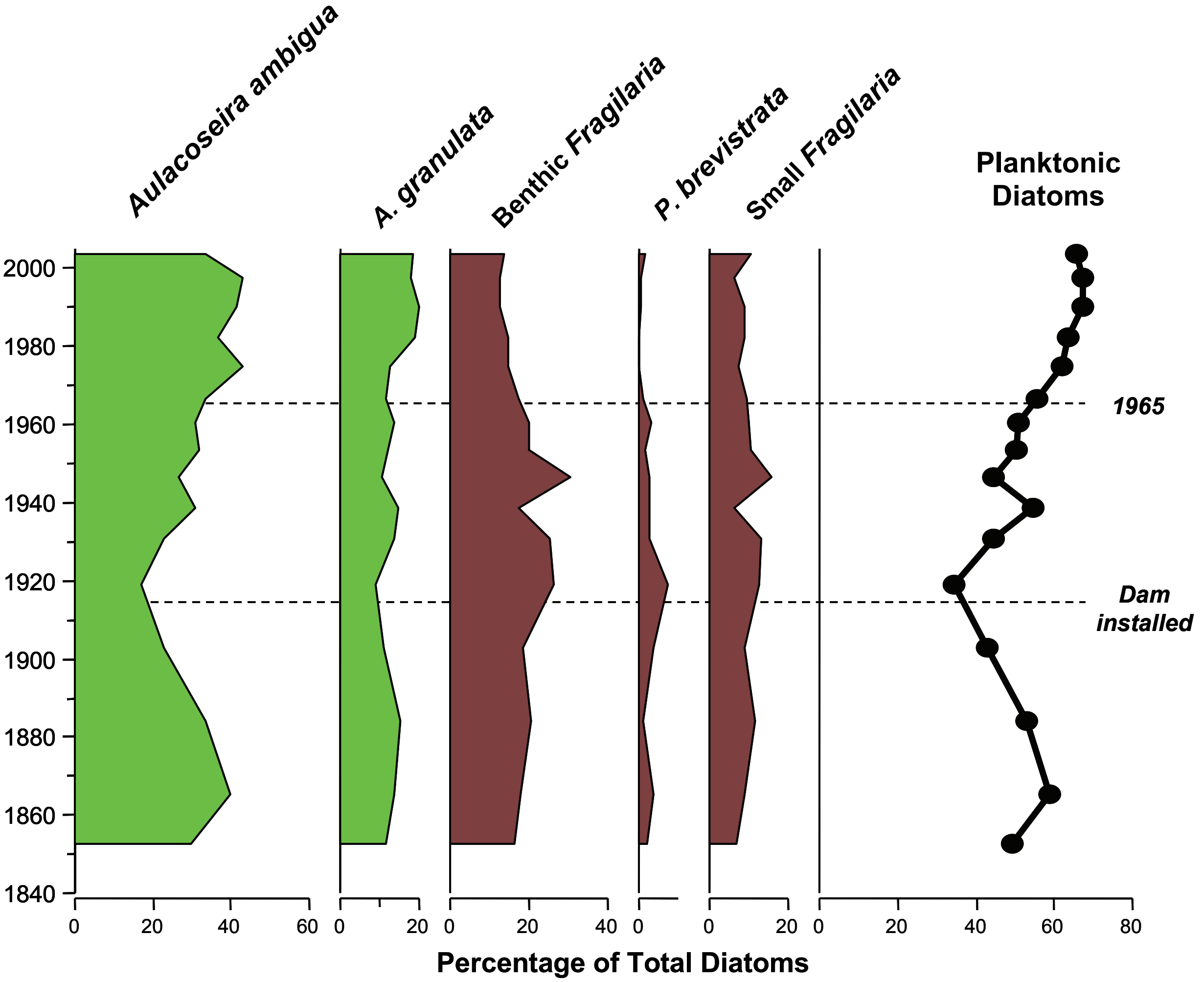

Figure 7. Profiles of selected diatom taxa. The taxa in green grow in the open water of the lake and are indicative of moderate nutrient levels. The taxa in brown grow on substrates such as aquatic plants. Planktonic diatoms are the group that grow in the open water.

these taxa tolerate a wide range phosphorus levels (Wilson et al. 1997; Bennion et al. 2001) they exhibit little change throughout the core further indicating that the phosphorus levels of the lake have changed little during the last 150 years. These diatoms also indicate that this lake has contained a significant aquatic plant community for many decades.

The group of diatoms that grow in the open water, planktonic diatoms, have shown a small increase since the mid-1960s (Figure 7). This may indicate a slight increase in nutrients since other studies have found that the production of planktonic diatoms increase as nutrient levels rise (Bradbury and Winter 1976; Batterbee 1978; Garrison and Wakeman 2000).

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.

A weighted average model of the historical water clarity was performed with the diatom community. The model indicates that the mean summer Secchi depth has been relatively unchanged varying between 6.5 and 7.5 feet during the last 150 years (Figure 8). This estimated Secchi depth is very close to the mean summer Secchi depth of 6 feet which has been measured in recent years. This indicates that nutrient levels may not have changed during the last 150 years.

Non-Diatom Algal Fossils

Other algae besides are diatoms sometimes are preserved the sediments. These groups include blue-green algae, green algae, and Chrysophytes. While nearly all diatom taxa are preserved, in the other groups only certain taxa are fossilized. In blue-green algae only the genera *Aphanizomenon, Anabaena,* and *Gloeotrichia* fossils are found in sediments. For Chrysophytes only taxa which produce cysts are preserved. These cysts can be very diagnostic where they are abundant (Zeeb and Smol 2001). Unfortunately, in the Upper Midwest, Chrysophyte cysts are generally not preserved in much abundance. Green algae that produce coenobia are also found in the sediments. Since only some taxa are preserved in each of these algal groups, interpretation of the results is more limited than with the diatom community. However, since blue-green algae are numerous at the present time in Big Round Lake, remains of these algal groups, especially blue-green algae were examined in the core.

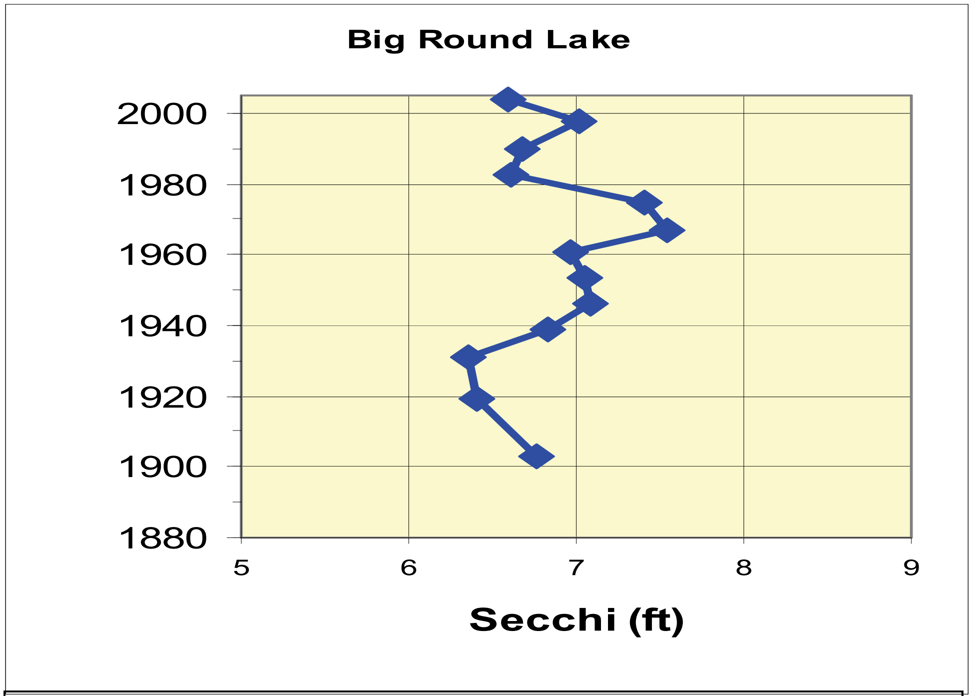

Figure 8. Estimated mean summer Secchi depth in the core. These values were inferred from the diatom community using weighted averaging modeling.

The blue-green algae that most frequently dominate algal blooms are *Aphanizomenon, Anabaena,* and *Microcystis*. The first two genera produce fossils while *Microcystis* does not. Blue-green algae were present throughout the core (Figure 9). The most common were *Aphanizomenon,* and *Anabaena* which often produce algal blooms and surface scums. It is clear that algal blooms were common in Big Round Lake prior to European settlement or the installation of the dam. *Aphanizomenon* was more common than *Anabaena* prior to about 1940. Both of these algae can obtain nitrogen from the atmosphere to supplement their nutrient requirements. *Aphanizomenon* may do better at lower phosphorus levels than *Anabaena* indicating that phosphorus levels may have been slightly lower prior to 1940. The levels of *Aphanizomenon* declined around 1960 but *Anabaena* numbers were high until around 1990. Based upon the presence of blue-green algal blooms at the present time, it is likely that the dominant species has shifted to *Microcystis*, which does not produce fossils.

Although interpreting past nutrient levels is more speculative with blue-green algae than with diatoms since not all blue-green algae are preserved in the sediments, it appears that they are more sensitive to nutrient changes in Big Round Lake than the diatoms. Since *Aphanizomenon* is reported to be more competitive under lower phosphorus levels than *Anabaena* (van Geel et al. 1994), the increase in the latter taxa after 1940 likely indicates an increase in phosphorus in the lake. After 1960, *Aphanizomenon* numbers are significantly reduced (Figure 9). During the last 15 years both *Aphanizomenon* and

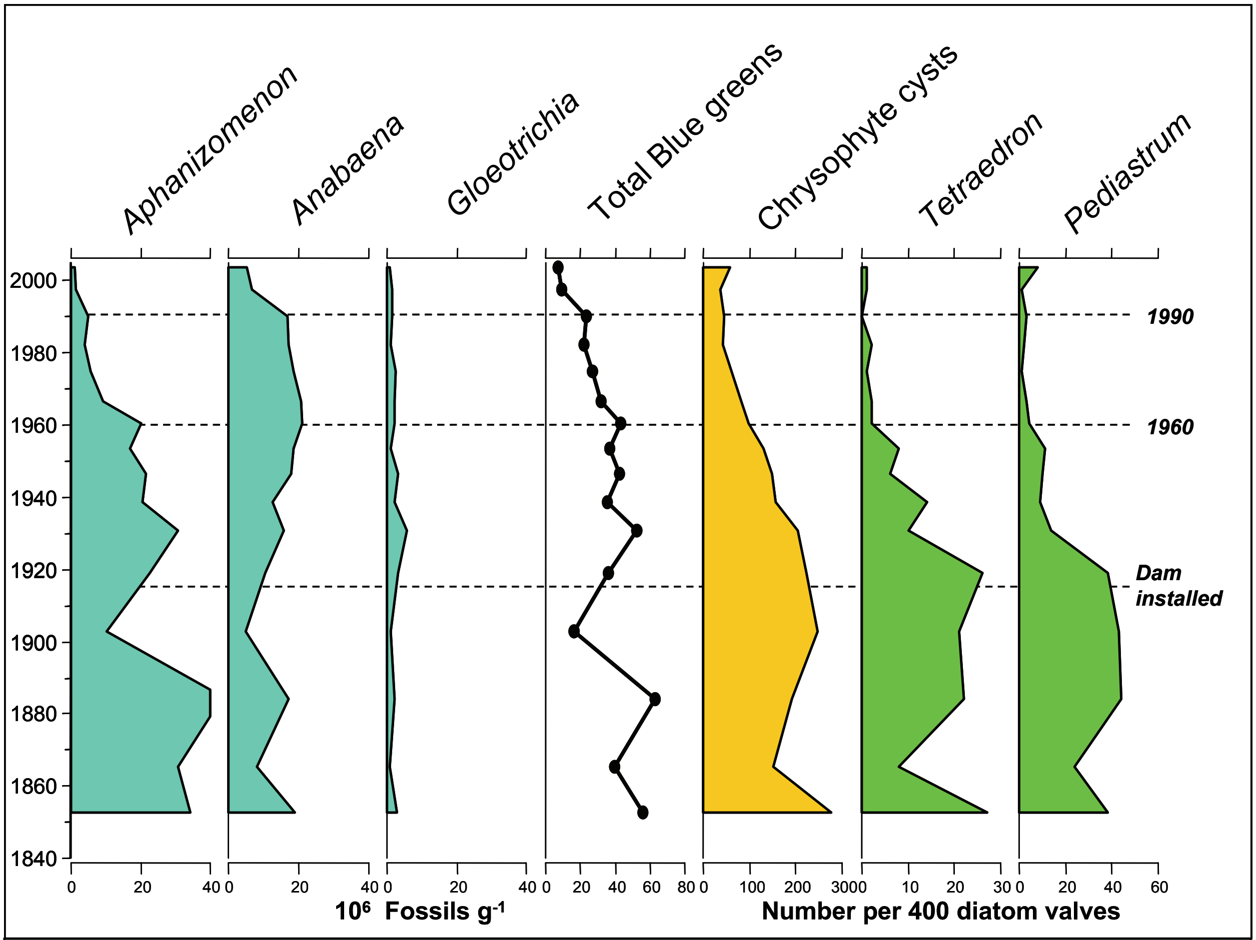

Figure 9. Profiles of non-diatom algal fossils found in the Big Round Lake sediment core. The three alga on the left side are blue-green algae. *Aphanizomenon* and *Anabaena* often form surface scums. These algae are present throughout the core indicating blue-green blooms were have been common during the last 150 years. The decline of these algae near the top of the core likely reflects a shift to blue-green algae which do not leave fossils, e.g. *Microcystis*. The other algal fossils shown declined soon after the dam was installed and may have been responding to the increase in water level.

Anabaena numbers have declined. It is very likely that the blue-green alga *Microcystis* which can form large blooms but does not leave fossils in the sediments became important. Big Round Lake currently experiences increasing phosphorus levels throughout the summer as well as declining water clarity (Figure 10). This implies that internal loading of phosphorus is occurring within the lake. The shift in blue-green algae from *Aphanizomenon* to *Anabaena* to *Microcystis* indicates an increase in nutrient levels since 1940. Although the diatom community generally does not indicate a change in nutrient levels in the core, the increase in planktonic diatoms after 1970 hints at increased phosphorus levels in the last 25 years.

The fossils of green algae (*Tetraedron*, *Pediastrum*) and Chrysophyte cysts were found in the greatest numbers at the bottom of the core (Figure 9). They declined soon after the dam was installed. It is

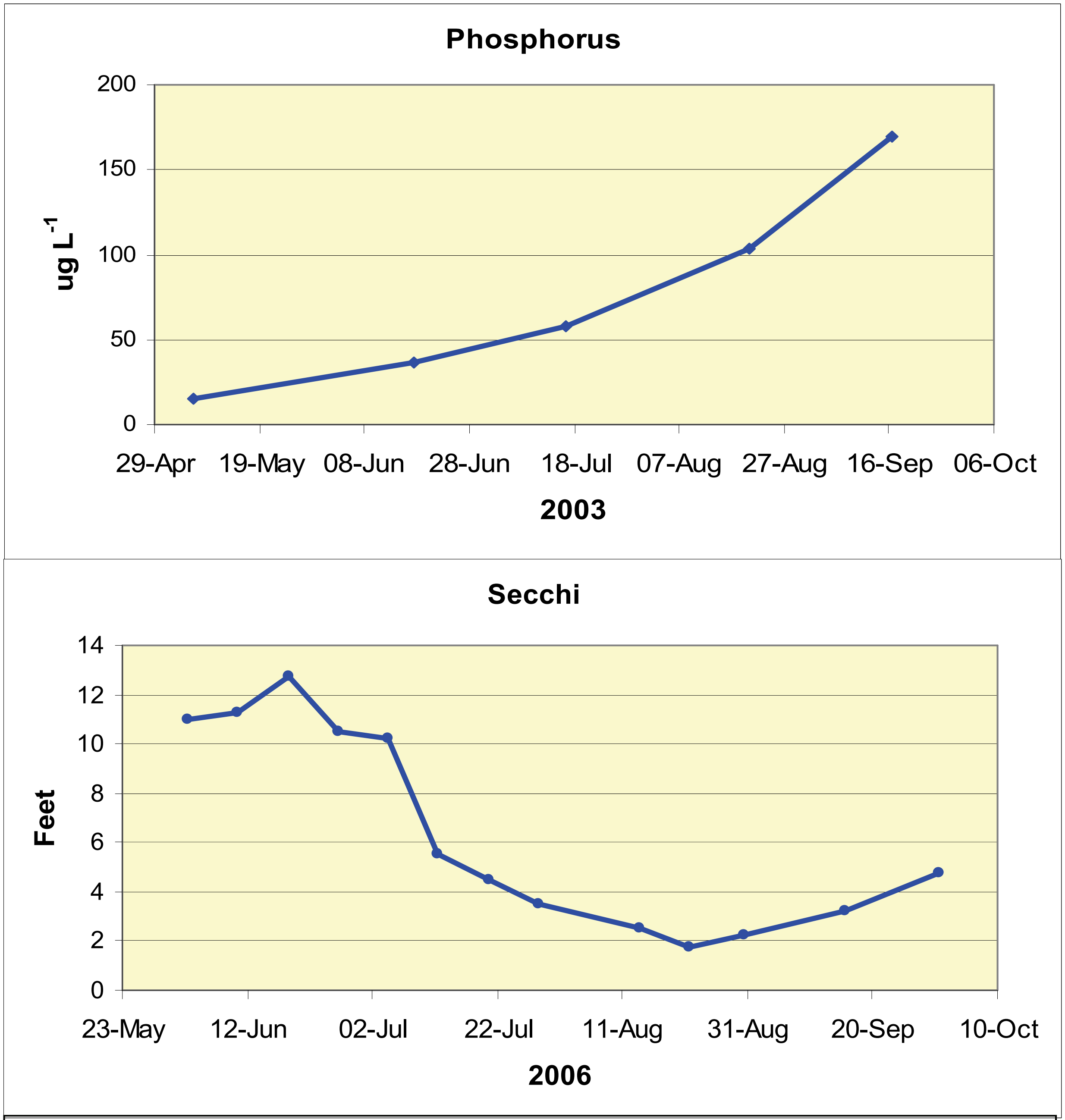

Figure 10. Seasonal trends of phosphorus and water clarity (Secchi depth) for Big Round Lake in different years. Phosphorus levels increase during the summer as a result of internal loading. This leads to algal blooms and consequently a decline in water clarity.

likely that the green algae declined as a result of the increased water level. While these taxa are planktonic, they are relatively heavy and need wind activity to remain in the water column. With the greater water depth it was easier for the algae to sink out of the mixing zone. The blue-green algae do not have this problem since they produce gas vacuoles which allows them to remain in suspension. Even though their numbers were reduced after the dam was installed, green algae were present in reduced numbers until about 1960. Chrysophyte numbers also were significantly reduced after 1960

(Figure 9). Chrysophyte cysts usually decline in response to higher nutrient levels. Their decline as well as the green algae after 1960 likely is the result of increased phosphorus levels indicated by the shift in blue-green algal species and the higher percentage of planktonic diatoms.

- The mean sedimentation rate for the last 150 years for Big Round Lake is one of the lowest measured in Wisconsin lakes.
- Since 1940 the bulk sedimentation rate has been higher than the 100 years previous, but the increase is relatively small compared with many other Wisconsin lakes.
- Many geochemical elements increased around 1940. As with the sedimentation rate, the increase in chemicals that are surrogates for soil erosion, aluminum and potassium, was relatively small.
- The input from soil erosion in the watershed remains at elevated levels compared with the time period prior to 1940.
- Since 1990 the addition of synthetic fertilizers, probably for use on shoreline lawns, has resulted in increased input of potassium and likely other nutrients as well.
- The diatom community showed little change throughout the core. The only significant trend was an increase in planktonic diatoms after 1960. This increase likely reflects increased phosphorus levels.
- The production of green algae that produce fossils was significantly reduced following the installation of the dam. This was likely the result of the increased water level.
- The blue-green algae appeared to be the most sensitive to changes in nutrient levels in the lake. They indicated that phosphorus levels increased around 1940 and levels continued to increase until the present time. This was indicated by a shift from *Aphanizomenon* to *Anabaena* and to a bloom forming species around 1990 which was not preserved in the sediments but was likely *Microcystis*.
- The reason the diatom community was relatively unchanged with the increase in phosphorus was that the increase is largely the result of internal loading. This occurs during the summer when the blue-green algae out compete the diatoms for nutrients and light.
- Although the sediment core indicates that phosphorus levels have been increasing since 1940, it is not possible to estimate how much of an increase has occurred.

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Funding for this study was provided by Big Round Lake District and Wisconsin Department of Natural Resources. Field help was provided by residents of Big Round Lake. Radiochemical analysis was provided by the Lynn West at the Wisconsin Laboratory of Hygiene. Geochemical analyses was provided by University of Wisconsin, Soil Testing Laboratory.