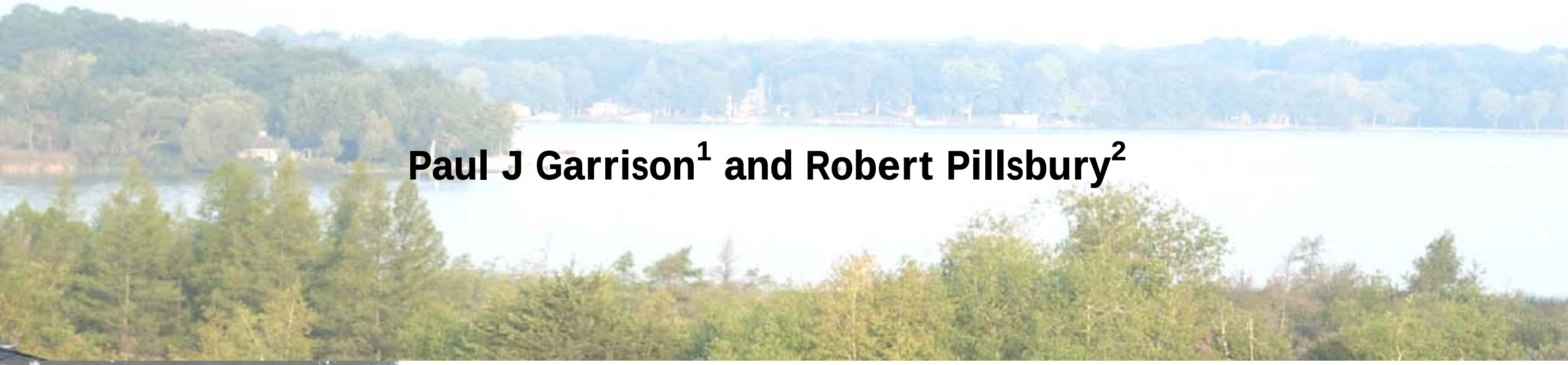
PALEOECOLOGICAL STUDY OF LAKE RIPLEY, JEFFERSON COUNTY



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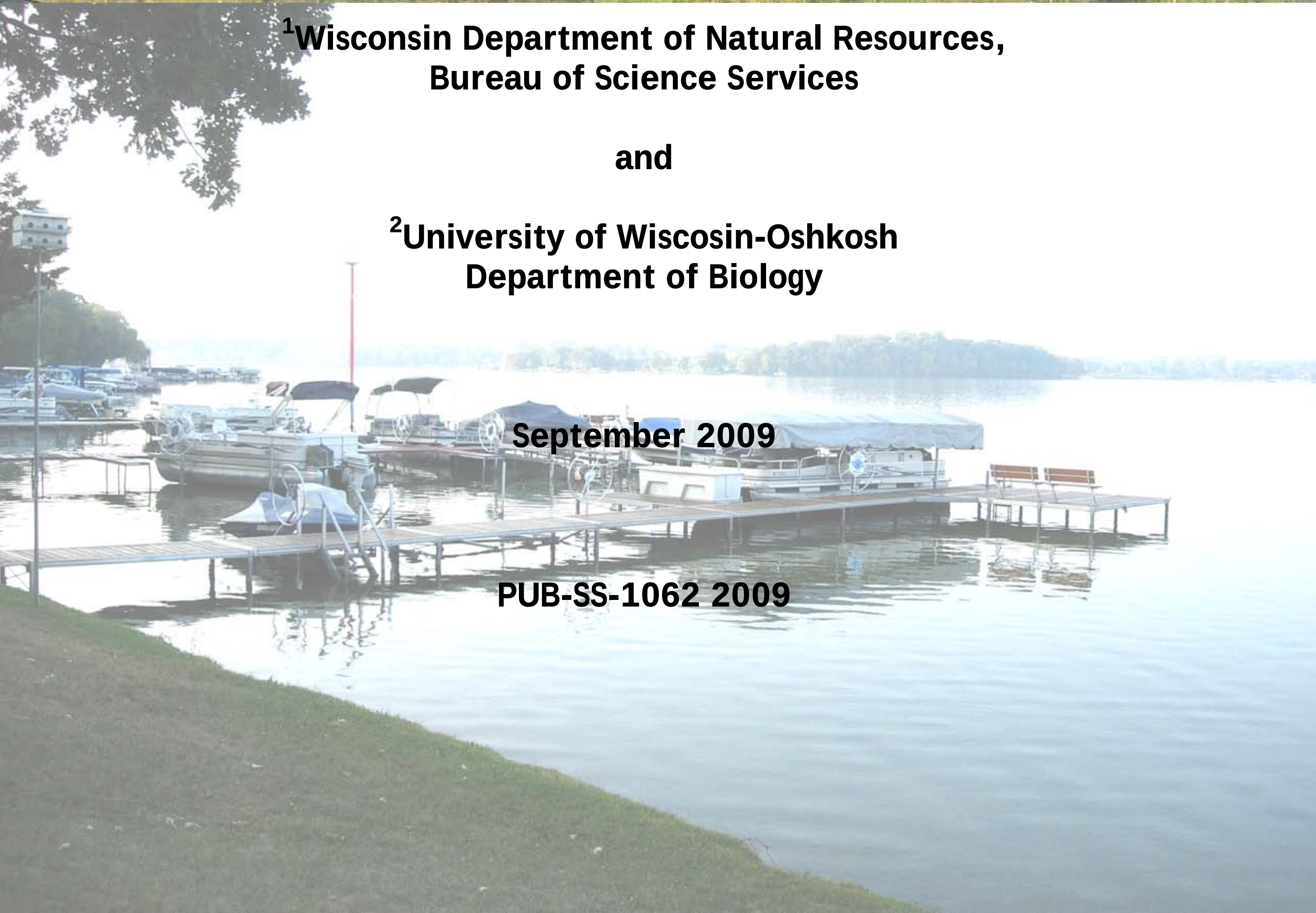

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Introduction

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. People often wonder about how a lake has changed, when the changes occurred and what the lake was like before the transformations began 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 Ripley, Jefferson County, is a 420 acre lake with a maximum depth of 44 feet and a mean depth of 18 feet. The lake is a drainage lake with one permanent inlet and a 7.3 squate mile watershed. A sediment core was collected from the deepest area on 13 August 2007. The location of the coring site was 43.00201° north and 88.99083° west in 43 feet of water (Figure 1). The core was collected with a piston corer with an inside diameter of 8.8 cm. The core was sectioned into 1 cm intervals for the top 40 cm and 2 cm intervals from 40 to 72 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.

Previously, a sediment core had been collected from the lake in 1991 and the paleoecological history determined for the time period 1800 to 1990. Since that time considerable work has been done in the watershed and within the lake to improve its water quality. The Lake Ripley Priority Lake Project was from 1993 to 2006. This purpose of this project was to improve the lake's water quality by installing best management practices to reduce sediment loading, restore over 100 acres of degraded wetlands, and restore eroded shorelines and ditch banks. The 2007 core was taken to evaluate the effectiveness of the watershed and shoreline work done since 1991.

The area around Lake Ripley was surveyed by the General Land Office in 1835. A sketch map of Oakland Township where the lake is located is shown in Figure 2. When the township was surveyed in 1835, there were already 15 lots around the lake. The landscape around the lake were diversified prairie and woodlands. Settlement in the area of the lake began in the 1840s as settlers arrived and

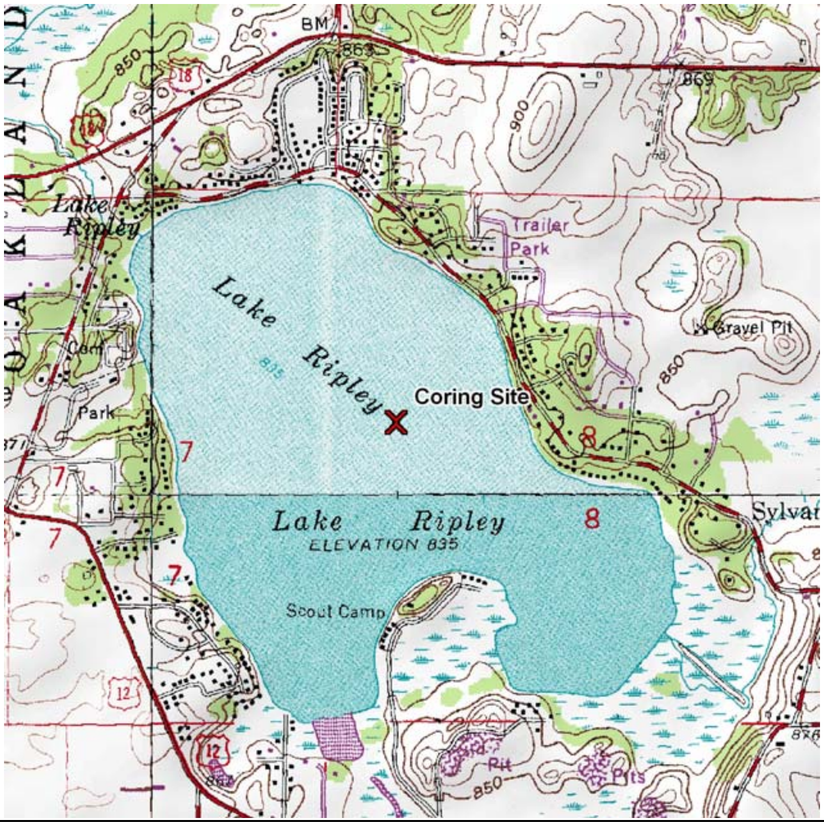

Figure 1. Map of Lake Ripley showing the coring site. The water depth at the site was 43 feet.

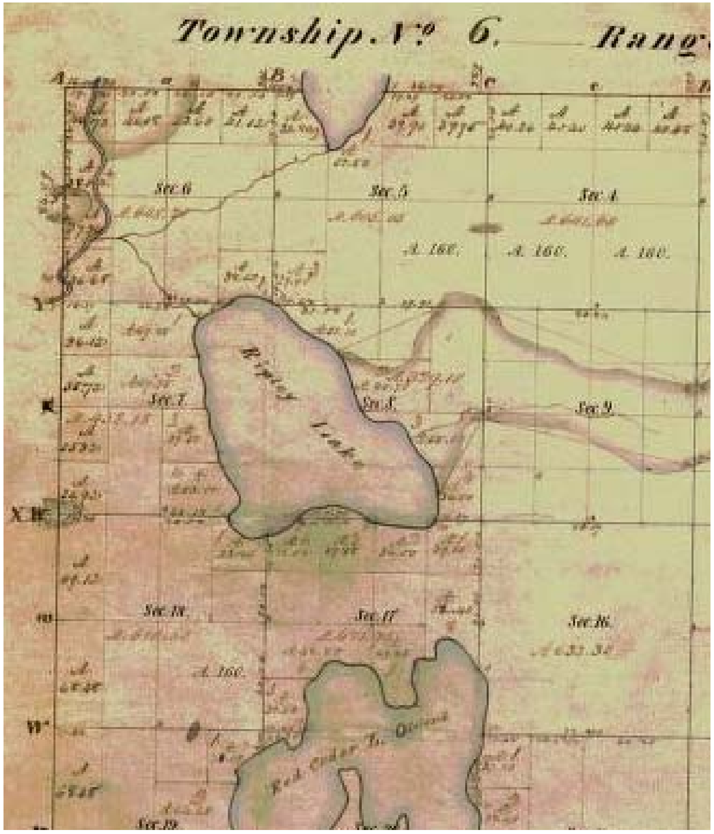

Figure 3. Plat map of Oakland Township drawn from survey notes taken in 1835. At this time there are 15 lots platted around Lake Ripley.

started farming. One of the earliest settlers was George Dow, an immigrant from Scotland. The lake at that time was known as Lake Dow (Dow and Carpenter 1877). The principal crops at this time were corn, wheat, oats and rye. During the early years, two colonies existed near the lake. One was at the west end near the village of Cambridge and the other was south of the lake. During the early part of the twentieth century Lake Ripley became a popular small summer resort area. In 1924 there were tow large hotels, three smaller ones as well as a number of privately owned cottages (Scott 1924).

Since the 1920s the Lake Ripley area has increased in popularity for summer vacations but the number of resorts has declined but the number of individual cottages has increased. Nearly all of these early cottages have been replaced by larger homes and most are now occupied all year. The amount of impervious surface has consequently enlarged and manicured lawns are the norm.

Agriculture has also changed in the last century. Following World War II, mechanization greatly increased and the use of synthetic fertilizers is common practice. This has resulted in increased land under cultivation and the application of increased amounts of nutrients onto the landscape. This has resulted in greater soil erosion and increased runoff of nutrients off the land and into the streams and lake.

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 it is sometimes 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 (g cm^{-2} yr^{-1}) were calculated from output of the CRS model.

Sedimentation Rate

In Lake Ripley the mean mass sedimentation rate for the last 200 years was 0.067 cm^{-2} yr^{-1} (Figure 3). This is at the higher end of rates that has been measured in 52 Wisconsin lakes. One of the contribut-

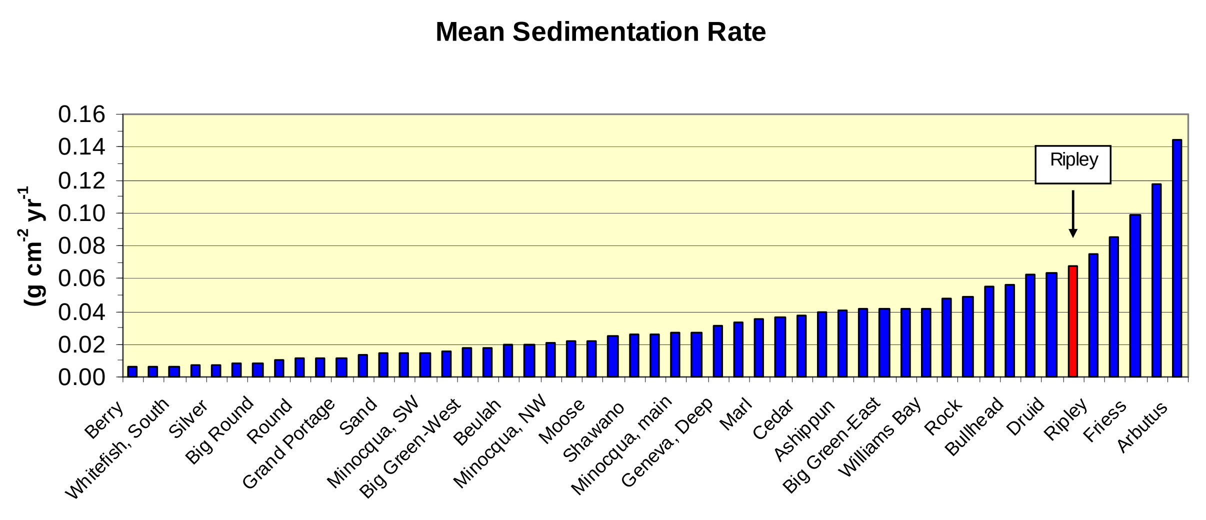

Figure 3. Mean sedimentation rate for the last 150 years for 52 Wisconsin lakes. The arrow indicates Lake Ripley. The rate in this lake is higher than many of the lakes. This is partially because the lake is a hardwater lake and experiences precipitation of calcium carbonate during much of the summer.

ing factors for the elevated rate is the fact that Lake Ripley is a marl lake. This means that calcium carbonate is precipitated during part of the year and this leads to a higher sedimentation rate. However, other marl lakes have a lower mean sedimentation rate than Lake Ripley. The mean sedimentation rate for the 2007 is slightly lower than the 1991 core which was 0.074 cm^{-2} yr^{-1}.

To account for sediment compaction and to interpret past patterns of sediment accumulation, the dry sediment accumulation rate was calculated. The sedimentation rate was very low in the first half of the nineteenth century being around 0.010 cm^{-2} yr^{-1} (Figure 4). The first peak in the sedimentation rate occurred during the early part of the 1910s. This may have been the result of major land clearing activity or wetland channeling in the watershed. The largest sedimentation peak occurred during the 1940s (Figure 4). The sedimentation rate at this time reached 0.25 cm^{-2} yr^{-1}, much higher than any other measured rate in the core. This exceptionally high rate may have been the result of channelization of wetlands in the watershed. This will discussed further below. From the period of the 1950s through the 1980s the rate was lower but still exceeded the historical rate. Since 1990 when the lake was part of the priority watershed program, the sedimentation rate has been reduced further than it was from 1950-90. It appears that the conservation practices in the watershed were effective in reducing sediment infilling in the 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 and titanium are surrogates of detrital aluminosilicate materials and thus changes in their profiles are an indication of changes in soil erosion. Zinc is associated with urban runoff because it is a component of tires and galvanized roofs and downspouts. Potassium is found in both soils as well as synthetic fertilizers. Therefore its profile will reflect 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 and calcium carbonate.

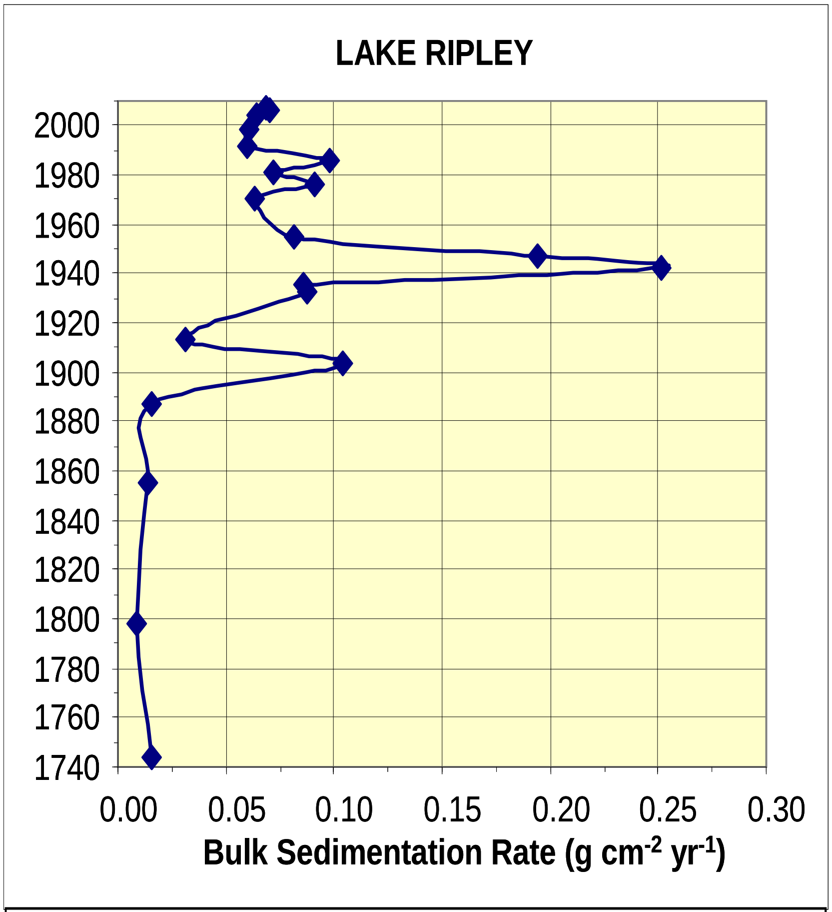

Figure 4. Sediment accumulation rate in Lake Ripley. The historical rate was very low. The peaks around 1900 and 1940 were largely the result of soil erosion from agricultural activities.

The accumulation rate of titanium, which indicates soil erosion, was low until the beginning of the twentieth century when it began to increase (Figure 5). This increase coincides with the first sedi-

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, aluminum
Ore smelting	zinc, cadmium, copper
Nutrients	phosphorus, nitrogen
Lake productivity	Organic matter, calcium carbonate

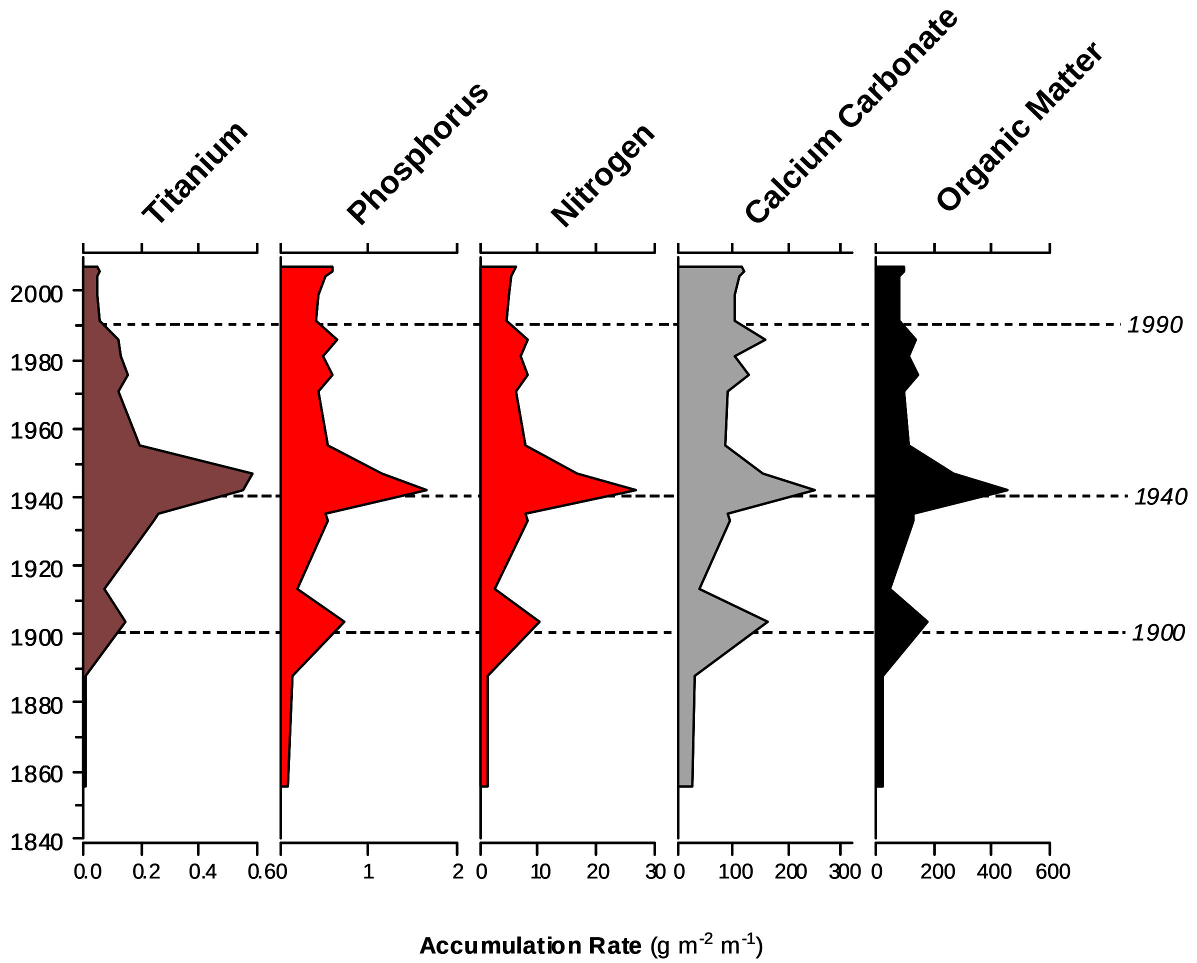

Figure 5. Profiles of the accumulation rate of selected geochemical elements. Titanium profiles are indicative of soil erosional rates. Phosphorus and nitrogen are essential nutrients for plant growth. Calcium carbonate is largely the result of marl precipitation and along with organic matter, indicates general lake productivity.

mentation rate peak (Figure 4) and likely indicates increased agriculture in the watershed. Titanium deposition continued to increase and was at its highest levels during the 1940s (Figure 5). After the 1950, titanium levels slowly declined until about 1990. Since the implementation of the priority lake project the titanium depositional rates have been at their lowest levels since the end of the nineteenth century. The titanium profile shows that soil erosion rates were highest from 1910 until about 1950. With the implementation of soil conservation practices beginning in the late 1950s, soil erosion in the watershed declined. The priority lake project appears to have been successful in further reducing soil erosion rates to their lowest levels since 1900.

Phosphorus and nitrogen levels were very low until about 1900 (Figure 5). As with soil erosion, there was an early peak around 1900 but the greatest deposition occurred around 1940. Much of this deposition was associated with soil particles as titanium accumulation rates also peaked at this time. Phosphorus and nitrogen rates were much lower from the mid-1950s until 1990 when they decreased further. The increase in phosphorus and nitrogen at the top of the core does not indicate an increase in deposition in the last few years but instead, that diagenesis is ongoing. Diagenesis is the conversion of organic material, to other forms. These other forms may be volatile so that the element leaves the system. For example, as nitrogen in its organic form is degraded, one breakdown product is a gas which may escape into the atmosphere.

Other authors have noted that phosphorus and nitrogen profiles may not reflect the lake's eutrophication history because of diagenesis (Schelske et al. 1988, Anderson and Rippey 1994, Fitzpatrick et al. 2003). Over the course of a few years some organic fractions of P and N breakdown into the inorganic components. Some of this material then may be recycled into the water column and out of the sediments. It appears that as a result of the priority lake project, phosphorus and nitrogen was reduced some, but not as much as soil erosion (titanium).

The calcium profile is mostly the result of calcium carbonate deposition or marl formation. This is very common in a hardwater lake like Ripley. Marl formation increases with increased photosynthetic productivity of the lake. This can be from algae or macrophytes. The peak calcium deposition in the early 1940s was likely the result of input of marl from the watershed and not inlake formation of marl.

Since 1950, calcium deposition as generally increased even after 1990. This indicates that the lake's productivity has increased. This may be from algal production or from macrophytes. The calcium deposition during the last 20 years increased faster than deposition of organic matter (Figure 5). In fact, the organic matter profile is very similar to the nitrogen profile. This is not surprising as nitrogen is often a significant component of organic matter. The peak organic matter deposition around 1940 is further evidence that dredging of the stream channel occurred at this

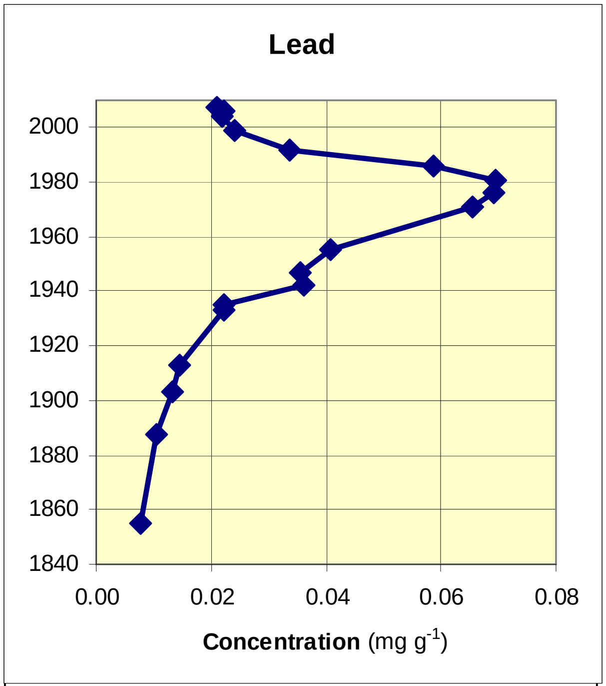

Figure 6. Profile of stable lead in the sediment core. The decline after 1980 reflects the reduction in the use of bonded lead in gasoline.

time. This peak is probably the result of wetland material disturbed during the dredging being delivered to the lake.

This peak deposition of all measured geochemical elements (Figure 5) as well total sediment (Figure 4) is probably a result of the dredging of the stream channel entering the lake. This channel straightening was very common in this region during the 1940s. Parts of nearby Koshkonong Creek was straightened during the same time.

Stable lead has an historical pattern of deposition that is very consistent among lakes, with lead concentrations increasing from around 1880 to the mid-1970s, and decreasing to the present. The decline of lead is largely the result of the discontinued use of bonded leaded gasoline in the mid-1970s (Gobeil et al. 1995; Callender and Van Metre 1997). The history of leaded gasoline in the region around Lake Ripley was very evident in the sediment core (Figure 6).

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 7 shows photographs of four diatom species that were found in the sediment core.

The diatom community at the bottom of the core was relatively diverse with diatoms typically found in oligo-mesotrophic conditions. *Cyclotella michiganiana* and *C. bodanica* var. *lemanica* were the most common diatoms (Figure 7). These diatoms grow in the metalimnion, indicating good water clarity and low nutrient levels (Garrison and Wakeman 2000). Around 1850, soon after European settlers arrived, *C. michiganiana* nearly disappeared indicating a decline in water clarity. At this same time the planktonic diatom *Aulacoseira ambigua* increased which prefers higher phosphorus levels than *C. michiganiana* (Bradbury 1975, Reavie et al. 1995). More significant changes in the diatom community occurred around 1910 with the decline in *C. bodanica* var. *lemanica* and the increase in *A. ambigua* (Figure 7) indicating a further increase in phosphorus levels. For the first time *Cyclostephanos dubius*

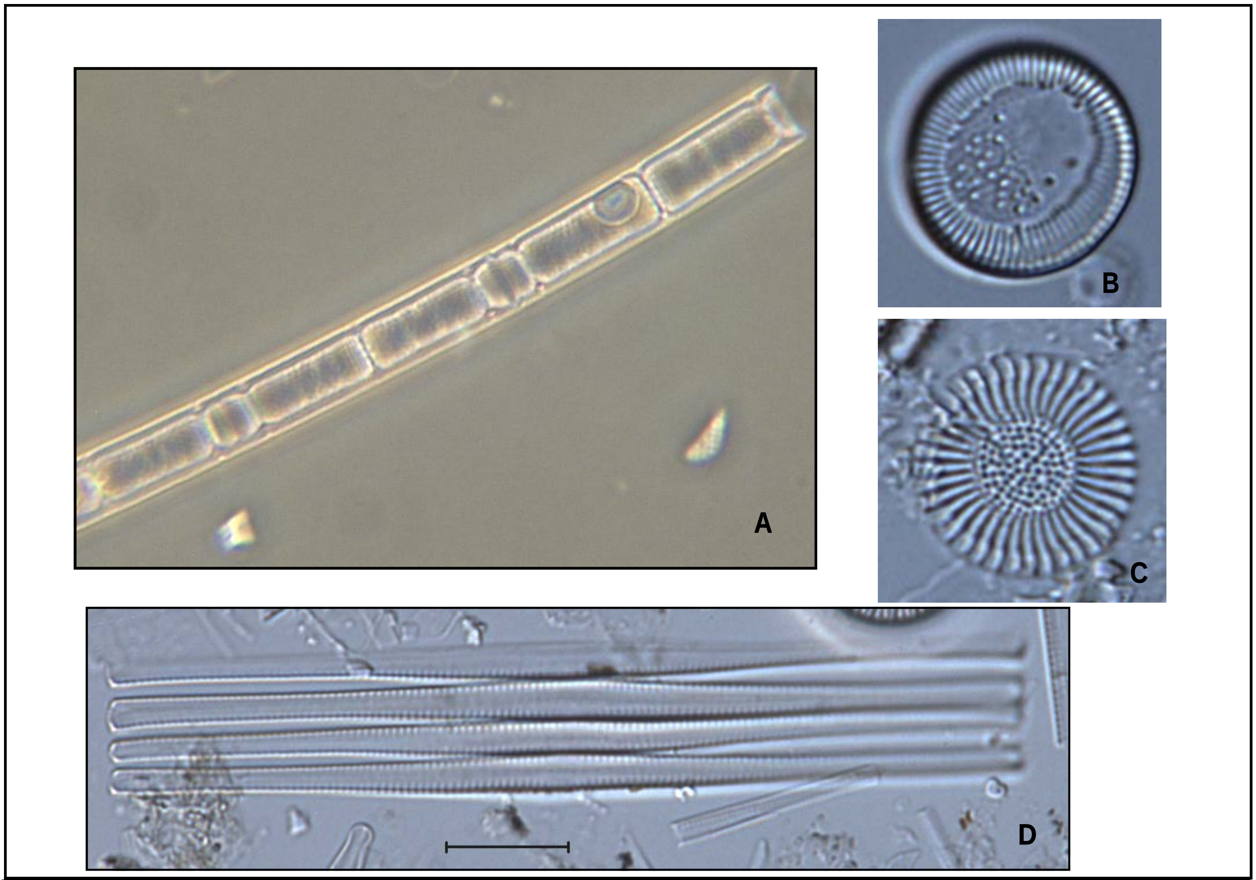

Figure 7. Photomicrographs of diatoms found in the sediment core. These diatoms are typically is found in open water environments. The diatom at the top left (A) *Aulacoseira ambigua* and the diatom at the bottom (D), *Fragilaria crotonensis*, indicate moderate nutrient levels while the diatom at the top right (B) *Cyclotella michiganiana*, indicates low nutrient levels. *Cyclostephanos dubius (*C) indicates high nutrient levels.

appeared. This taxa is common under high phosphorus levels. A greater increase in phosphorus occurred after 1940 with a further decline in *C. bodanica* var. *lemanica* and the increase in *A. ambigua* as well as an increase in *Fragilaria crotonensis* (Figure 7). At this time the benthic diatom *Gomphonema minutum*, which had been present throughout the core, nearly disappeared. This diatom grows attached to macrophytes and is found with good water clarity.

During the 1970s the diatom *C. dubius* was at it peak (Figure 7). This diatom indicates elevated phosphorus levels (Håkansson and Regnéll 1993, Anderson 1997, Sayer 2001). In other cores its increase is followed by the increase of small *Stephanodiscus* taxa which has been interpreted to mean a continued increase in phosphorus levels. This did not happen indicating that phosphorus levels in Lake Ripley may have peaked during the 1970s. *C. dubius* has not been present for the last two decades (Fritz 1989, Håkansson and Regnéll 1993, Anderson 1997, Sayer 2001).

Following the priority watershed project in the 1990s, the diatom community hints at a slight improvement in nutrient levels. There was a decline in *A. ambigua* and *C. bodanica* var. *lemanica* abundance has increased somewhat. *F. crotonensis* remains one of the dominant diatoms indicating that nutrient levels are still elevated compared with presettlement levels.

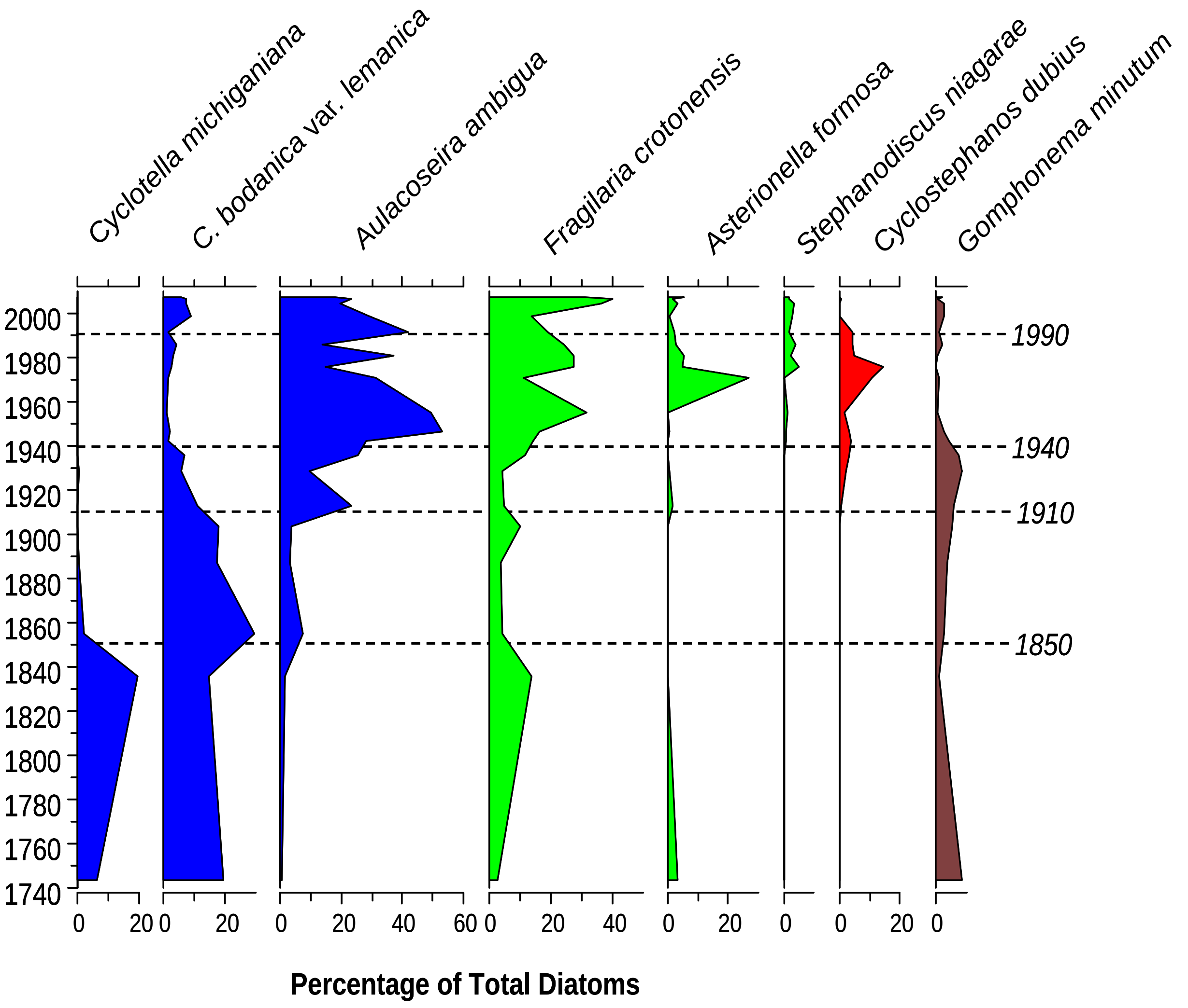

Figure 8. Profiles of common diatoms found in the core. The diatoms in blue are indicative of low nutrients, green-moderate nutrient levels, red-higher nutrient levels. The brown colored diatom is the only one shown which grows attached to plants. The other diatoms float in the open water.

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.

The diatom community was used to estimate changes in the summer phosphorus levels throughout the core. Historical P levels were low, being about 12-13 µg L^{-1} (Figure 9). Phosphorus concentrations began increasing after the early episodic sedimentation event around 1900. Phosphorus levels continued to increase and reached their highest levels during the period 1940-1990. Since the priority watershed project in the 1990s, phosphorus levels have declined, although they are not as low as pre-settlement levels. The diatom estimated phosphorus levels at the top of the core are 17-19 µg L^{-1} (Figure 9) which are slightly lower than measured summer values which are about 23-25 µg L^{-1}. It is not unusual for the modeling to be somewhat different from actual values because the diatom community responds to multiple variables besides phosphorus. Because the trend in diatom estimated phosphorus generally agrees with changes in the stratigraphy. These results indicate that the method is sufficiently reliable to indicate dominant trends in changing phosphorus concentrations over time. In other words, phosphorus levels during the last 2 decades are likely lower than the were during the period 1940-1990.

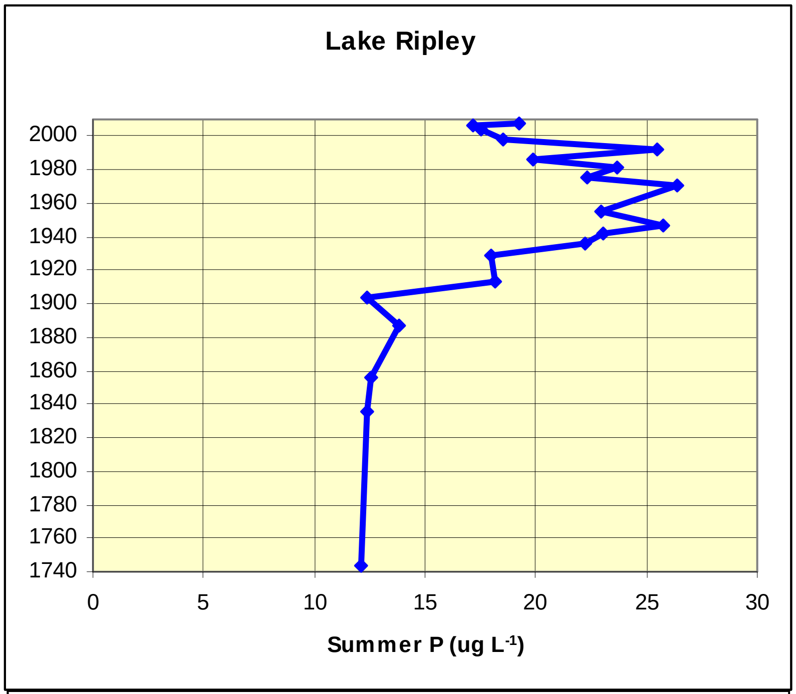

Figure 9. Estimated summer phosphorus levels in the core. These values were inferred from the diatom community using weighted averaging modeling.

The results of the sediment core study indicate that Lake Ripley has been significantly impacted by actions in the lake's watershed. Since settlement in the mid-1800s the infilling rate of the lake has increased and phosphorus concentrations have also increased. Conservation actions in the watershed have significantly improved the water quality of the lake. Soil conservation practices which were instituted in the 1960-80s reduced soil erosion rates. The priority watershed project in the 1990s resulted in further reduction in the soil erosion rates which resulted in reduced infilling of the lake and lower phosphorus levels. The diatom community demonstrates how sensitive lakes are to development around the lake. Early settlers in the mid-1800s contributed enough nutrients to begin to change the lake’s water quality. Of course the greatest degradation of the lake’s water quality occurred during the last half of the twentieth century.

- The mean sedimentation rate for the last 150 years in Lake Ripley was towards the high end measured in 52 Wisconsin lakes. This was partially because it is a marl lake.

- Their were two episodic peaks in the sedimentation rate, around 1900 and the early 1940s. The first peak was likely the result of a short timed event in the watershed. The 1940s peak was much larger and likely was the result of dredging the stream channel where it enters the lake.

- The sedimentation rate since 1990 is the lowest experienced in the last 100 years.

- The rate of soil erosion largely mirrors the lake's sedimentation rate with the peak occurring during the 1940s and the lowest rates during the last 100 years being after 1990.

- Phosphorus deposition largely mirrors soil erosion but has not declined since 1990 at the same rate as soil erosion.

- The deposition of marl in recent years is at higher levels than during much of the twentieth century. This indicates that the lake's productivity remains elevated. This is not necessarily the result of algal production but may be in the form of macrophyte growth.

- The diatom community indicated that phosphorus levels first began to increase at the beginning of the twentieth century with peak concentrations occurring during the period 1940-1990. Phosphorus levels have been lower during the last 2 decades but are higher than presettlement levels.

- This study shows that the conservation efforts that were part of the priority lake project in the 1990s were successful in reducing soil erosion. This has resulted in a decline in the sediment infilling of the lake and a reduction in the mean summer phosphorus concentration.

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