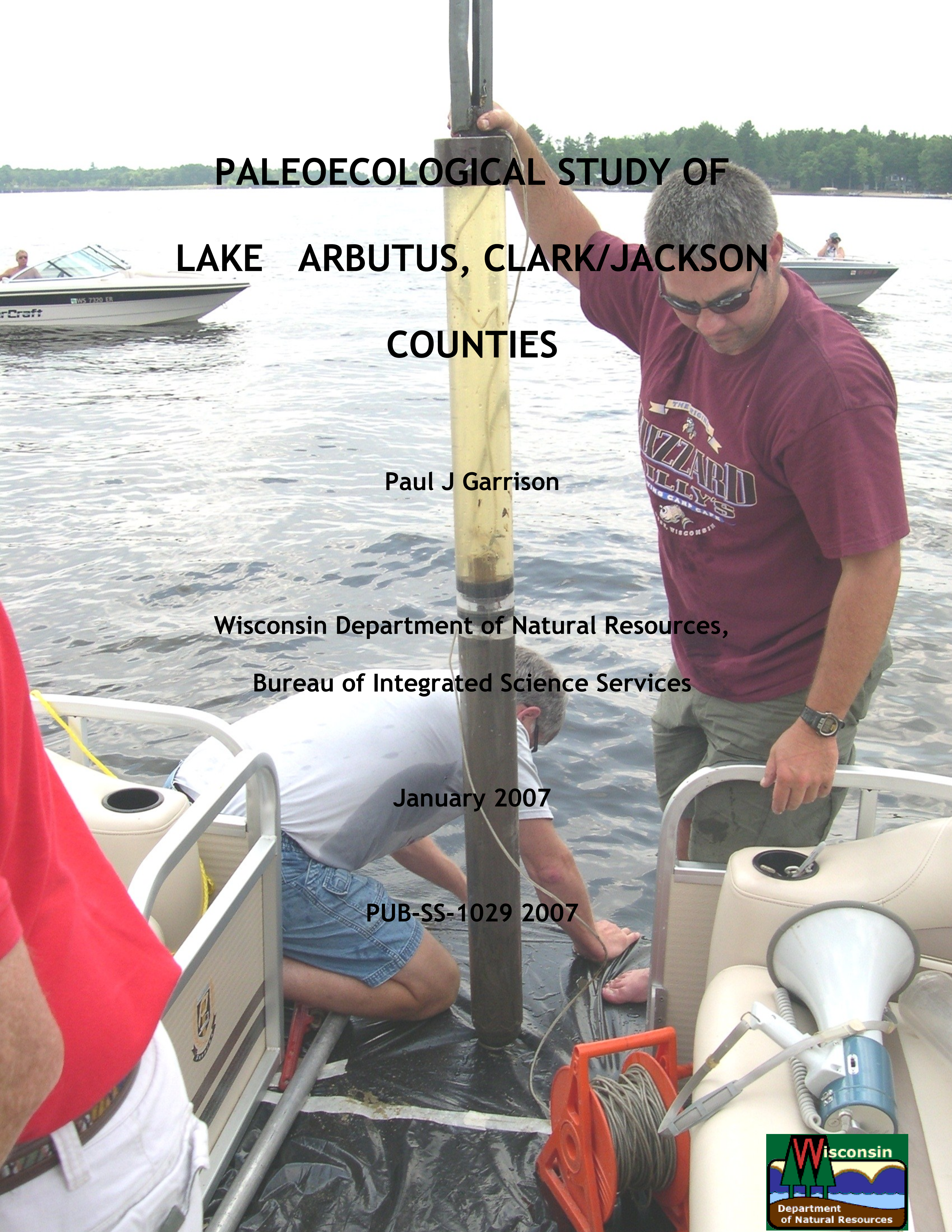

PALEOECOLOGICAL STUDY OF LAKE ARBUTUS, CLARK/JACKSON COUNTIES

Paul J Garrison

Wisconsin Department of Natural Resources,

Bureau of Integrated Science Services

January 2007

PUB-SS-1029 2007

Wisconsin Department of Natural Resources

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.

Lake Arbutus is a 839 acre lake located in Clark and Jackson counties. The maximum depth is 50 feet with a mean depth of 16 feet. A sediment core was collected from the lake on 16 July 2005. The core was collected with a piston core with a plastic tube having an inside diameter of 8.8 cm. The core was collected in 34 ft of water near where Arnold Creek enters the lake (Figure 1). The location of the coring site was 44º 25.289' north, 90º 43.247' west. The core was sectioned into 2 cm intervals for the entire core (78 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 geochemical elements were examined to determine the causes of changes in the water quality.

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 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 settlement 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

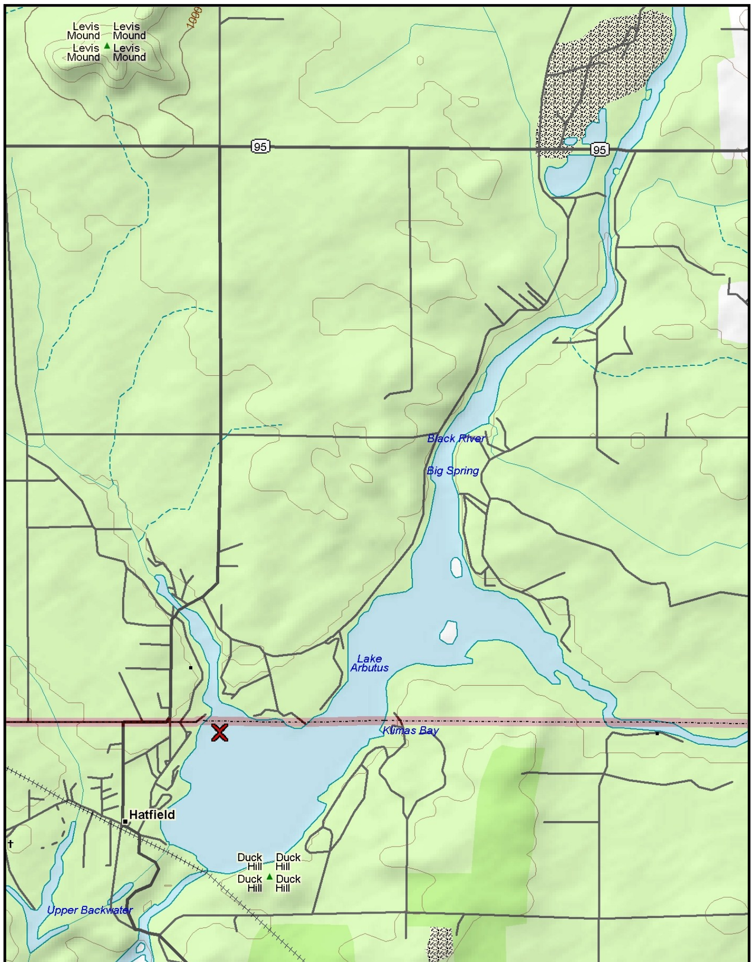

Figure 1. Map of Lake Arbutus showing the coring site. The water depth of the coring site was 34 ft.

(g cm^{-2} yr^{-1}) were calculated from output of the CRS model (Appleby and Oldfield, 1978). The CRS model requires that the entire inventory of Pb-210 be present. Because Lake Arbutus was not formed until 1908 this is not possible. To correct for this, the bottom of the core was assumed to deposited in 1908. This means that the portion of the inventory missing was estimated. 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 0.252 cm^{-2} yr^{-1}. This is one of the highest rates measured in 42 Wisconsin lakes (Figure 2). The average linear rate for the same time period is 0.83 cm yr^{-1} which equates to about 0.3 inch of sediment per year. The high rate is not surprising

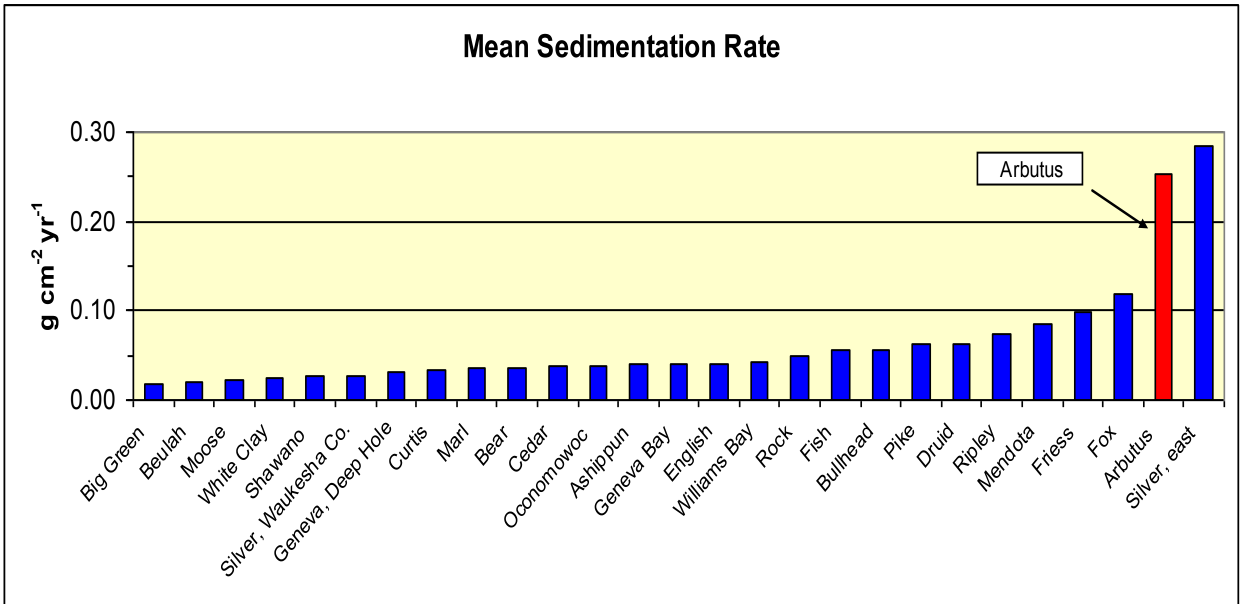

Figure 2. Mean sedimentation rate for the last 180 years for 27 hardwater Wisconsin lakes. The arrow indicates Lake Arbutus.

since Lake Arbutus is a reservoir and has a large watershed. The rate represents the sediment accumulation rate in the area where the core was taken. It is highly likely that the rate differs in other areas of the lake. The flux of Pb-210 at the coring site was about 5 times higher than values that would be expected in the Upper Midwest (Binford et al. 1993). This indicates that considerable sedi-

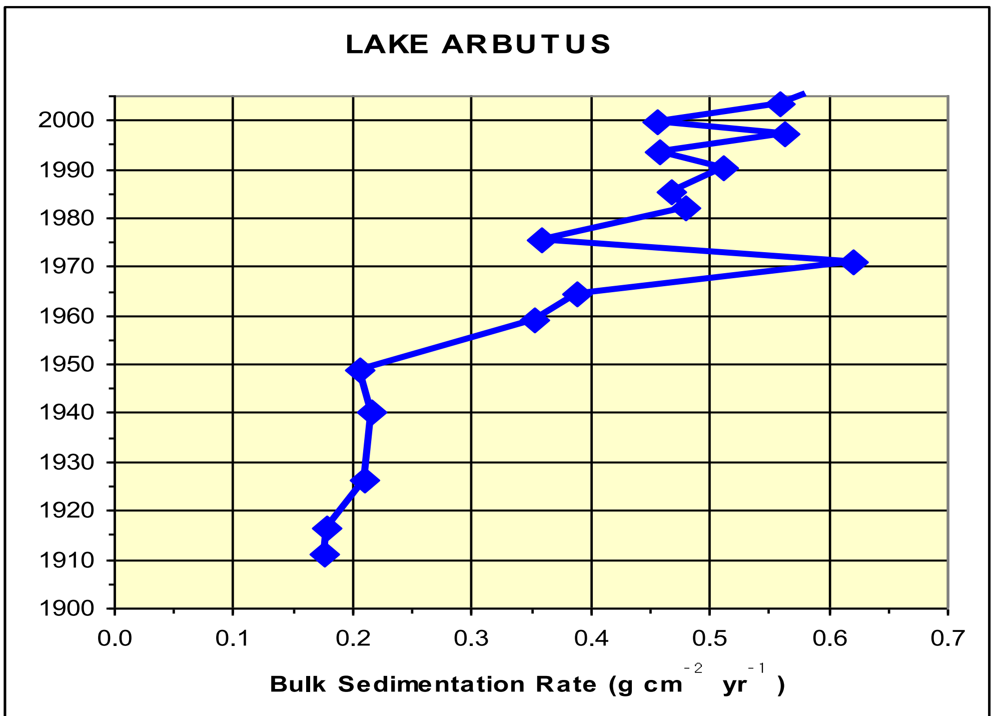

Figure 3. Sediment accumulation rate for Lake Arbutus since 1908 when the lake was formed.

ment focusing is occurring at this site. It is likely that the average lake sedimentation rate is much lower than was measured in this study.

To account for sediment compaction and to interpret past patterns of sediment accumulation, dry sediment accumulation rates were calculated. The sedimentation rate during the 40 years after the lake was formed was around 0.20 g cm^{-2} yr^{-1}(Figure 3). The rate has steadily increased since 1950 and was about 0.55 g cm^{-2} yr^{-1} during the last 10 years (Figure 3). The increased sedimentation rate after 1950 is likely the result of increased mechanization of agriculture. Around this time, tractors became larger and it was easier to cultivate the land. This increase in sedimentation rate after 1950 has occurred in other Wisconsin lakes that have a significant amount of agriculture in their watersheds. The USGS has been collecting flow data on the Black River at Neillsville on a continuous basis since 1905. Peak stream flow, which is an indication of flood events, is shown in Figure 4. The highest flows occurred in 1939 and 1942. These flood events do not correspond with peaks in the sedimentation rate. Apparently floods did not result the deposition of significant amounts of sediment at the coring site. Instead, non-flood events are controlling the sedimentation rate. With the exception of the peak in the rate around 1971, the highest sedimentation rates have occurred since 1995 (Figure 3). In general, peak flows have not been higher in the last 25 years compared with the previous 75 years (Figure 4). It appears that landuse changes in the watershed in recent years have resulted in an increase in the

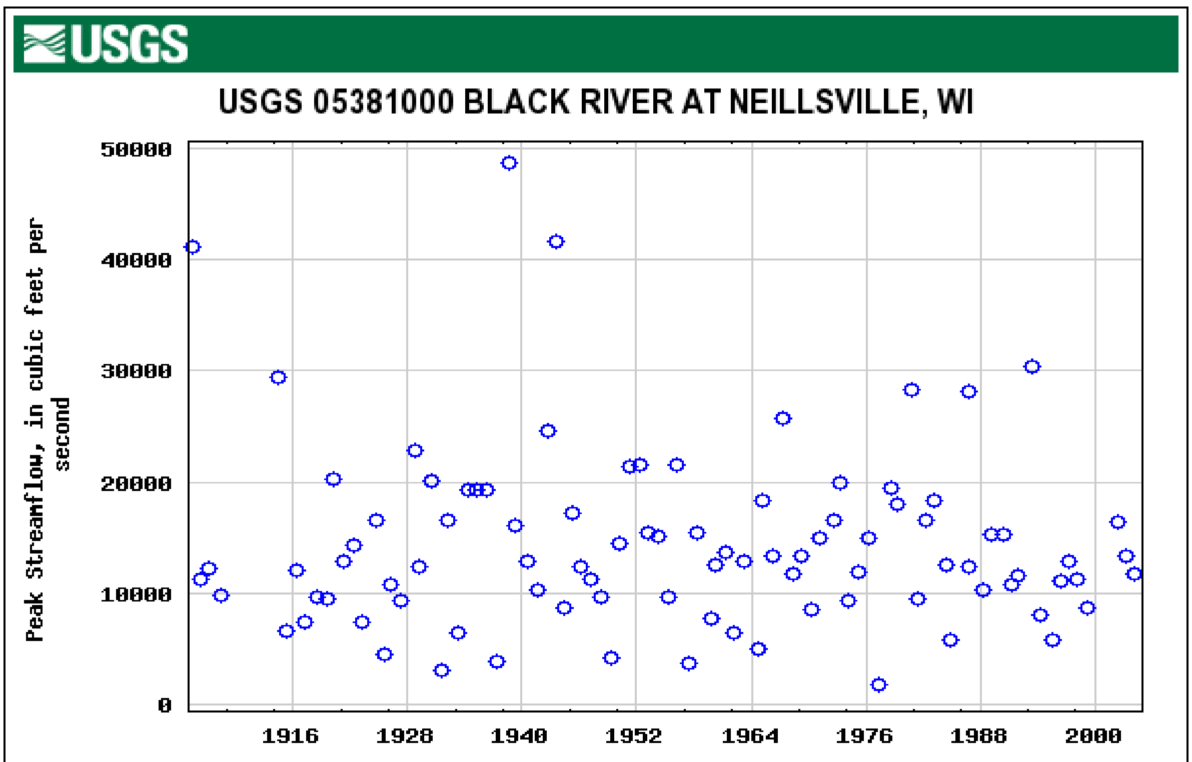

Figure 4. Peak stream flow on the Black River upstream of Lake Arbutus at Neillsville. The peak events are an indication of floods. This information was obtained from http://nwis.waterdata.usgs.gov/wi/nwis/peak/?site_no=05381000&agency_cd=USGS

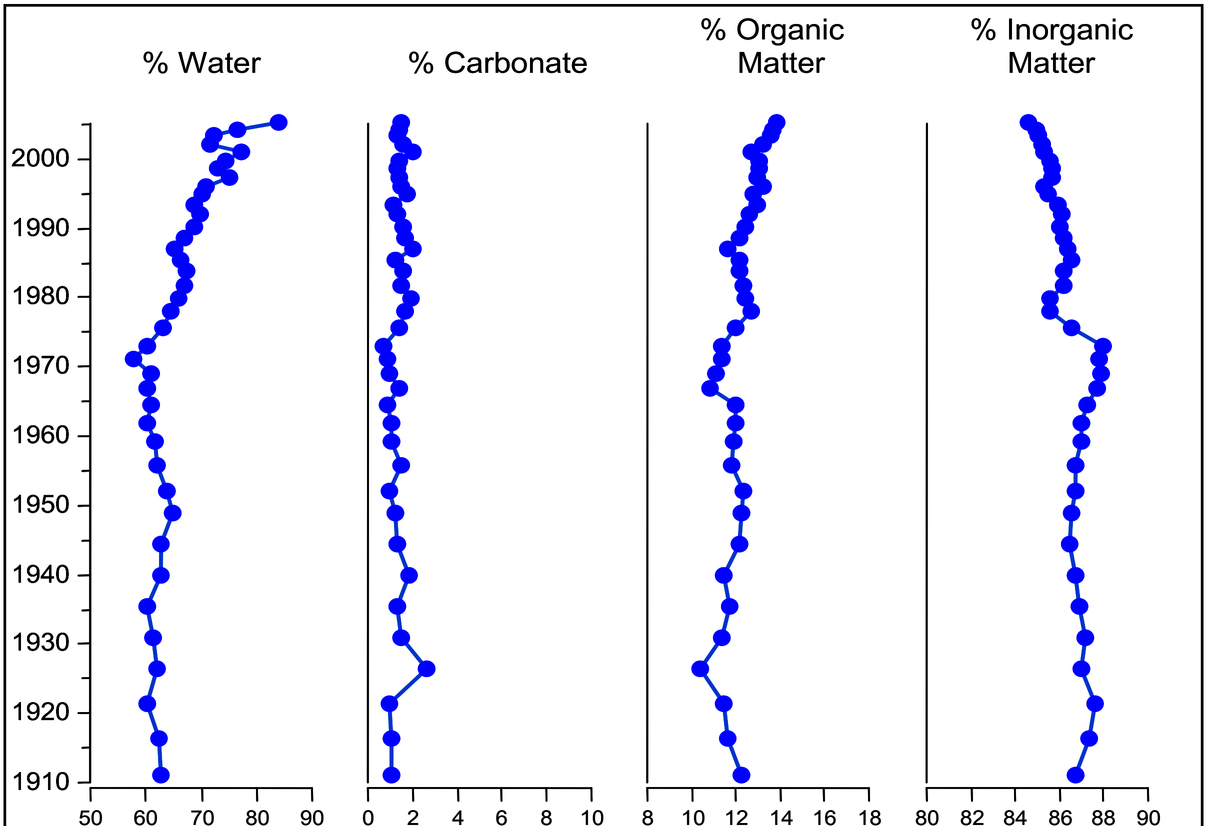

Figure 5. Percent water, carbonate, organic matter, and inorganic matter from the sediment core. Inorganic matter largely reflects changes in delivery of soil erosion from the watershed.

sedimentation rate.

Sediment Lithology

The increase in the percent water content towards the top of the core was consistent with the general trend that normally occurs in sediment cores (Figure 5). This increase is largely the result of reduced sediment compaction at the top of the core. The percent of carbonate was low in the core which reflects the fact that carbonate materials are a small component of the geology in the lake's watershed. Organic matter was relatively constant at about 12 percent until about 1990 when it began to increase. The increase in organic matter was associated with compensatory decline in inorganic matter (Figure 5). This indicates that sediment deposited during the last 15 years is composed of higher amounts of organic material. This may reflect a change in the sources of sediment as well as a greater contribution from biological material produced within the lake.

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

Process	Chemical Variable
Soil amendment	calcium
Soil erosion	aluminum, titanium
Urban	zinc, copper
Nutrients	phosphorus, nitrogen

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 1). The chemical aluminum (Al) is found in soil particles, especially clays. Changes in Al are an indication of changes in soil erosional rates throughout the lake's history. Zinc (Zn) is associated with urban runoff because it is a component of tires and galvanized roofs and down-spouts. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. Calcium is an indication of the use of soil amendments for agriculture and lawns.

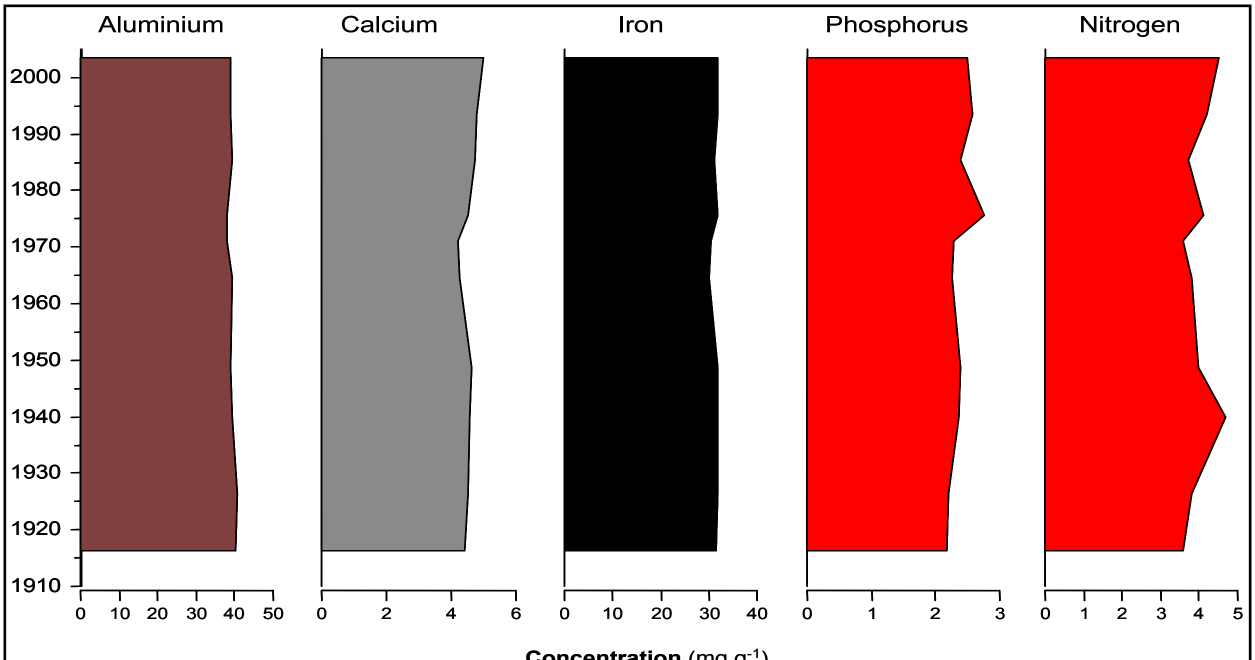

Figure 6. Profiles of the concentration of selected geochemical elements. Aluminum and iron profiles are indicative of soil erosional rates in the watershed. Calcium is often used as a soil amendment in agricultural fields. Nitrogen and phosphorus profiles reflect changes in nutrient deposition shed. Since none of these elements show any appreciable changes through time, this indicates that changes in landuse in the watershed have an equal impact on all of the elements. The exceptions are calcium and nitrogen which increased after 1975.

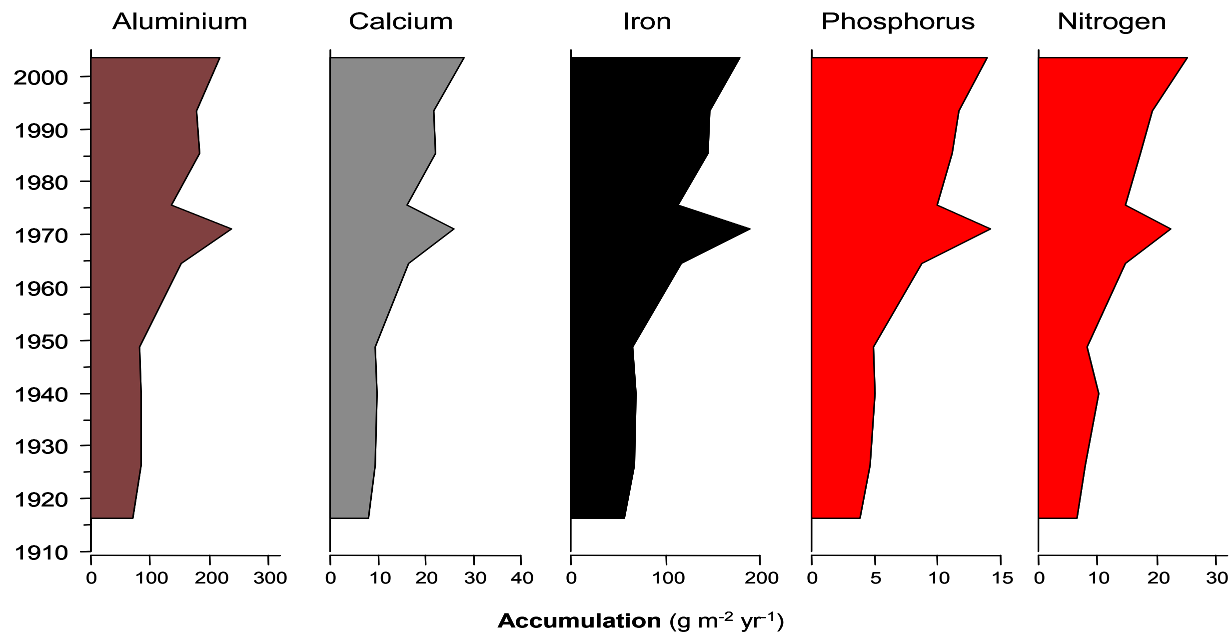

Figure 7. Profiles of the accumulation rate of selected geochemical elements. Aluminum, calcium, and iron profiles are indicative of soil erosional rates in the watershed. Nitrogen and phosphorus profiles reflect changes in nutrient deposition rates.

The concentrations of the important geochemical variables are relatively unchanged throughout the entire core (Figure 6). This indicates that changes in the lake's watershed have not had a significant impact on the delivery of chemicals to the lake. This does not mean that there have been no changes in the watershed. Just that impacts that result in increased soil erosion equally affect the important geochemical variables. The exception to this was calcium as well as nitrogen. This steadily increased after 1970 and probably reflects increased use of agricultural lime as a soil amendment in agricultural fields. Neither zinc or copper (not shown) showed increased concentrations in the upper part of the core. This indicates that urban runoff is not an important contributor to sediment to Lake Arbutus.

The sediment core does indicate that there has been considerable change in the amount of soil that enters the lake. This is reflected in the increased sedimentation rate throughout the core as well as increased deposition of all the important geochemical variables (Figure 7). Since the concentrations of these elements do not change through time, the increased deposition is almost entirely the result of the increase in the sedimentation rate. This increase in deposition after 1950 reflects increased mechanization of agriculture after World War II. In most natural lakes in the Upper Midwest, we have observed a similar increase. However, in many of these lakes, soil erosion has been reduced in the last couple of decades as a result of conservation practices. It appears that these practices are not as effective in Lake Arbutus' watershed.

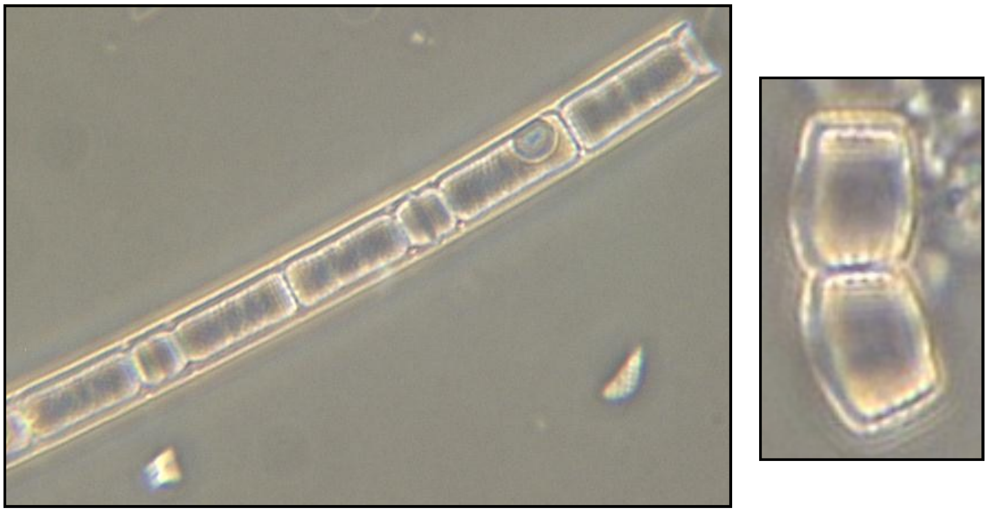

Figure 8. Photomicrographs of diatoms common in the core from Lake Arbutus. The diatom on the left (*Aulacoseira ambigua*) typically is found in open water environments while the picture on the right is *Staurosirella pinnata* which is commonly found attached to substrates such as downed trees and aquatic plants in lakes and streams.

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 8 shows photographs of two diatom species that were common in the sediment cores.

The diatom community for most of the core consisted diatoms that grow attached to substrates, e.g. aquatic plants and woody habitat. Although this group is very diverse in Lake Arbutus, the most important group was benthic *Fragilaria* (Figure 9). An example of this type of diatom is shown in the right panel of Figure 8. Although some of these benthic diatoms are probably produced within the

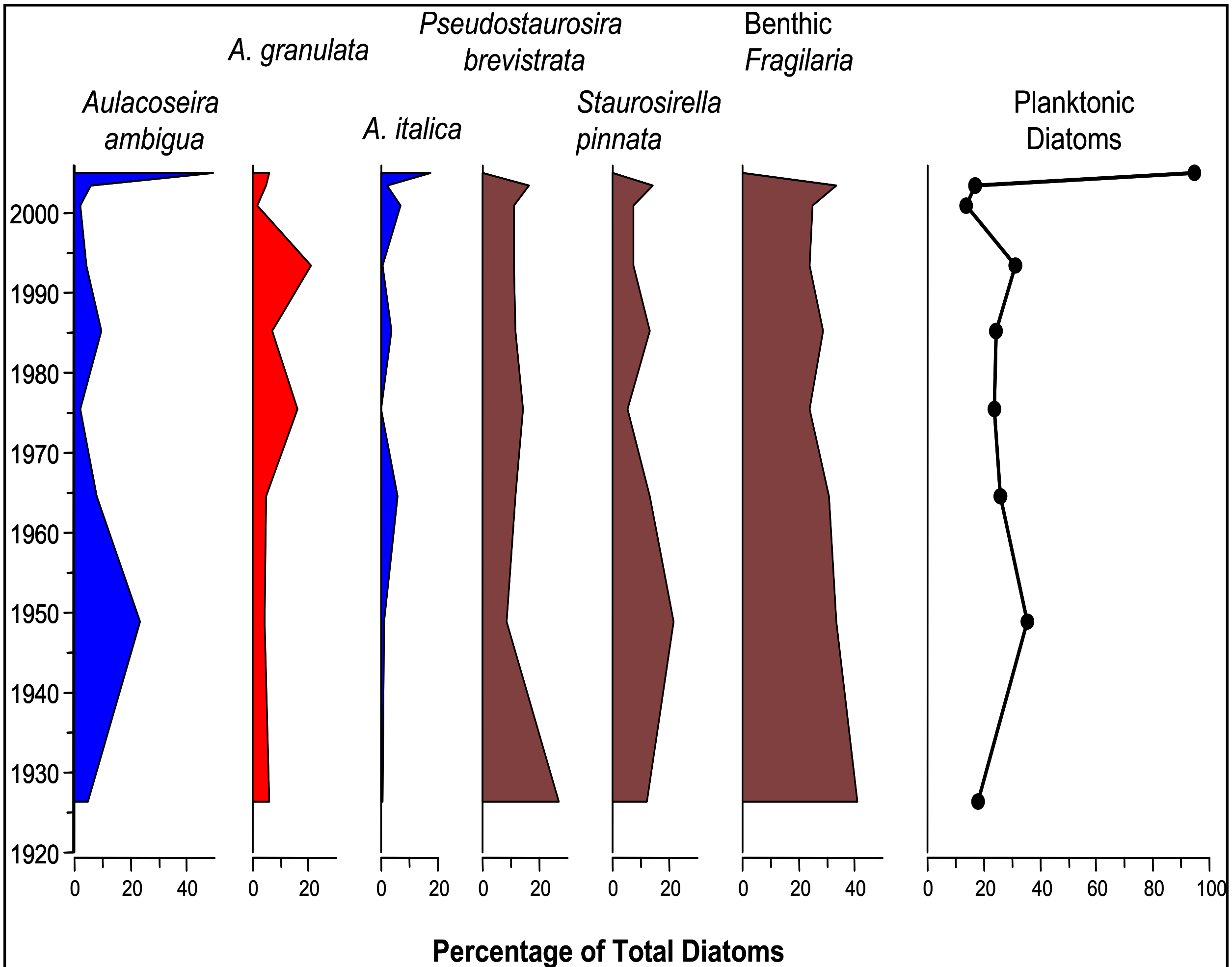

Figure 9. Profiles of the most common diatoms in the core. The taxa in blue are indicative of moderate nutrient concentrations. The diatoms in red indicate elevated nutrient levels. The diatoms depicted in brown grow attached to substrates such as aquatic plants and woody habitat.

lake, many of them enter the lake from the inflowing streams, e.g. Arnold Creek. This is reflected partially by the large number of benthic *Fragilaria* but also by many taxa not shown that typically are found in flowing water. Since the diatoms that grow attached to substrates, e.g. benthic *Fragilaria*, grow in a wide range if nutrient levels (Wilson et al. 1997; Bennion et al. 2001), it is difficult to reconstruct phosphorus levels from their changes.

The planktonic diatoms respond better to changes in phosphorus levels since they grow in the open water of the lake and derive their nutrients from this water. Prior to 1960, the dominant *Aulacoseira* (pictured in Figure 8) is *A. ambigua* which is generally found in moderate nutrient levels (Ramstack et al. 2004). During the period 1970-95 there is an increase in *A. granulata*, which typically indicates higher nutrient concentrations (Ramstack et al. 2004). The amount of this diatom declined in the last 10 years which likely indicates a reduction in phosphorus levels.

The large preponderance of planktonic diatoms at the top of the core likely reflects the fact that rainfall in the area has been low in the last couple of years which is reflected in reduced stream flow in the Black River (Figure 4) and presumably in Arnold Creek as well. Consequently few benthic diatoms are washed into the lake. Diatoms that are produced within the lake are then able to dominate the diatom community. The importance of streams as a source of benthic diatoms is reflected in the low numbers at the top of the core when stream flow was reduced. This is reflected in the decreased abundance of benthic *Fragilaria* as well as the elevated percentage of planktonic diatoms (Figure 9).

In summary, Lake Arbutus has one of the highest mean sedimentation rates of the 42 Wisconsin lakes where this has been measured. This largely reflects the large watershed of the lake. The sedimentation rate has been steadily increasing since 1950 and the highest rate has occurred during the last 10 years. This increased rate is largely the result of increased mechanization in agriculture which occurred since World War II. This increase is reflected in the higher deposition of nearly all of the geochemical variables that were measured.

The diatom community reflects the importance of stream input to the lake. The dominant type of diatoms were those that grow attached to substrates such as aquatic plants and woody habitat. These types of diatoms composed most of the diatom community except at the top of the core. Few of these diatom entered the lake within the last 1-2 years because of the low streamflows resulting from a regional drought. The diatom community reflects an increase in phosphorus in the lake during the period 1970-1995. Phosphorus levels appear to have declined in the last 10 years.

While the sediment core indicates that nutrient levels have not significantly increased in recent years, there has been a significant increase in sediment infilling, especially since 1980. Efforts should be made to encourage farmers to reduce soil erosion in the lake's watershed.

- The mean sedimentation rate for the last 150 years for Lake Arbutus was one of the highest measured in Wisconsin lakes.

- The sedimentation rate was steady from 1908 when the lake was formed until the early 1950s. For the last 50 years the rate has been increasing.

- The increased sedimentation after 1950 was likely the result of increased mechanization in agriculture.

- Many natural lakes in Wisconsin show a decline in soil erosion rates in the last couple of decades because of conservation practices. This does not appear to be occurring in Lake Arbutus' watershed.

- Calcium, which is often used as a soil amendment in agricultural fields, showed an increase in its deposition since 1980. This reflects the increased use of lime on fields in the watershed.

- The diatom community indicates that inlake phosphorus levels were higher during the period 1970-1995, but they have declined somewhat in the last decade.

- The sediment core indicates that the biggest impact on Lake Arbutus is from increased sediment infilling. Efforts should be made to reduce the sedimentation rate by encouraging soil conservation practices in the watershed.

References

Appleby, P.G., and F. Oldfield, 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena. 5:1-8.

Bennion H., P.G. Appleby, and G.L. Phillips. 2001. Reconstructing nutrient histories in the Norfolk Broads, UK: implications for the role of diatom-total phosphorus transfer functions in shallow lake management. J. Paleolim. 26:181-204.

Binford, M.W., J.S. Kahl, and S.A. Norton. 1993. Interpretation of ^{210}Pb profiles and verification of the CRS dating model in PIRLA project lake sediment cores. J. Paleolim. 9:275-296.

Ramstack, J.M., S.C. Fritz, and D.R. Engstrom. 2004. Twentieth century water quality trends in Minnesota lakes compared with presettlement variability. Can. J. Fish. Aquat. Sci. 61:561-576.

Wilson, S.E., J.P. Smol, and D.J. Sauchyn. 1997. A holocene paleosalinity diatom record from southwestern Saskatchewan, Canada: Harris Lake revisited. J. Paleolim. 17:23-31.

Funding for this study was provided by Lake Arbutus Association and Wisconsin Department of Natural Resources. Field help was provided by Dan Helsel of the WI Dept of Natural Resources and many volunteers from the lake association . Radiochemical analysis was provided by the Lynn West's group at the Wisconsin Laboratory of Hygiene. Geochemical analyses was provided by University of Wisconsin, Soil Testing Laboratory and the George Bowman's group at the Wisconsin Laboratory of Hygiene.