Hydrology, Water Quality, and Phosphorus Loading of Little St. Germain Lake, Vilas County, Wisconsin

Introduction

Little St. Germain Lake, which is in Vilas County, Wisconsin, just northeast of St. Germain (fig. 1), is one of 21 impoundments operated by Wisconsin Valley Improvement Company (WVIC) to provide storage for power and recreational use. The level of the lake, which was originally dammed in 1882, has been maintained by the WVIC at about 5 feet above its natural level since 1929, and it is annually drawn down about 1.5 feet from December through March. In the interest of protecting and improving the water quality of the lake, the Little St. Germain Lake Improvement Association was established in 1959. Later, the Little St. Germain Lake District was formed. The Wisconsin Department of Natural Resources (WDNR), in collaboration with the Lake District, did a study during 1983–85 to document the water quality of the lake and examine management alternatives (Wisconsin Department of Natural Resources, 1985). Results of the study indicated that, because of relatively high phosphorus loading to the lake, most of the lake was eutrophic (relatively productive), with the possible exception of the West Bay. The results also indicated monitoring of the lake should continue, and that actions should be taken to decrease nutrient loading to the lake by controlling erosion, fertilizer runoff, and leakage from septic systems.

The lake was monitored in detail again during 1991–94 by the U.S. Geological Survey (USGS) as part of a cooperative study with the Lake District. This study demonstrated water-quality variation among the basins of Little St. Germain Lake and extensive areas of winter anoxia (absence of oxygen). Further in-depth studies were then conducted during 1994–2000 to define the extent of winter anoxia, refine the hydrologic and phosphorus budgets of the lake, quantify the effects of annual drawdowns, and provide information needed to develop a comprehensive lake-management plan. This report presents the results of the studies since 1991.

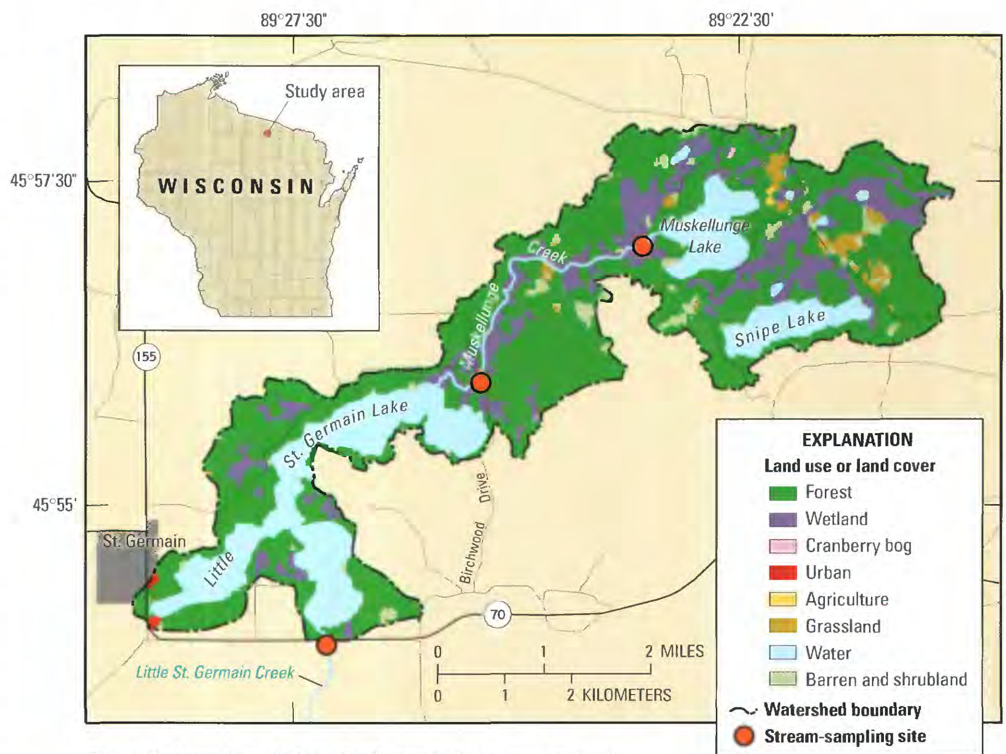

Figure 1. Location of Little St. Germain Lake, watershed characteristics, and location of stream-sampling sites.

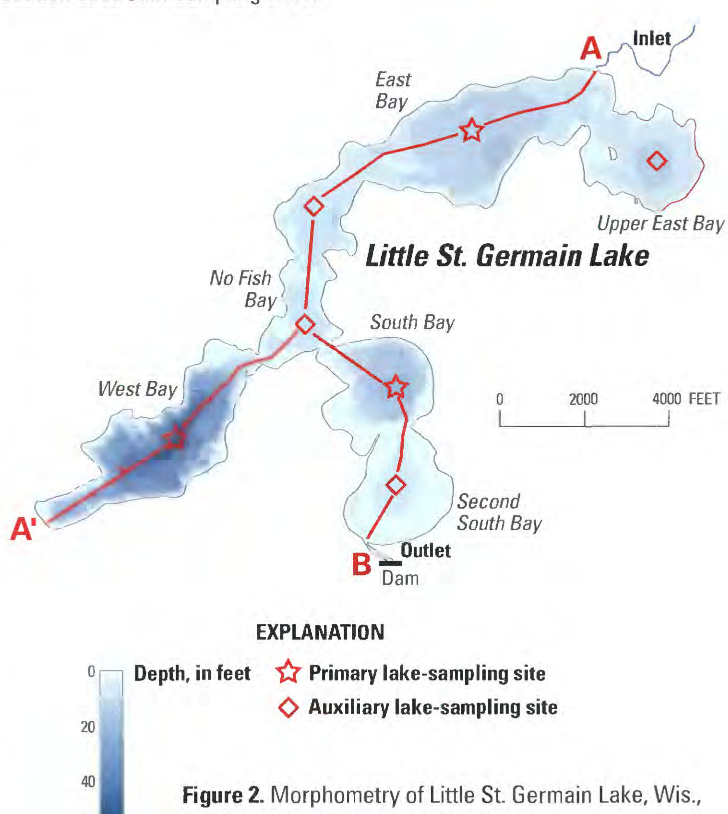

Figure 2. Morphometry of Little St. Germain Lake, Wis., and locations of lake-sampling sites.

The Lake and its Watershed

Little St. Germain Lake (fig. 1) is a multibasin lake with a total surface area of 977 acres and volume of 11,500 acre-feet. In this report, the lake is discussed in terms of six basins (fig. 2): Upper East Bay (119 acres, maximum depth—16 feet), East Bay (336 acres, 16 feet), No Fish Bay (69 acres, 10 feet), West Bay (213 acres, 53 feet), South Bay (122 acres, 22 feet), and Second South Bay (119 acres, 10 feet). The major tributary to the lake is Muskellunge Creek, which flows about 3 miles from shallow, eutrophic Muskellunge Lake into the north end of the East Bay. Outflow from the lake is to Little St. Germain Creek, which leaves the south side of the Second South Bay and flows about 1 mile before draining into the Wisconsin River.

The total watershed area of Little St. Germain Lake is 10 mi². The watershed is predominantly forest (68 percent), wetland (17 percent), and water (24 percent), although areas of low-density residential development are increasing (fig. 1). The soils in the watershed consist mainly of well-drained sand and sandy loams. These soils are thought to be naturally high in phosphorus content (Wisconsin Department of Natural Resources, 1985).

Data Collection—sites and techniques

Data used to describe the water quality of the lake were collected from April 1991 to January 2000; however, no data were collected from September 1994 to July 1996 and September 1997 to February 1999. Lake water-quality properties were generally measured five times per year (late winter, May, June, July, and August) at three sites: the centers of the East, West, and South Bays (fig. 2). At all sites, depth profiles of water temperature, dissolved oxygen, specific conductance, and pH were measured during each visit with a multiparameter instrument. Water samples were collected at these sites at either or both near surface (1 foot below the surface during open water or just below ice during ice cover) or near bottom (1 foot above bottom). Near-surface water samples were analyzed for concentrations of total phosphorus (an indicator of nutrient availability) and chlorophyll *a* (an indicator of the algal population). During ice-free periods, Secchi depths (an indicator of water clarity) also were measured. All water samples were analyzed by the Wisconsin State Laboratory of Hygiene.

Additional depth-profile measurements of temperature and oxygen were made at seven locations (the main sampling sites, the center of each of the other bays, and the western end of the East Bay; fig. 2) throughout the winter of 1996–97 to assess the extent and timing of anoxia. Profiles also were collected between these sites in March 1997 and 1999 to describe the spatial extent of anoxia (transects A–B and A'–B ; fig. 2).

Data collected during this study were published in two annual USGS data report series, the most recent of each being "Water Resources Data, Wisconsin—Water Year 1999" (Holmstrom and others, 2000) and "Water Quality and Lake-Stage Data for Wisconsin Lakes, Water Year 1999" (U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2000). Water levels at the dam on Little St. Germain Creek were monitored almost daily from 1991–99 by the WVIC (U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2000).

Inflow to the lake was determined from measurements and water samples collected monthly in Muskellunge Creek at Birchwood Drive (fig. 1) during October 1996–September 1997 and December 1998–January 2000. During 1996–97, water samples were analyzed for total phosphorus concentration. During 1998–99, water temperature and dissolved oxygen also were measured, and the samples also were analyzed for dissolved phosphorus.

Surface-water outflow from the lake was estimated from water-elevation measurements made at the dam by WVIC. To better describe the outflow, additional flow measurements and water samples were collected monthly just below the dam from December 1998 through November 1999. Water samples were analyzed for total phosphorus. Measured flow at the dam indicated that low flows were underestimated and therefore those flows were adjusted accordingly.

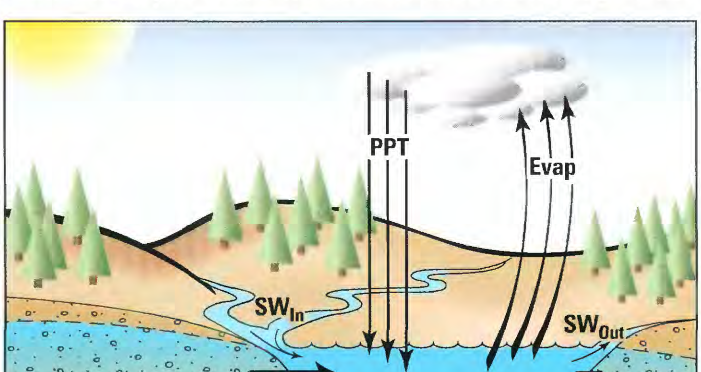

Figure 3. Schematic of the hydrologic budget of Little St. Germain Lake, Wis. Abbreviations are defined in the text.

Hydrology

The hydrology of Little St. Germain Lake can be described in terms of components of its water budget (fig. 3). The water budget for the lake may be represented by

$$\Delta S = (PPT + SW_{In} + GW_{In}) - (Evap + SW_{Out} + GW_{Out}), \qquad (1)$$

where ΔS is the change in the volume of water stored in the lake during the period of interest and is equal to the sum of the volumes of water entering the lake minus the sum of the volumes of water leaving the lake. Water enters the lake as precipitation (PPT), surface-water inflow (SW_{In}), and ground-water inflow (GW_{In}). Water leaves the lake through evaporation (Evap), surface-water outflow (SW_{Out}), and ground-water outflow (GW_{Out}).

Each term in the water budget was computed for two different year-long periods: October 1996–September 1997 (1997) and December 1998–November 1999 (1999). Changes in lake volume were determined from water elevations monitored at the outlet dam (fig. 2) and the morphometry of the lake. Precipitation was measured by a weather observer in St. Germain. Surface-water inflow was estimated to equal the flow in Muskellunge Creek at Birchwood Drive. Flows were expected to change rather slowly and therefore daily inflows were estimated by linearly interpolating between monthly measurements. Evaporation from the lake was estimated on the basis of average monthly evaporation-pan data collected at Rainbow Flowage (about 10 miles southwest of the lake). Surface-water outflow consisted of flow past the dam into Little St. Germain Creek. Ground water seeps into and out of the bottom of Little St. Germain Lake. The monthly net ground-water flow (GW_{In} - GW_{Out}) was computed as the residual in the budget equation (eq. 1). These data did not allow ground-water inflow and ouflow to be computed independently; therefore, to estimate these components, ground-water inflow was assumed to be 50 percent more than net ground-water flow and ground-water outflow was assumed to be 50 percent less than net ground-water flow.

that at the beginning of the period; however, the lake stage was about 0.65 foot higher at the end of 1999 than at the beginning of that study year.

After converting all of the hydrologic components in the budget equation (eq. 1) into acre-feet, there was a net ground-water input to Little St. Germain Lake of about 3,900 acre-feet in 1997 and 2,400 acre-feet in 1999 (fig. 5). After assuming the total ground-water input was 50 percent more than net ground-water flow (an assumption that needs further evaluation), the total ground-water input was estimated to be 5,800 acre-feet in 1997 and 3,500 acre-feet in 1999. Ground-water studies conducted by the WDNR indicate that most, if not all, of the ground water is expected to enter into the East Bay (Wisconsin Department of Natural Resources, 1985).

The complete hydrologic budget (fig. 5) indicated that the major source of water to the lake is from surface-water inflow from Muskellunge Creek; however, during years following extended dry periods (such as prior to 1999), direct precipitation and ground water can be nearly as important. The major loss of water from the lake is through the outlet.

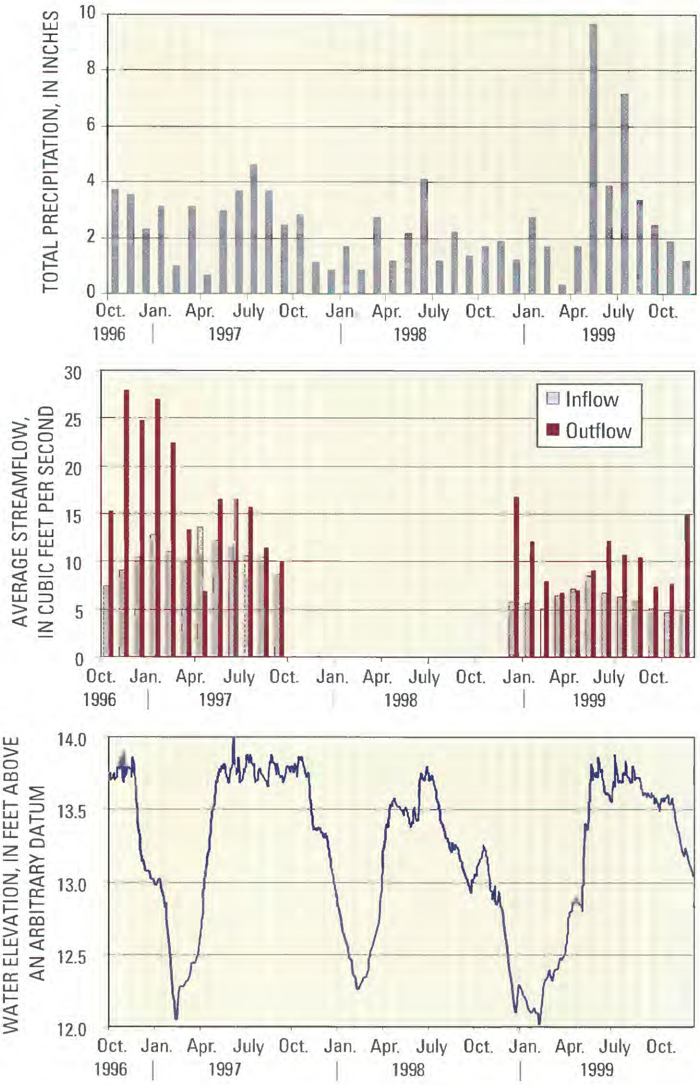

Figure 4. Monthly precipitation, inflow, outflow, and water elevation, Little St. Germain Lake, Wis.

Total monthly precipitation at St. Germain, monthly average surface-water inflow to and outflow from the lake, and water level of the lake are shown in figure 4. Total precipitation during 1997 (34.8 inches) was 4.4 inches less than in 1999 (39.2 inches). The average flow into the lake through Muskellunge Creek was 10.6 ft^3/s (cubic feet per second) in 1997 and 6.0 ft^3/s in 1999. The average flow out of the lake was 17.3 ft^3/s in 1997 and 10.6 ft^3/s in 1999. Inflow to the lake throughout 1997 was about 1.7 times that throughout 1999, even though there was less precipitation in 1997. This demonstrates that the flow in Muskellunge Creek is driven by long-term changes in precipitation rather than short-term fluctuations. Outflow from the lake in 1997 also was about 1.7 times that in 1999. In both years, outflow from the lake was about 1.7 times greater than that which came in from Muskellunge Creek. Evaporation from the lake was estimated to be 22.4 inches in both years.

Lake stage fluctuated from a minimum of 12.05 feet (relative to an arbitrary datum) to a maximum of 13.95 feet (fig. 4). The lake stage was relatively stable from May through mid November, lowered about 1.5 feet between mid November and early February, and remained relatively stable until mid March before again filling to its summer level. The lake stage at the end of 1997 was similar to

Phosphorus Budget

Previous studies indicated that most of Little St. Germain Lake was eutrophic because of relatively high phosphorus loading to the lake (Wisconsin Department of Natural Resources, 1985). Therefore, to help define where the phosphorus originated, a detailed phosphorus budget was computed. Sources of phosphorus to the lake include precipitation, the inflowing stream, ground water, and

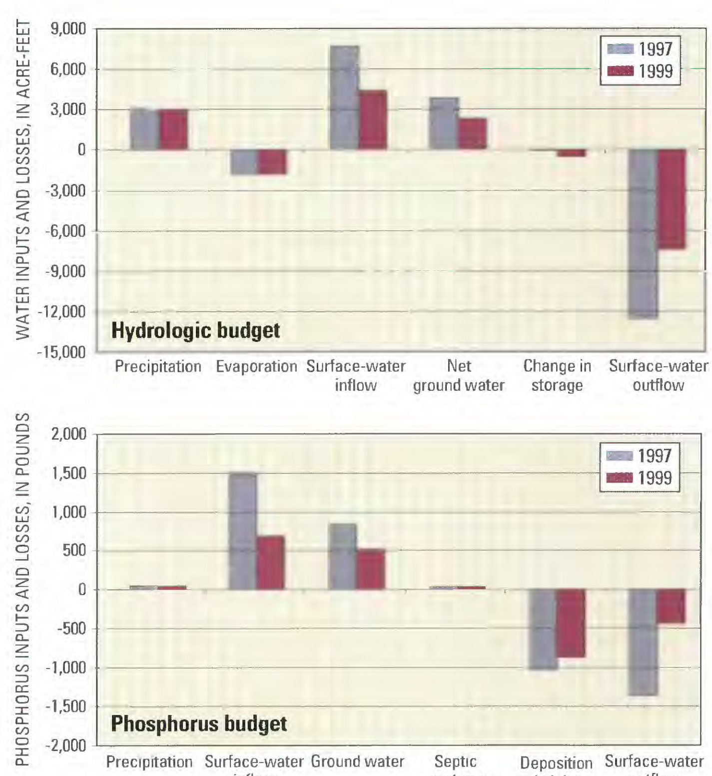

Figure 5. Hydrologic and phosphorus budgets of Little St. Germain Lake, Wis.

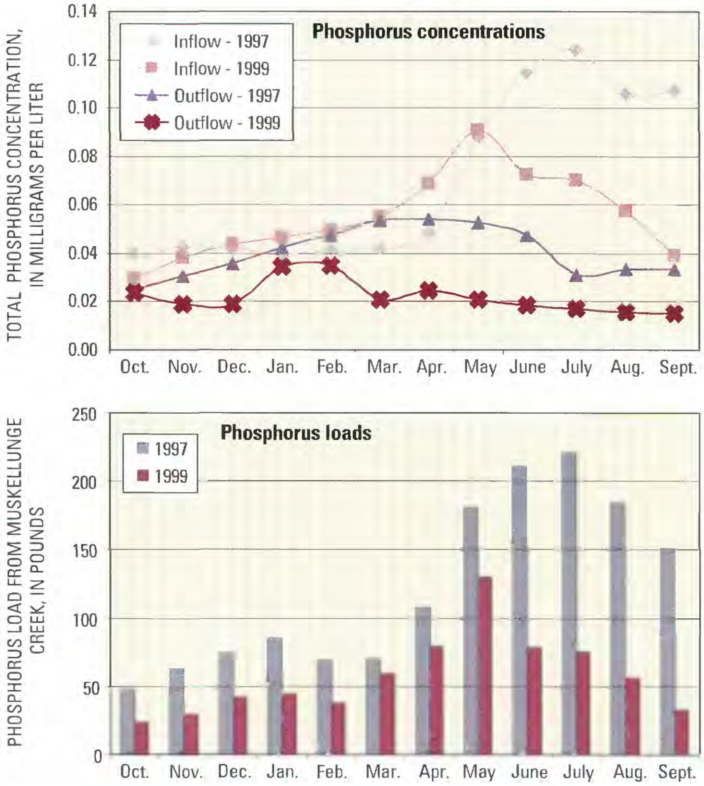

Figure 6. Phosphorus concentrations and loads in the inflow and outflow from Little St. Germain Lake, Wis., and phosphorus loads to the lake from Muskellunge Creek.

contributions from septic systems. Phosphorus concentration in precipitation was assumed to be 0.007 mg/L, a value found by Rose (1993) for northern Wisconsin. Therefore, direct precipitation contributes about 55 lbs of phosphorus per year to the lake (fig. 5).

Phosphorus concentrations in Muskellunge Creek inflow ranged from about 0.04 mg/L in winter to about 0.12 mg/L in July 1997 and about 0.09 mg/L in May 1999 (fig. 6). In 1999, about 30 percent of the phosphorus was in dissolved forms; however, the percentage in dissolved forms was not measured in 1997. Phosphorus concentrations were much higher in 1997 than in 1999, especially in mid to late summer. The high concentrations in 1997 may have been due to effects of beaver activity on Muskellunge Creek downstream from Muskellunge Lake. It is thought that ponding of water behind beaver dams resulted in a high release of phosphorus from the organic-rich wetland sediments that are not otherwise inundated with water. With this increased release of phosphorus from the sediments, a higher percentage of phosphorus would probably be in dissolved forms than was measured in 1999. Phosphorus concentrations in Muskellunge Creek, in both years, were high considering most of the watershed of Little St. Germain Lake is relatively pristine. The high concentrations are thought to be the result of leaching from the soils that are rich in phosphorus (Wisconsin Department of Natural Resources, 1985). Daily phosphorus concentrations were estimated by linearly interpolating between monthly measurements. The amount of phosphorus delivered to the lake was then computed by multiplying the daily phosphorus concentrations by the daily runoff volumes. The total input of phosphorus from stream inflow was estimated to be 1,500 and 700 pounds in 1997 and 1999, respectively (fig. 5). The difference between years was primarily due to the reduced flows in 1999, but decreased concentrations also contributed to the decreased loads in 1999.

Phosphorus concentrations in ground water were not measured as part of this study, and those measured as part of other studies were quite variable. Therefore, a phosphorus concentration for ground water was estimated by use of equation 2:

$$[TP]_{GW} = \frac{(Q_{BW}*[TP]_{BW} - Q_{MLO}*[TP]_{MLO})}{(Q_{BW} - Q_{MLO})} . \qquad (2)$$

This equation is based on two assumptions: (1) during winter, biological and chemical processes have minimal effect on the water quality of Muskellunge Creek, and so changes in the concentration of phosphorus in Muskellunge Creek as it flows from Muskellunge Lake outlet (MLO) to Birchwood Drive (BW) are caused only by the addition of ground water, and (2) ground water entering Little St. Germain Lake has the same concentration as that entering Muskellunge Creek. Therefore, an estimate of the phosphorus concentration in ground water ($[TP]_{GW}$) can be obtained by the change in the phosphorus load (Q*[TP]) from MLO to BW divided by the increase in the flow of the creek ($Q_{BW} - Q_{MLO}$). Average phosphorus concentrations (from December 1999 and January 2000) increased from 0.035 mg/L at Muskellunge Lake Outlet to 0.045 mg/L at Birchwood Drive, while average streamflow increased by 2.1 ft^3/s. Therefore, an average phosphorus concentration of 0.053 mg/L was obtained for ground water after applying these values to equation 2 and resulted in an estimated total input of phosphorus from ground water of 835 and 512 pounds in 1997 and 1999, respectively (fig. 5). Most phosphorus contributed by ground water is expected to enter into the East Bay of the lake.

The input of phosphorus from septic systems (M) was estimated by use of equation 3 (Reckhow and others, 1980):

$$M = E_S * (\text{Number of Capita Years}) * (1 - S_R), \qquad (3)$$

where M is a function of an export coefficient, E_S, and a soil retention coefficient, S_R. In applying equation 3, it was assumed that the most likely value for E_S was 1.8 pounds of phosphorus per capita per year. The number of capita years was estimated to be 165 (only residents on the East and Upper East Bays were included: 90 full-year residents, 270 three-month residents, and 90 one-month residents), and the most likely value of S_R was 0.85. Only residents on these bays were included because past studies indicated that most of the ground water entered the lake through these areas (Wisconsin Department of Natural Resources, 1985). The total input from septic tanks was then computed to be 44 pounds per year. By applying low and high estimates for E_S (1.1 and 2.2 pounds of phosphorus per capita per year) and S_R (0.9 and 0.5), low and high estimates of phosphorus from septic systems were 18 and 182 pounds, respectively.

Phosphorus concentrations leaving the lake ranged from about 0.02 to 0.05 mg/L (fig. 6). Concentrations in 1997 were higher than in 1999, especially from March through June. The higher concentrations reflect higher phosphorus concentrations in the lake in 1997 than in 1999. Daily phosphorus concentrations were estimated by linearly interpolating between monthly measurements, and the amount of phosphorus removed from the lake was then computed by multiplying the daily phosphorus concentrations by the daily outflows. The total amount of phosphorus in stream outflow was estimated to be 1,370 and 440 pounds in 1997 and

1999, respectively (fig. 5). The greater load in 1997 was due to a combination of higher concentrations and flows in 1997 than in 1999.

The phosphorus budget (fig. 5) indicates that inflow from Muskellunge Creek was the major source of phosphorus to the lake (53–61 percent) and ground water was the secondary source (35–39 percent). The concentrations and volumes of ground water entering the lake, however, are based on several untested assumptions. Approximately 57 and 33 percent (1997 and 1999, respectively) of the total phosphorus input to the lake (2,410–1,310 pounds in 1997 and 1999, respectively) was exported through the outlet. The remaining 43 to 67 percent of the phosphorus input (1,400 and 870 pounds in 1997 and 1999, respectively) was deposited in the bed sediment of the lake or discharged with ground-water outflow.

Lake-Water Quality

Water quality in Little St. Germain Lake varied consistently among basins, except for a few water-quality characteristics that were similar throughout the lake but varied seasonally: specific conductance, which ranged from about 75 microsiemens per centimeter (µs/cm) in summer to about 90 µs/cm in winter; and pH, which ranged from about 7 in winter to about 8 in summer.

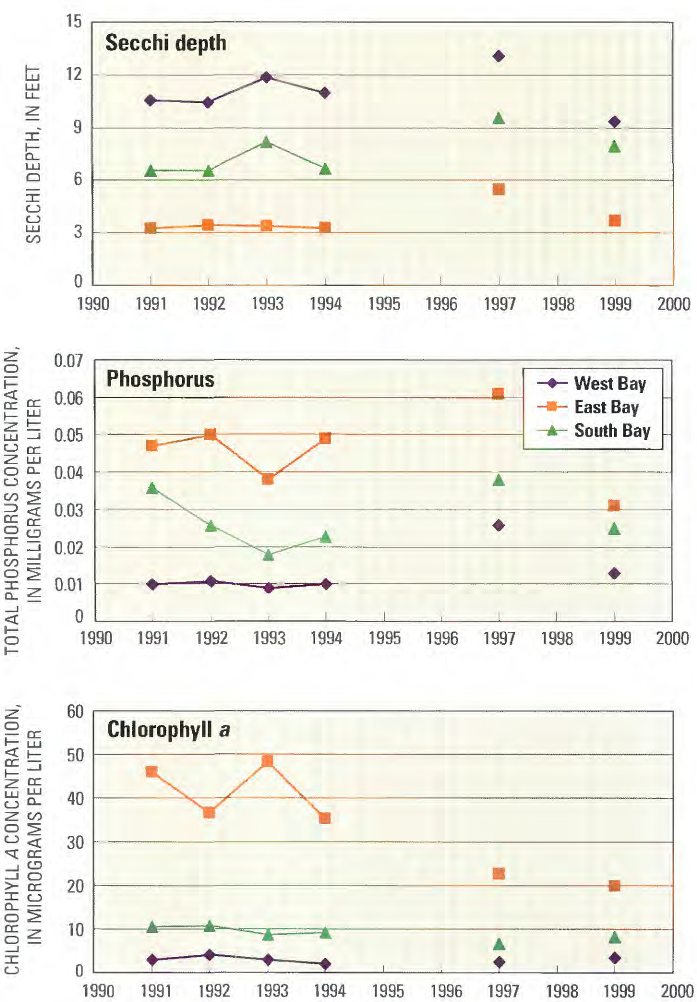

Figure 7. Average summer Secchi depth, and surface concentrations of phosphorus and chlorophyll *a* in the three main basins of Little St. Germain Lake, Wis., by year.

Water Clarity

Water clarity, the distribution of temperature and dissolved oxygen, and the concentrations of nutrients, were all consistently different among basins. The differences indicated that the West Bay generally had the best water quality and the East Bay had the poorest quality. Water clarity, based on Secchi depth readings, ranged from 7–15 feet in the West Bay (average summer clarities of 9–13 feet) to 4–14 feet in the South Bay (average summer clarities of 7–10 feet) to 2–8 feet in the East Bay (average summer clarities of 3–6 feet) (fig. 7). Clarity was usually the best in late summer in the West Bay; however, it was usually best in early summer in the East Bay.

Water Temperature and Dissolved Oxygen

Thermal stratification also differed among basins because of differences in their morphometries and limited circulation between basins. The West Bay, being relatively deep and having a relatively short length, became strongly stratified during summer, with bottom temperatures remaining around 8–9°C. The South Bay, being moderately deep, became only weakly stratified during summer, and stratification was frequently broken down by wind mixing. Bottom temperatures in the South Bay gradually increased throughout the summer. Thermal stratification throughout the rest of the lake was very weak, with seldom more than 2 or 3°C of stratification. During the winter, weak thermal stratification was also present throughout the lake.

Thermal stratification during summer, primarily in the West Bay, isolated the deepest water from surface interactions. Thus, as summer progressed, dissolved oxygen concentrations in water below the thermocline decreased as a consequence of decomposition of dead algae that settled from the surface and the biochemical oxygen demand of the sediment. Water below about 30 feet in the West Bay usually became anoxic in late June and stayed anoxic throughout summer. In the South Bay, the weak stratification resulted in only the deepest water becoming nearly, but almost never completely, anoxic.

Before freezing, most of the lake was nearly saturated with oxygen; however, after the lake froze and winter progressed, oxygen was quickly consumed, especially in the shallower basins. Although oxygen is consumed slowly during periods of low temperatures, extensive oxygen depletion occurred in every basin of the lake. Oxygen depletion was much more severe during winter than during summer because of the lack of oxygen transfer through the surface, as a result of ice cover. Changes in oxygen concentrations for the East and Upper East Bays of the lake are shown in figure 8. Other than the shallowest areas of the West and East Bays, the remaining parts of the lake can become almost completely depleted of oxygen by mid-February. To demonstrate the spatial extent of oxygen depletion, transects of temperature and oxygen profiles were collected from the inlet to the outlet (A–B: fig. 2) and from the West Bay to the outlet (A'–B; fig. 2) in March 1997 and March 1999 (fig. 9). Detailed transects were collected in March because this was near to when oxygen depletion was expected to be most severe. As figure 9 shows, anoxia occurred throughout each of the basins; and by mid-March only small areas of the lake would be habitable by most fish (areas with dissolved oxygen concentrations greater than about 2 mg/L). These habitable areas include water down to about 30 feet in the West Bay and down to about 5 feet in the East Bay.

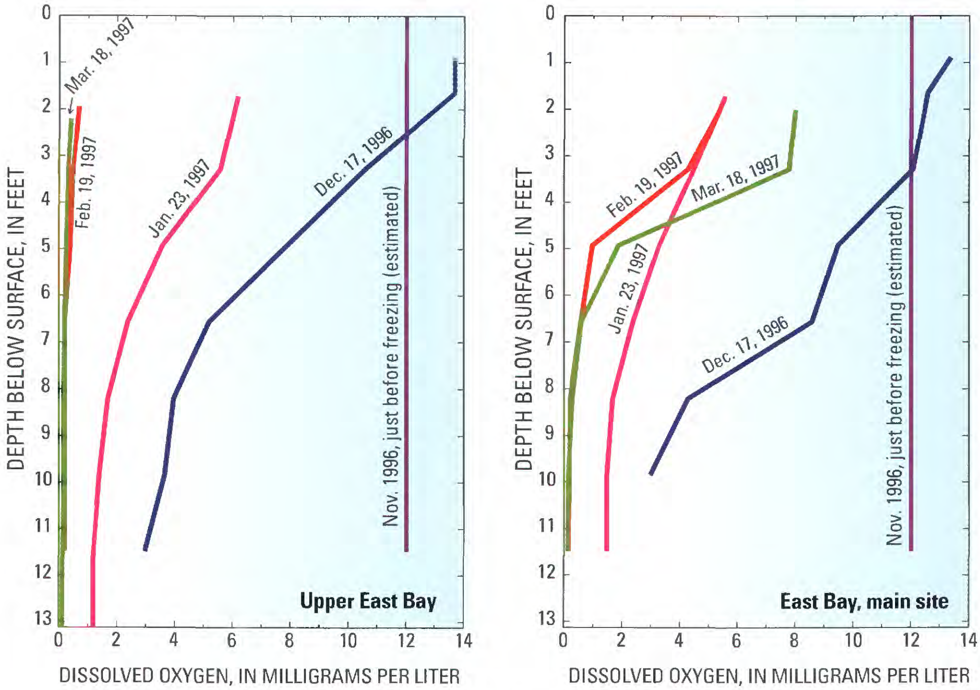

Figure 8. Oxygen distributions in the Upper East and East Bays of Little St. Germain Lake, Wis., during winter 1996–97.

Water entering from Muskellunge Creek can alleviate the extent of winter anoxia in the East Bay. Although dissolved oxygen concentrations in Muskellunge Creek may be low in midwinter (less than 6 mg/L in February 1999 and possibly much lower in other years), concentrations can be high later in winter (greater than 10 mg/L in March 1999). Dissolved oxygen concentrations in the middle of the East Bay were lower in February 1997 than they were later in March 1997 (fig. 8). This increase appears to be associated with cold, highly oxygenated water originating from Muskellunge Creek propagating across the basin (fig. 9). Dissolved oxygen concentrations in the Upper East Bay, which are not influenced by Muskellunge Creek inflow, did not increase from February to March. A detailed analysis of the flow in the lake demonstrated that the upper 3 feet of water (just below the ice) throughout the East Bay could be replaced by water from Muskellunge Creek in about 30 days.

Phosphorus Concentration

Phosphorus is one of the essential nutrients for plant and algal growth and is often the nutrient that limits this growth in midwestern lakes. High concentrations of phosphorus can cause high algal populations (blooms) and can therefore be a major cause of eutrophication (that is, accelerated aging and increased productivity) of lakes. Phosphorus concentrations were consistently highest in the East Bay (average summer concentrations of 0.031–0.061 mg/L), moderate in the South Bay (0.018–0.038 mg/L), and lowest in the West Bay (0.009–0.026 mg/L). These differences among basins appear to be directly related to the input of nutrients from both Muskellunge Creek and ground water and to differences in basin morphometry.

Phosphorus can be released from lake sediments, especially during periods of anoxia. Increased phosphorus concentrations just above the sediments were observed primarily in the West Bay during late summer, when the deep water was anoxic. Phosphorus concentrations reached 0.2–0.3 mg/L in late summer in the West Bay, but only 0.08–0.09 mg/L just above the sediments in the South Bay. The extensive anoxic area during winter, especially during 1997, resulted in phosphorus concentrations reaching 0.17 mg/L in the West Bay, but only 0.08 mg/L in the South Bay and 0.10 mg/L in the East Bay.

Chlorophyll *a* Concentration

Chlorophyll *a* is a photosynthetic pigment found in algae and other green plants. Its concentration, therefore, is commonly used as a measure of the density of the algal population of a lake. Concentrations greater thatn 15 µg/L are considered to be very high and usually associated with algal blooms. Differences in chlorophyll *a* concentrations among basins directly

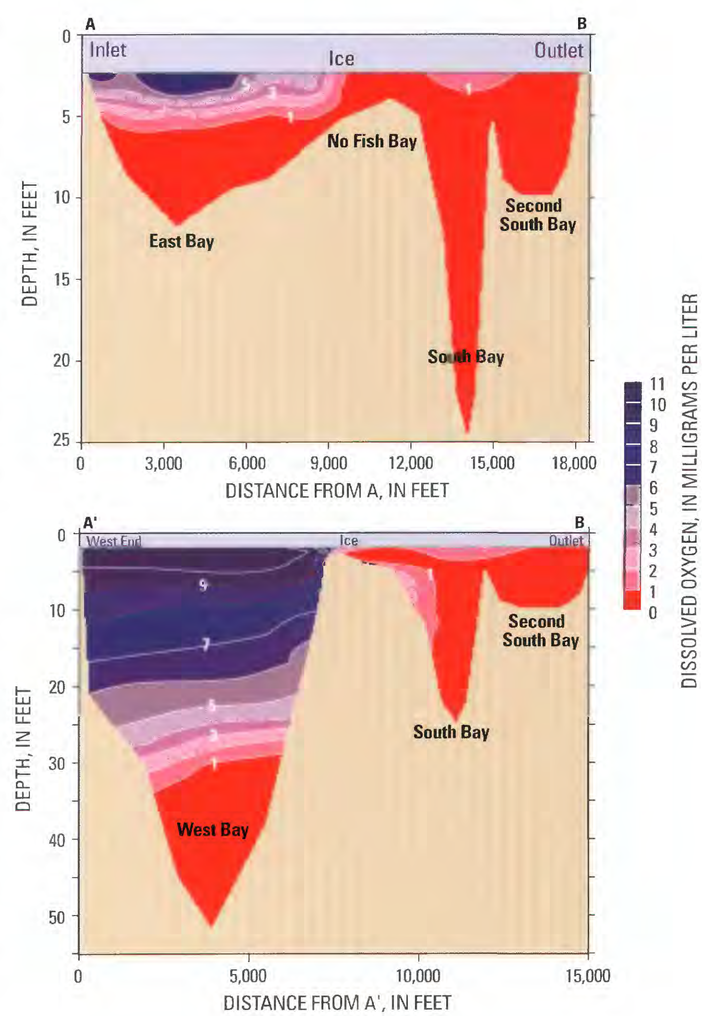

Figure 9. Distributions of dissolved oxygen in Little St. Germain Lake, Wis., March 18, 1997. (Trace of sections are shown in figure 2.)

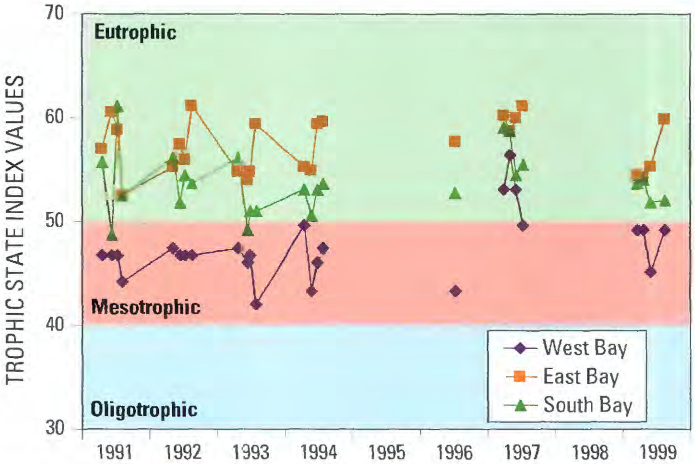

Figure 10. Trophic state indices based on surface total phosphorus concentrations in the West, East, and South Bays of Little St. Germain Lake, Wis., by year.

coincided with the differences in the phosphorus concentrations among basins. Concentrations were highest in the East Bay (average summer concentrations ranged from 20–48 µg/L), moderate in the South Bay (7–11 µg/L) and lowest in the West Bay (2–4 µg/L) (fig. 7). Concentrations were commonly greater than 15 µg/L in the East Bay and occasionally above 15 µg/L in the South Bay, but never observed above 15 µg/L in the West Bay.

Trophic State Indices

One method of classifying water quality or productivity of lakes is by computing water-quality indices (Trophic State Indices, or TSI's). These indices, based on near-surface concentrations of total phosphorus and chlorophyll *a* and on Secchi depths, were developed by Carlson (1977) and modified for Wisconsin lakes by Lillie and others (1993). Oligotrophic lakes (TSI's less than 40) typically have a limited supply of nutrients and are typically clear, algal populations and phosphorus concentrations are low, and the deepest water is likely to contain oxygen throughout the year. Mesotrophic lakes (TSI's between 40 and 50) typically have a moderate supply of nutrients, are prone to moderate algal blooms, and have occasional oxygen depletions at depth. Eutrophic lakes (TSI's greater than 50) are nutrient rich with correspondingly severe water-quality problems, such as frequent seasonal algal blooms, oxygen depletion in lower parts of the lakes, and poor clarity. Lakes with TSI's greater than 60 are considered hypereutrophic and usually have extensive algal blooms throughout summer. These three indices are related to each other in complex ways that differ seasonally and among lakes. All three of the indices indicated that the East Bay was eutrophic and often hypereutrophic during summer (average summer TSI based on surface phosphorus was 58, based on surface chlorophyll *a* was 60, and based on Secchi depth was 58). All three of the indices indicated that the South Bay was mesotrophic to eutrophic (average summer TSI based on surface phosphorus was 53, based on surface chlorophyll *a* was 51, and based on Secchi depth was 48). All three of the indices indicated that the West Bay was mesotrophic (average summer TSI based on surface phosphorus was 47, based on surface chlorophyll *a* was 43, and based on Secchi depth was 42).

Effects of Winter Drawdown

As mentioned previously, the WVIC controls the water level of the lake in accordance with their Federal Energy and Regulatory Commission license. Each winter the lake is drawn down about 1.5 feet. The drawdown is begun in November and completed in early February (fig. 4). In 1997, outflows from the lake were highest during November through February. Refilling then begins in early March and typically by May the water level is back to its normal summer elevation. Outflow from the lake in 1997 was lowest during March and April.

Effects on Nutrient Loading

Total phosphorus concentrations in the outflow generally increase from November through April (fig. 6). The average concentration increased 0.015 mg/L from November–February to March–April in 1997; however, there was no increase in 1999. Therefore, increased early-winter water removal associated with the drawdown may decrease the amount of nutrients that would be removed from the lake. If it is assumed that the drawdown resulted in 1,500 acre-feet of water (a 1.5-foot drawdown) being released in early winter instead of late winter, this would equate to about 65 pounds of phosphorus being retained in the lake in 1997 and no change in 1999. This amount represents about 0–3 percent of the total input of phosphorus. Therefore, the drawdown has only a small effect on the phosphorus budget for the lake as a whole.

Winter drawdown may, however, increase the phosphorus loading to the West Bay. During the drawdown period, water with a relatively low concentration of phosphorus flows from West Bay into No Fish Bay, whereas during refilling, water with a relatively high concentration of phosphorus flows from No Fish Bay into West Bay. To determine the effects of this process, the average drawdown for the 1991–99 period was examined.

During 1991–99, average drawdown was 1.57 feet, average time to achieve drawdown was 106 days, average precipitation during drawdown was 0.42 foot, and evaporation was considered to be negligible. Therefore, there was a net release of 1.99 feet of water from West Bay. If the average concentration of phosphorus in the water was 0.014 mg/L (the average near-surface concentration measured in the West Bay), there would be a net removal of 14.6 pounds of phosphorus from West Bay. During 1991–99, the average time to achieve refilling of the lake was 81 days, average precipitation during refilling was 0.46 foot, and average evaporation was estimated to be 0.18 foot. Therefore, there was a net inflow of 1.29 feet of water to West Bay. If the average concentration of phosphorus was 0.045 mg/L (the average near-surface concentration measured in the East Bay), there would be a net increase of 31.2 pounds of phosphorus to West Bay. Hence the net effect, on average, of the drawdown and refilling of the lake is a16.6-pound increase in phosphorus loading to West Bay. This amount is slightly more than that contributed by precipitation for the year (12.2 pounds). Therefore, although the drawdown contributes only a small amount of phosphorus to the West Bay, it may be a major source given the few other sources to this basin.

Effects on Dissolved Oxygen

The drawdown may also affect dissolved oxygen concentrations in the lake because oxygen concentrations decrease dramatically from November through April (fig. 8); therefore, more oxygen would be removed if more water was taken out earlier in the winter. The average concentration of dissolved oxygen in the South Bay decreased 7.2 mg/L from November–February (8.8 mg/L) to March–April (1.7 mg/L) in 1997. If it is assumed that the drawdown resulted in 1,500 acre-feet of water being released in early winter instead of late winter, this would equate to about 30,000 pounds of oxygen being released. This amount represents about 8 percent of the total dissolved oxygen in the entire lake when it freezes, or about 18 percent of the dissolved oxygen in East, No Fish, and South Bays combined, or about 44 percent of the dissolved oxygen in just the South Bays when the lake freezes. The smaller the amount of oxygen available for consumption by biochemical reactions, the sooner the concentrations will decrease below critical levels. Therefore, the drawdown can significantly decrease the length of time certain areas of the lake are habitable by fish.

Effects of Phosphorus Reductions

The total phosphorus input to the lake was estimated to be 2,410 and 1,310 pounds in 1997 and 1999, respectively. Most of this phosphorus is input into the East Bay and results in the water quality in this basin being significantly poorer than in other parts of the lake. One way to determine how much phosphorus loading would need to be reduced to improve the water quality of this basin is through the use of empirical models. These models relate phosphorus loading to measures describing lake-water quality (such as phosphorus and chlorophyll *a* concentrations and Secchi depth).

Several empirical models within the Wisconsin Lakes Modeling Suite (WiLMS; J. Panuska, Wisconsin Department of Natural Resources, written commun., 1999) relate hydrologic and phosphorus loading to in-lake phosphorus concentrations. Six of these models were applicable to the East Bay of Little St. Germain Lake. Therefore, the recent hydrologic and phosphorus loading to the lake (1997 and 1999) and various phosphorus-reduction scenarios were input into these models to predict phosphorus concentrations. The average phosphorus concentration predicted by the models for 1997 and 1999 was 0.051 mg/L, which is comparable to the measured lake concentration of about 0.046 mg/L. The models were then applied to various phosphorus-reduction scenarios: 50, 75, and 100 percent reduction in tributary loading, with all other sources maintained at their present levels. The models predicted that these reductions in tributary loading would cause the average phosphorus concentration in the East Bay to decrease by 0.012, 0.019, and 0.021 mg/L, respectively. Another empirical model, developed by Lillie and others (1993) and contained in WiLMS, relates in-lake phosphorus concentration to average summer Secchi depth. This model predicted that reductions in phosphorus concentrations of 0.012, 0.019, and 0.021 mg/L would be expected to increase the average summer Secchi depth by 0.7, 1.0, and 2.0 feet, respectively. Therefore, a total elimination of the phosphorus loading from Muskellunge Creek is predicted to increase the summer Secchi depth from 3.8 feet to about 5.8 feet. In addition to improving water clarity, the reduction in total phosphorus would be expected to decrease the frequency of blue-green algal blooms.

Because of the significant contributions of phosphorus to the lake estimated from ground water, even with tributary loading eliminated, the predicted phosphorus concentrations and Secchi depths still resulted in the East Bay being classified as a eutrophic system. As mentioned previously, however, estimates of ground-water inflow are considerably uncertain, and further studies would be needed to better quantify the importance of ground water to the lake.

References

Carlson, R.E., 1977, A trophic state index for lakes: Limnology and Oceanography, v. 22, p. 361–369.

Holmstrom, B.K., Olson, D.L., and Ellefson, B.R., 2000, Water resources data-Wisconsin, water year 1999: U.S. Geological Survey Water-Data Report WI-99-1, 578 p.

Lillie, R.A., Graham, Susan, and Rasmussen, Paul, 1993, Trophic state index equations and regional predictive equations for Wisconsin Lakes: Wisconsin Department of Natural Resources Management Findings, no. 35, 4 p.

Reckhow, K.H., Beaulac, M.N., and Simpson, J.T., 1980, Modeling phosphorus loading in lake response under uncertainty: A manual and compilation of export coefficients: U.S. Environmental Protection Agency, EPA-440/5-80-011.

Rose, W.J., 1993, Water and phosphorus budgets and trophic state, Balsam Lake, northwestern Wisconsin, 1987–89: U.S. Geological Survey Water-Resources Investigations Report 91-4125, 28 p.

U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2000, Water-quality and lake-stage data for Wisconsin lakes, water year 1999: U.S. Geological Survey Open-File Report 00-89, 140 p.

Wisconsin Department of Natural Resources, 1985, Little St. Germain, Vilas County, feasibility study results and management alternatives: Bureau of Water Resources Management, Lake Management Program, 22 p.

Information

For information on this study or on other USGS programs in Wisconsin, contact:

District Chief
U.S. Geological Survey
8505 Research Way
Middleton, WI 53562
(608) 828-9901
http://wi.water.usgs.gov/

Authors: Dale M. Robertson and William J. Rose

Layout and illustrations: Michelle Greenwood, Aaron Konkol, and David Saad

Printed on recycled paper