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Report

Lake Managment Plan

Little St. Germain Lake

Scope ID: 99L005

Little St. Germain Lake Protection District

January 2001

Foth & Van Dyke

consultants · engineers · scientists

Executive Summary

Foth & Van Dyke was retained by the Little St. Germain Lake Protection District (District) to evaluate management alternatives based on water quality studies completed over the last several years. The District received a Lake Management Planning Grant from the Wisconsin Department of Natural Resources (WDNR) which provided funding up to $10,000 for this project.

This evaluation and report focused on the existing water budget and water quality, lake management alternatives available to improve the water quality of Little St. Germain Lake, and the cost to implement these alternatives.

Water Quality

Much of Little St. Germain Lake is classified as eutrophic. Algae blooms and excessive weed growth occur in summer and anoxic (lack of oxygen) conditions occur in winter in much of the lake. These water quality problems are due to high levels of phosphorus in the lake. Studies identified the main tributary, Muskellunge Cr., as the primary contributor to the high levels of phosphorus in the lake.

Water and Phosphorus Budget

The study of the water and phosphorus budget for Little St. Germain Lake shows Muskellunge Cr. to be the largest input of water and phosphorus. Groundwater is the second largest source of both water and phosphorus. Little St. Germain Cr. is the largest source of water outflow. Surface runoff and septic systems were minor sources of phosphorus and contribute little to the water quality status.

Water Quality Improvement Alternatives

Effective phosphorus reduction can best be accomplished by removing phosphorus from Muskellunge Cr. Other sources of phosphorus were either minor or could no be treated at one location. Chemical phosphorus removal using alum was evaluated and determined to be the recommended approach. Alum can be added to the creek and settled in the lake or water from the creek can be diverted and treated separately before discharge back into the creek. Alum added directly to the creek will have sludge settle in the lake that may need to be removed at a future time.

Oxygen can be added to the Upper East Bay and the South Bay to minimize the anoxic conditions that occur there in winter. The lake water can be aerated with an in-lake aeration device, utilizing compressed air or by pumping lake water to a cascade device on the shore and discharging back into the lake.

Cost and Impact Analysis

The cost for direct alum addition to Muskellunge Cr. for phosphorus removal is the lowest capital cost estimated at $188,000. The future cost for dredging the lake of accumulated sludge could be high and the annual operation cost assumed accumulating funds for a future dredging project. The present worth of this alternative is $1,967,000. A second alternative evaluated pumping approximately 75% of the creek water to a pond where the chemically treated water would settle the phosphorus sludge before returning to the creek. The capital cost is higher for this alternative but the lake would not need to be dredged in the future. The sludge could be removed from the pond at a much lower cost than dredging the lake. The capital cost is estimated at $817,000. The present worth cost for this alternative is $1,626,000. The chemical treatment alternatives are nearly equal in present worth costs and should be selected based on other factors. The alternative that is most protective of the lake is the use of the treatment pond.

The cost for pumping lake water to a cascade device is estimated at $170,000. The cost for a compressed air system with air diffusers at the lake bottom will be about $44,000. Based on these costs, the compressed air system is the most cost-effective system and is recommended.

The report concludes with a recommendation to obtain a lake planning grant for installing two aeration devices and completing preliminary engineering to develop a design for phosphorus removal. This engineering work would perform chemical addition and settling tests to confirm the correct chemical dosage and sludge settling rate.

Lake Management Plan

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Appendices

1 Introduction

1.1 Purpose

The purpose of this lake management plan is to identify the problems relating to Little St. Germain Lake and develop a plan to address these problems. The planning process evaluates alternatives to address the problems. The intent of this process is to determine the most cost-effective and environmentally sound approach to address the water quality problems in Little St. Germain Lake.

1.2 Scope

The work contained in the lake management plan includes the following major items:

- Summarize water quality issues.
- Determine existing water budget.
- Determine existing phosphorus budget.
- Identify alternatives for water quality improvements in Little St. Germain Lake.
- Evaluate alternatives on cost and environmental impact.
- Recommend alternatives for implementation.
- Provide an implementation schedule and financial approach.

1.3 Project Planning Area

The project planning area is the physical watershed around Little St. Germain Lake. Appendix A contains a recent report published by USGS regarding water quality studies done on Little St. Germain Lake. Figure 1 in Appendix A shows the project planning area and the land use in the planning area.

2 Existing Conditions

Little St. Germain Lake has been the subject of significant research in the past decade. This research has helped lake district members and the scientific community understand the existing conditions. This lake management plan will not provide detailed information on past work but will summarize the research to document the water quality problems in the lake and provide a basis for identifying water quality improvement alternatives.

2.1 Fishery

The Wisconsin Department of Natural Resources completed a creel survey report on Little St. Germain Lake in 1997. The survey showed that Little St. Germain Lake has the highest fishing pressure of any lake in north east Wisconsin. Fishermen spent about 106 hours of effort for each acre in the lake. This is a rate over three times the county average.

From this data we can conclude that fishing is an important recreational activity. To maintain a quality fishery, water quality must be maintained.

2.2 Water Quality

Little St. Germain Lake is unique in that water quality varies considerably from one area of the lake to another. A common tool in evaluating water quality is trophic status index. This index considers concentrations of phosphorus and chlorophyll a as well as Secchi depth to determine the trophic state of the lake. The three lake categories based on trophic state are :

Oligotrophic: Young lakes with low productivity which are generally clear, cold, deep, and free of weeds or large algae blooms. Oligotrophic lakes are low in nutrients and therefore do not support plant growth or large fish populations, however are capable of sustaining a desirable fishery of large game fish.

Mesotrophic: These lakes are in an intermediate stage between the oligotrophic and eutrophic stages. They are moderately productive, supporting a diverse community of native aquatic plants. The bottoms of mesotrophic lakes lack oxygen in late summer months or winter periods which limits cold water fish and causes phosphorus cycling from sediments. Overall however, mesotrophic lakes support good fisheries.

Eutrophic: Lakes which are high in nutrients and support a large biomass are categorized as eutrophic. These old age lakes are usually weedy and/or experience large algae blooms. Most often they support large fish populations, however are also susceptible to oxygen depletion which limits fishery diversity. Rough fish are common in eutrophic lakes.

The trophic state of a lake can be determined by observing three lake characteristics including total phosphorus concentration (Total-P) which indicates the amount of nutrients present which are necessary for algae growth, Chlorophyll *a* concentration which is a measure of the amount of algae actually present, and Secchi disc readings which is an indicator of water clarity. As expected, low levels of Total P are related to low levels of Chlorophyll *a*, which are related to high Secchi disc readings.

To determine the trophic state of the lake, the Wisconsin Trophic State Index (WTSI) can be applied to each of the above noted factors. The WTSI converts the actual measurement into a value which is representative of one of the trophic states. Values less than or equal to 39 indicate oligotrophic conditions, values from 40-49 indicate mesotrophic conditions, and values equal to or greater than 50 represent eutrophic conditions.

The Northeast Basin had trophic status index values that were consistently in the eutrophic range. The South Basin had trophic status index values that were both eutrophic and mesotrophic. The West Basin had trophic status index values consistently in the mesotrophic range.

2.2.1 Phosphorus

The lower water quality in the East and South Basins is predominantly caused by high phosphorus concentrations from Muskellunge Cr. Muskellunge Cr. enters Little St. Germain Lake in the East Basin. This creek influences flow patterns in the lake and water flows south and west through the South Basin to exit at St. Germain Cr. The West Bay is isolated from the impacts of the creek and has consistently better water quality.

Phosphorus concentrations in Muskellunge Cr. averaged 71 ug/l in 1997 and 55 ug/l in 1999. Phosphorus in Little St. Germain Lake was affected by the creek. The East Bay had P concentrations of approximately 50 ug/l, the South Bay had concentrations of approximately 35 ug/l, and the West Bay had concentrations of approximately 15 ug/l. The water quality in the East Bay and the South Bay are affected by Muskellunge Cr. The high phosphorus concentrations in the East Bay and South Bay have led to algae blooms and reduced water clarity.

2.2.2 Dissolved Oxygen

Dissolved oxygen is an important water quality parameter in regard to fisheries. The Upper East Bay, East Bay, and South Bay in Little St. Germain Lake have experienced oxygen depletion in winter. Studies showed dissolved oxygen greater than 2 mg/l (the minimum concentration for fish survival) within 5 feet of the surface in East Bay and almost no dissolved oxygen (anoxic) in Upper East Bay and South Bay and West Bay had adequate dissolved oxygen at depths of over 20 feet.

The anoxic conditions in Upper East Bay, East Bay and South Bay have a negative impact on fisheries. These areas are not habitable by fish during anoxic conditions. Fish either leave these areas or die. Late in winter, fish are congregated in West Bay which is good for fisherman but may not be good for fish. Anoxic conditions also impact other biological organisms that live in the sediments. These organisms are food for fish but most cannot survive extended periods of anoxic conditions.

Anoxic conditions also affect the lake chemistry. When oxygen is present in the water, phosphorus is less soluble and will remain in the sediment. Organic material decomposing under anoxic conditions can release odorous compounds and may cause a nuisance at some times of the year.

2.2.3 Water Level Fluctuation

Water levels in Little St. Germain Lake are controlled by the Wisconsin River Authority. Each winter the lake level is drawn down by about 1.5 feet. This draw down removes a supply of oxygen from the lake and contributes to the anoxic conditions in South Bay and East Bay. Unfortunately, this condition will continue since the Wisconsin River Authority uses the draw down and refilling for power and flood control.

2.3 Water Budget

A water budget was prepared to aid in analyzing inputs to Little St. Germain Lake. Figure shows the water budget. Muskellunge Creek is the largest input to the lake. The flow from Muskellunge Cr. varied considerably from 1997 to 1999. The flow in 1999 was about 40% lower than the flow in 1997. This was due to a decrease in rainfall and water table in the drainage basin. The lake also shows a net groundwater inflow to the lake. The outlet, St. Germain Cr. is the largest outflow from the lake.

2.4 Phosphorus Budget

Muskellunge Cr. is the largest input to phosphorus in Little St. Germain Lake. Groundwater is another significant component. The phosphorus input from Muskellunge Cr. is apparently flow sensitive. In 1997, the phosphorus load from Muskellunge was 1,500 pounds. The phosphorus load dropped to 700 pounds in 1999. Most of the decrease was due to lower flows in Muskellunge Cr., although the phosphorus concentration in the creek also decreased from 1997 to 1999. This analysis shows that 50% to 60% of the phosphorus entering the lake came in from Muskellunge Cr.

Groundwater is the second largest source of phosphorus added to Little St. Germain Lake. The actual concentration of phosphorus in the groundwater and the volume of groundwater was not measured but estimated based on the overall water and phosphorus budget. The estimated phosphorus load from groundwater was 835 pounds in 1997 and 512 pounds in 1999. This represents 35% to 39% of the total phosphorus budget.

The phosphorus budget also shows that precipitation related phosphorus addition is a minor amount compared to additions from Muskellunge Cr. and groundwater. The land use tributary to Little St. Germain Lake has little or no agriculture and as a result, precipitation has little impact on the lake water quality. Approximately 2% of the total phosphorus budget is contributed by precipitation.

Septic systems were also shown to be a minor source of phosphorus. The typical on-site wastewater system does remove particulate forms of phosphorus in the septic tank. A properly sited and operating soil absorption system will also remove phosphorus. The result is little impact from septic systems when compared to the significant impact of Muskellunge Cr. Approximately 2% of the total phosphorus budget is contributed by septic tanks.

It should be noted that soil has a finite capacity for phosphorus removal. When soil capacity has been reached, phosphorus will leach into the groundwater. The potential contribution by septic systems is significant.

2.5 Summary

Little St. Germain Lake is a popular recreational lake and productive fishing lake. Water quality is eutrophic in many areas of the lake and could lead to impairment of the recreational uses. Eutrophic conditions are evident from algae blooms, excessive weed growth and anoxic conditions in winter. The eutrophic conditions are primarily caused by high phosphorus loading from Muskellunge Cr. Dissolved oxygen becomes depleted in some areas of the lake in winter which can have a negative impact on fish and their food supply.

3 Watershed and Land Use

The watershed around Little St. Germain Lake is almost entirely natural woodland and wetland. Residential and commercial development is mainly along the shores of the three large lakes in the watershed; Little St. Germain Lake, Muskellunge Lake, and Snipe Lake. The land use is shown on Figure 1 in Appendix A. The analysis done on the phosphorus budget indicated a low percentage of phosphorus came from septic systems or precipitation.

Initial studies show a significant quantity of phosphorus enters Muskellunge Cr. between Muskellunge Lake and Little St. Germain Lake. The source of the phosphorus was concluded to be groundwater. This conclusion was based on the native woodland and wetland environment between the two lakes, therefore, the phosphorus addition is a natural occurrence predominantly coming from groundwater.

Muskellunge Cr. is prime habitat for beavers. The high phosphorus loading in 1997 was during a period of significant beaver activity. Beaver dams cause the creek to flood areas of wetland which can release phosphorus from sediments and vegetation. The removal of beaver dams in 1999 may have had a positive impact on the phosphorus concentration in Muskellunge Cr.

4 Need and Problem Assessment

Residents of the Little St. Germain Lake Protection District have been involved with the water quality study over the past several years. The lake district commissioners have held public meetings to discuss issues regarding the lake. The concerns expressed by most residents are:

- algae blooms
- weed growth
- anoxic conditions in winter

These problems have been documented through water quality research. The problems indicate a eutrophic condition in the lake and the high concentration of phosphorus in the lake is the cause for this condition.

Many residents expressed a desire to move forward with steps to improve the lake water quality rather than continue to study the lake. The eutrophic conditions that have caused algae blooms and excess weed growth in the lake will likely continue and increase in intensity without taking positive steps to change those conditions.

5 Water Quality Improvement Alternatives

5.1 No Action

This alternative allows conditions to remain as they are without expending money or effort on lake improvements. The existing problems will continue and likely will increase without actions to improve the water quality. This alternative is not recommended.

5.2 Weed Control

Chemical and physical weed control have been used at many lakes as part of an overall lake management plan. Weed growth has been a concern to residents and may require management at some time. At the present time, residents have stated that a greater emphasis should be placed on improving the algae problems.

5.3 Phosphorus Reduction

The eutrophic conditions in portions of Little St. Germain Lake have high phosphorus concentrations as the primary cause. The phosphorus budget showed Muskellunge Cr. to be the primary source of phosphorus in Little St. Germain Lake. Reducing phosphorus concentrations in Muskellunge Cr. will have a direct impact on the quantity of phosphorus entering Little St. Germain Lake.

Models done by USGS show that phosphorus concentrations in the East Bay could be reduced by 25% to 46% depending on the amount of phosphorus removed from Muskellunge Cr. Even with this reduction, the water would still be classified as eutrophic. However, water clarity would improve and the blue-green algae nuisance blooms would be expected to decrease in frequency and intensity.

5.3.1 Biological Phosphorus Reduction

Phosphorus is an essential plant nutrient and is readily taken up by many plants. Constructed wetland systems have been designed to enhance the natural phosphorus uptake by plants. Removal of the plants (and the phosphorus they contain) from the system is a key element of this approach. Wetland plants include emergent types like rushes and cattails or floating types like hyacinth and duckweed. Duckweed (Lemna spp.) has a high phosphorus uptake rate and is a native plant species to Muskellunge Cr. Engineered systems are available which contain the floating duckweed plants in a plastic grid. The plants can be harvested by a special harvesting machine without removing the grid or draining the pond.

A large scale pilot system using duckweed was installed on Plum Creek near Denver, Colorado in 1994. The results were mixed caused by the low concentrations of nitrogen and phosphorus in the water. Influent concentrations of phosphorus in Plum Creek were about 100 ug/l. Effluent concentrations were about 50 ug/l. Operation was difficult due to the slow growth rate of the duckweed. Nitrogen and phosphorus fertilizers were used to enhance the duckweed growth. In the first year of operation, no duckweed was harvested and the appropriate plant density was not obtained in spite of several duckweed additions. The detention time used was 10 days.

A full scale system on Muskellunge Cr. would require a treatment pond of 80 to 100 million gallons to achieve a detention time of 10 days. A pond with a depth of 6 feet would require over 50 acres of land area for a volume of 100 million gallons. The estimated cost for this system would be prohibitive (greater than $1,000,000). Other disadvantages are the seasonal operation of the system. Duckweed would be active from mid May through September in north Wisconsin. No phosphorus removal would take place when the duckweed plants were not actively growing. This would allow phosphorus removal to take place in about one-third of the year. Maintenance may be significant to keep the duckweed growing well. For these reasons biological phosphorus removal is not recommended for further evaluation.

5.3.2 Chemical Phosphorus Removal

Phosphorus can be removed from water solutions by the use of metal salts. Aluminum and iron are the most common chemicals used for phosphorus removal. Aluminum is the preferred chemical for natural waters for several reasons. Iron is an effective chemical for phosphorus removal when maintained in an aerobic environment. When iron phosphates are subjected to an anaerobic environment, the phosphorus can be released back into solution. Aluminum phosphates do not re-dissolve which makes aluminum a better chemical choice for this application. Aluminum is also less hazardous to work with. For these reasons, only aluminum will be evaluated for use at Little St. Germain Lake.

Aluminum reacts with phosphorus to convert soluble phosphorus to an insoluble precipitate. Aluminum also reacts with other compounds in the water to form other precipitates. The most common aluminum salt is aluminum sulfate or alum. This chemical is commonly used in wastewater treatment facilities for phosphorus removal. It is also used for clarifying surface waters in potable water treatment plants. In natural waters the alum will form hydroxides and will coagulate small particles and colloidal compounds. The result will be the removal of bacteria, algae, and other small particles. The water will be clearer and a sludge will be formed.

Foth & Van Dyke conducted jar tests on water samples collected in Muskellunge Cr. Alum was added at concentrations of 20 mg/l and greater. Tests showed that nearly all soluble phosphorus was removed with that chemical dosage. It is estimated that effective phosphorus removal can be achieved with dosages of 10 mg/l. The initial phosphorus concentration in Muskellunge Cr. on 9-3-99 was 47 ug/l. The conclusion is that chemical phosphorus removal can be an effective process when applied to Muskellunge Cr. Appendix B contains the phosphorus test information.

Implementing chemical phosphorus removal can be done in several ways. A simple method would be chemical addition to the creek. The advantages of this alternative is minimal construction cost and effective treatment of the entire stream volume. The disadvantages include chemical sludge that will settle out in the lake. The continuous chemical addition will result in an accumulation of sludge in the lake. The sludge would settle similar to a river delta with most sludge around the creek mouth and smaller amounts in the rest of the lake. This sludge may cause a nuisance and will require dredging at some future time. Dredging in a lake is relatively expensive.

A second treatment method is to provide a pond for settling the sludge before the water is discharged to the lake. Water from the creek would need to be diverted to the treatment pond. A pump station would pump the water to the treatment pond where alum would be added. The resulting sludge would settle in the pond. Treated water would be discharged back to the creek and flow to the lake. This alternative would treat water on a continuous basis but would be able to treat only about 75% of the water. The advantage of this alternative is that sludge would settle in the treatment pond rather than in the lake itself. When it became necessary to remove sludge from the pond, the pond could be taken out of service and the sludge removed. The cost for sludge removal from the pond would be much less than sludge removal from the lake.

A third treatment method is to provide a mechanical treatment system for phosphorus removal. Typical unit processes include chemical addition, flocculation, clarification, and sludge removal/storage. All processes will require a building to protect the units from the weather. These processes will be expensive compared to the first two alternatives and will require labor intensive operation. For these reasons, a mechanical phosphorus removal treatment will not be used.

5.4 Supplemental Oxygen

Large portions of Little St. Germain Lake experience anoxic conditions in winter. Adding oxygen at one or more sites in the lake will increase oxygen levels in the lake. Several alternatives exist for oxygen addition.

5.4.1 On-Shore Oxygen Addition

Water can be pumped from a lake or stream up to a cascade structure on the lake shore. The water falls over the cascade structure, adding oxygen as it splashes. The oxygenated water is then discharged back into the water.

There are two potential locations for this type of aeration system. The first is on Muskellunge Cr. before it enters Little St. Germain Lake. Oxygen addition at that point will have an impact on the East Bay since the creek flow moves through the bay. Data collected from Muskellunge Cr. shows relatively high oxygen levels on March 18, 1997 (7.8 mg/l). The dissolved oxygen in the creek would need to be raised to 11 to 12 mg/l to have a significant impact on the lake. As the oxygen concentration increases in water, it requires significantly more energy to transfer oxygen to the water. The size and cost of a cascade aeration system would be prohibitive to raise the dissolved oxygen concentration in water from 7.8 mg/l to 12 mg/l. On-shore oxygen addition on Muskellunge Cr. will not be considered further.

A more efficient location for on-shore aeration is in South Bay or Upper East Bay where the dissolved oxygen concentration is zero in winter. Water would be pumped from the lake bottom to a cascade structure on shore. After the water cascades over the structure and dissolved oxygen is added, the water would be discharged to the lake bottom. This system will be more efficient because the anoxic water drawn from the lake bottom easily receives oxygen from the air. An advantage of this system is that the water can be drawn from a deeper portion of the lake and discharged to a deep portion of the lake. This will minimize surface turbulence and may allow the lake to freeze over these points. Winter recreational activities may be allowed to continue without a problem. Disadvantages are the large structure and pumping system on the lake shore and the large diameter pipes needed to transfer water from the lake to the cascade aeration system.

5.4.2 In-Lake Oxygen Addition

Most lakes with anoxic conditions provide an in-lake oxygen addition system. This typically consists of a blower or air compressor on the lake shore and an air diffuser system installed in the lake. The aeration system adds oxygen to the water and the current caused by the rising air bubbles creates and open area in the lake. This open area also adds oxygen from the atmosphere.

The advantage of this system is the minimal amount of equipment required. The disadvantage is the potential hazard open water creates for winter recreation. The open area must be well marked and blocked from access by snowmobilers and fisherman.

5.5 Evaluate and Improve Septic Systems

Septic systems can be a source of pollutant discharge to lakes. This is true where septic systems are improperly installed, maintained or designed. Pollutants can enter the lake through surface waters when septic systems fail above ground. Pollutants can also enter the lake through groundwater where there is inadequate soil for treatment before the wastewater enters the groundwater.

A sanitary survey is a study that identifies the potential for pollution to enter the lake from septic systems. Various study techniques can be used including on-site inspections, soil borings, and in-lake chemical studies. The findings can be used to upgrade septic systems and reduce the amount of pollutants entering the lake.

The phosphorus balance showed septic systems to be a minor source when compared to Muskellunge Cr. and natural groundwater. Eliminating all septic systems would have a neglible impact on the lake water quality. For this reason, evaluating septic systems is not a high priority and is not recommended for further evaluation at this time.

5.6 Reduce Runoff from Agricultural and Construction Site Sources

The phosphorus budget showed precipitation related phosphorus sources to be minor when compared to Muskellunge Cr. and natural groundwater. With a vast majority of the existing watershed in natural forest and wetland, runoff from agricultural and construction site sources is a small source of phosphorus addition to Little St. Germain Lake.

Erosion control from construction or residential land use should be emphasized by the lake district. This could be done by education and supporting state and local erosion control ordinances. Many publications have been produced regarding residential landscaping and pollution control. These publications should be made available to the district residents and promoted in newsletters. Beyond this effort, runoff related phosphorus control is not a high priority and is not recommended for further evaluation at this time.

6 Cost and Impact Analysis

6.1 Supplemental Oxygen

Supplemental oxygen will be evaluated for locations in Upper East Bay and South Bay. These areas consistently become anoxic in winter and receive no oxygen from Muskellunge Cr. These bays also have areas with a depth of 15 feet or greater. This depth is necessary for aeration devices to be effective. Figure 6-1 shows the proposed aeration locations.

6.1.1 On-Shore Oxygen Addition

This aeration system will require an electrically powered pump on the lake shore to draw water from the lake bottom to the pump. The pump would be located in a wet well with the suction pipe connected to the lake. Lake water would be pumped to a cascade structure with a series of steps where the splashing of the water would add oxygen. Aerated water would discharge from the bottom of the cascade through a pipe to the lake bottom.

The cascade size was assumed to be large enough to add 200 pounds of oxygen per day. To add this amount of oxygen, the oxygen concentration must be raised from 1 mg/l to 5 mg/l and the flow rate must be 4,000 gallons per minute. This flow rate requires a large pump with suction and discharge piping of 20 inch size. The cascade would also be a large structure approximately 10 feet by 20 feet to spread out the water over the steps.

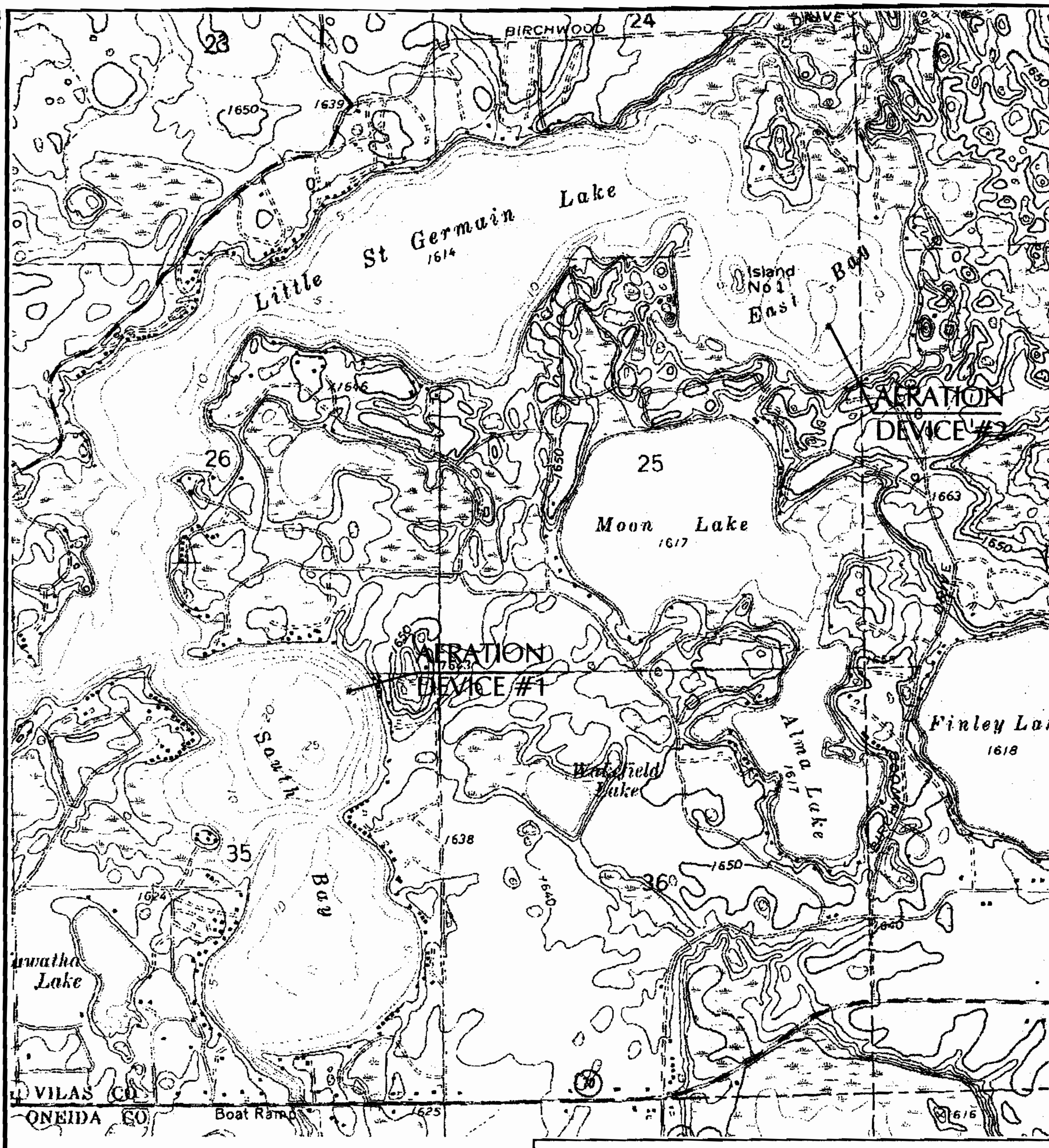
The cost for each on-shore aeration system is estimated at $170,000. Operation costs including power costs for a typical three month aeration season would be approximately $5,000. The large motor size (30 - 40 hp) will require three phase electrical power which may need to be brought in from a long distance or a phase converter required to meet the electrical requirements.

6.1.2 In-Lake Oxygen Addition

This aeration system will require an air blower located on shore with aeration piping extending into the lake. The piping would have air diffusers installed at the end of the pipe and the diffusers would be installed on the lake bottom at about a 15 foot depth. The blowers would need to be housed in a structure on shore for sound control and weather protection.

The operation of the aeration system will keep the ice from forming above the diffusers. This will require the lake district to provide fencing and signs to warn winter sports enthusiasts to avoid the area.

The cost for each in-lake aeration system is estimated at $44,000. Operation costs including power costs for a typical three month aeration season would be approximately $3,000 per year.



SOURCE: U.S.G.S. 7.5-MINUTE TOPOGRAPHIC QUADRANGLE - ST. GERMAIN (1970) VILAS COUNTY, WISCONSIN

N

0 700 1400 2100 2800 3500 Feet

FIGURE 6-1
LAKE AERATION DEVICE SITE LOCATION
Little Saint Germain Lake
Vilas County, Wisconsin

DATE: 1/15/2001	Foth & Van Dyke consultants · engineers · scientists	m:\99\005\ apr\little_sg_1.apr

Lake maps show water depths of 15 feet or greater in Upper East Bay and South Bay. The lake district would need to find property owners willing to have the blowers installed on their property.

6.1.3 Oxygen Addition Alternative Comparison

The in-lake aeration system has a capital cost much lower than the on-shore aeration system. The physical structure is smaller and the operation costs are also less than the on-shore aeration system. Developing safety precautions will be an important part of this alternative.

Based on this analysis, in-lake aeration is recommended for implementation.

6.2 Phosphorus Reduction

6.2.1 Direct Chemical Addition to Muskellunge Cr.

Adding alum directly to Muskellunge Cr. will remove soluble phosphorus and coagulate other particles in the water. These particles would primarily settle in the lake. The equipment necessary for this alternative would include a chemical storage tank and chemical feed system. A building would need to be constructed to house the equipment and prevent the equipment from freezing. The most likely location for would be near the Birchwood Drive crossing of Muskellunge Cr. Good road access will be required for chemical delivery trucks. The lake district will need to purchase some land to construct the building but would only need about one acre.

The capital cost for the direct chemical addition alternative is about $188,000. This cost includes equipment, structures, piping, electrical, land, and technical work.

The annual operation cost is estimated at $167,000. Much of this cost is related to sludge disposal. Sludge disposal costs were calculated assuming that dredging would be required in 20 years. Since the sludge would be dispersed in the lake, only 50% of the sludge was assumed to be removed by the dredging process. The dredging process would require a sludge retention pond located on shore to hold the sludge and allow it to settle. Final disposal would remove sludge from the retention pond to apply on land. The estimated cost for the sludge dredging process is $2,600,000. To budget for this future expense, a sum of $131,000 per year was included in the operation and maintenance cost to fund this future expense at year 20.

6.2.2 Chemical Addition to a Sidestream of Muskellunge Cr.

This process would pump water from Muskellunge Cr. to a treatment pond. Alum would be added to the water before it reaches the treatment pond. The phosphorus and other sludge would settle out in the treatment pond. The clean water would be discharged back into Muskellunge Cr. before it enters Little St. Germain Lake.

The treatment pond would be sized based on chemical treatability tests to determine the detention time needed for sludge settling. The cost estimate assumed a pond of about 6 million gallons which allows a detention time of 24 hours or longer. The pond would have an influent and effluent piping header to provide good hydraulics and avoid short circuiting. The land requirement for the treatment pond will be about 10 acres with the pond size of 4.4 acres. The pond is designed without a liner to prevent leakage. The pond will be treating river water that is relatively clean. The water that may leak into the soil would likely discharge back into the river or the lake depending on the pond location and groundwater flow. This design will reduce project cost without impacting the treatment process or groundwater quality.

Advantages of this alternative are that the sludge will be removed in the treatment pond rather settling out in the lake. The sludge can be removed from the treatment pond much easier than from the lake and the cost of removal will be less. It would be possible to take the treatment pond off-line for a time period to drain the pond and remove sludge.

Disadvantages of this alternative are that only a portion of the total stream flow would be treated. The preliminary design assumed about 6 million gallons per day would be pumped from the stream to the treatment pond. Typical stream flow is 8 to 10 million gallons per day. The reason for the partial treatment is to keep the stream open for navigability. Any flow over 6 millions gallons per day would not be treated. This level of treatment will still have a significant impact on the phosphorus concentration in Muskellunge Cr. and will reduce the phosphorus loading to Little St. Germain Lake.

The capital cost for the direct chemical addition alternative is about $817,000. This cost includes equipment, structures, piping, electrical, land, and technical work.

The annual operation cost is estimated at $80,000. Much of this cost is related to sludge disposal. Sludge will need to be removed from the lagoon every 2 to 3 years. The cost of sludge removal is much less from the lagoon than from the lake. The sludge can be removed hydraulically and pumped into a truck or the lagoon can be drained and the sludge allowed to dry before removal. No settling pond will be required. To budget for this expense, a sum of $44,000 per year was included in the annual operation and maintenance cost.

6.2.3 Chemical Phosphorus Removal Alternative Comparison

A present worth analysis was used to compare capital and operating costs for the two chemical addition alternatives. The present worth analysis assumed a 20 year project life and an interest rate of 7% during that time. The results of the present worth analysis show that direct chemical addition to Muskellunge Cr. has a present worth of $1,967,000. The sidestream treatment alternative has a present worth of $1,626,000. The sidestream treatment alternative is favored at this time. More engineering work is needed to develop the appropriate chemical dose and lagoon size. Detailed costs are shown in Appendix C.

7 Recommendations and Implementation

7.1 Install In-Lake Aeration

Previous studies identified anoxic conditions in Upper East Bay, East Bay and South Bay during winter. Eliminating the anoxic conditions will improve fish habitat and survival in winter. In-lake aerators should be installed in Upper East Bay and South Bay since these are the first to become anoxic and have the deepest water allowing efficient aeration. This work should be done to begin aerator operation in the winter of 2001-2002

7.2 Evaluate Phosphorus Removal from Muskellunge Cr.

Little St. Germain Lake is unique in that phosphorus removal from Muskellunge Cr. can have a positive impact on water quality in the lake. The challenge is the relatively large flow and low concentration of phosphorus in the creek. Chemical treatment was determined to be the best technology for removing phosphorus. Two options were identified for phosphorus removal; direct chemical addition to the creek and diverting a majority of flow to a settling lagoon where chemicals are added and solids are removed before flowing into the lake. Due to the potentially high cost of these options, further evaluation and preliminary engineering is recommended. The preliminary engineering work should evaluate the following items:

- Optimum chemical addition rate.
- Sludge production.
- Sludge settling rate.
- Optimum lagoon size and shape
- Settling lagoon location - pump to nearby site; gravity flow to site adjacent to creek.
- Regulatory conditions/obstacles to implementing treatment of creek water.

7.3 Obtain Lake Protection Grant for Implementing the Aeration and Phosphorus Removal Work

The lake district has applied for protection grant funding to implement the recommended action items. The grant was awarded in the fall of 2000.

7.4 Implementation

The funding should be directed to two areas, installation of aeration equipment and further refinement of the recommended phosphorus removal option.

The funds from the grant should be used to purchase and install the aeration systems. It is anticipated that the aeration systems will be in place for the winter of 2001-2002. The lake district will need to include the operation and maintenance cost for the aerators in their annual budget. They will also need to identify one or more people to be responsible for operating the aeration system. This will include maintaining equipment, operating the system, and providing and maintaining fencing around open water.

The grant funds should also be used for evaluating the phosphorus removal options. Revised costs and preliminary layouts should be developed based on laboratory scale chemical and settling tests. Cost reduction alternatives should be evaluated such as constructing a settling lagoon adjacent to the creek to avoid pumping. Alternatives should be discussed with the Department of Natural Resources to identify regulatory issues dealing with chemically treating the stream or removing water from the stream for treatment and the resulting instream structures required. This work should take place in 2001.

A

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Appendix A

USGS Report

USGS
science for a changing world

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.

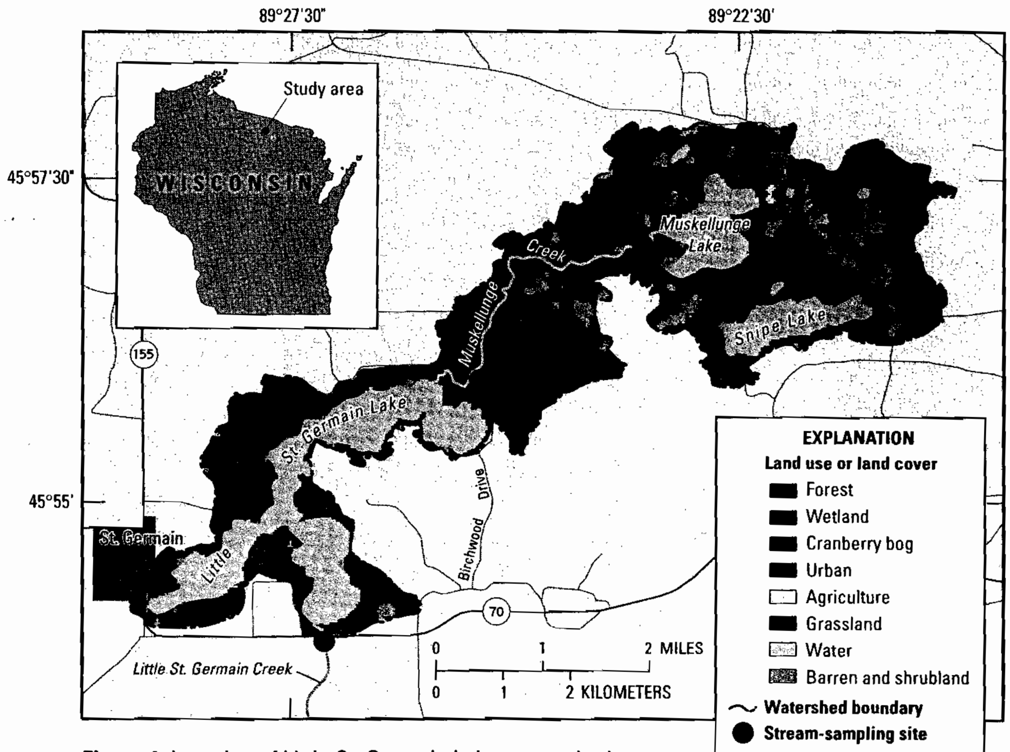

Figure 1. Location of Little St. Germain Lake, watershed characteristics, and location of stream-sampling sites.

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.

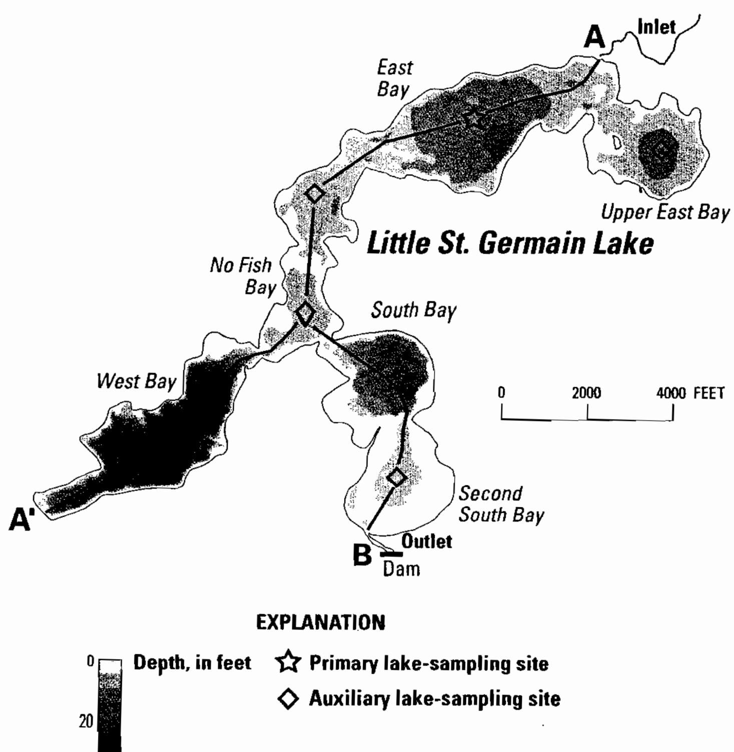

Figure 2. Morphometry of Little St. Germain Lake, Wis., and locations of lake-sampling sites.

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 mi^2. 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).

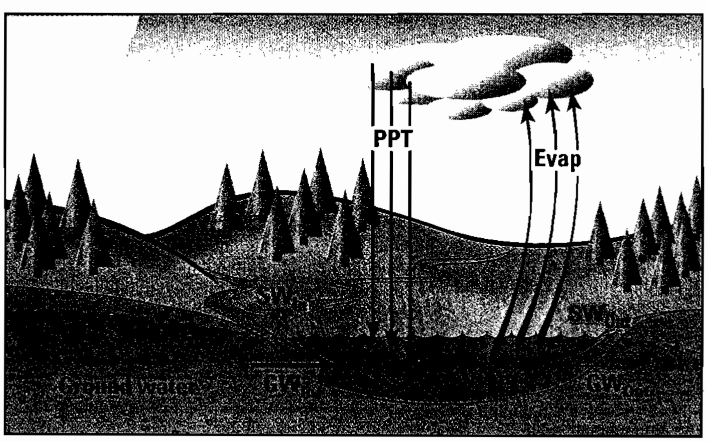

Figure 3. Schematic of the hydrologic budget of Little St. Germain Lake, Wis. Abbreviations are defined in the text.

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.

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.

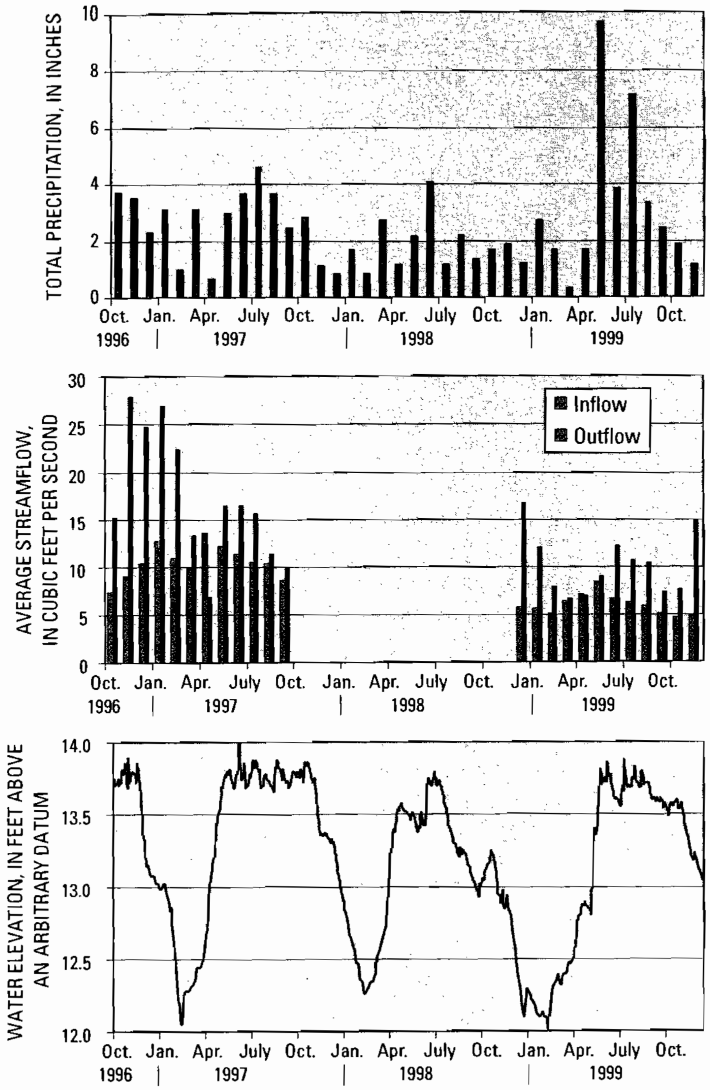

Figure 4. Monthly precipitation, inflow, outflow, and water elevation, Little St. Germain Lake, Wis.

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 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.

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

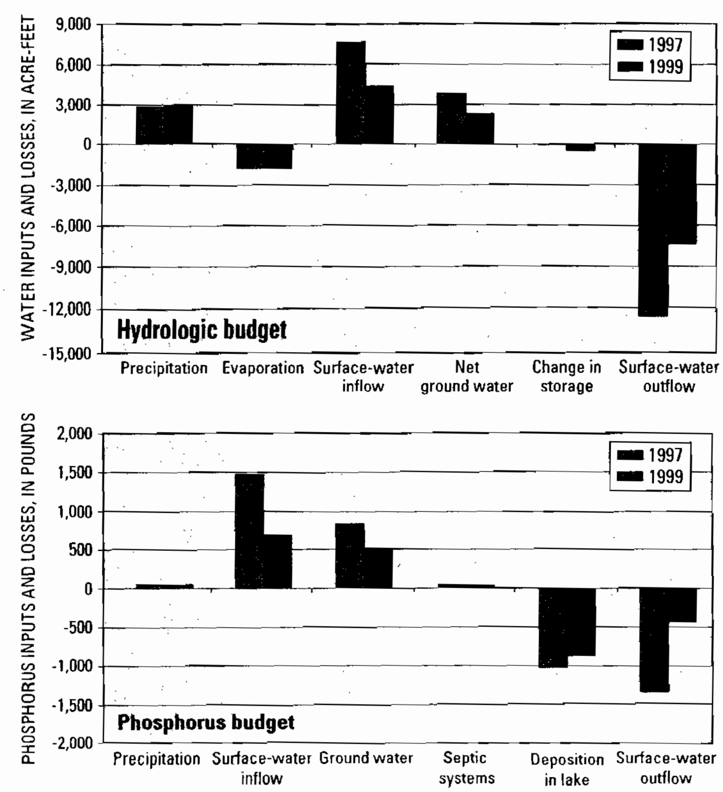

Figure 5. Hydrologic and phosphorus budgets of Little St. Germain Lake, Wis.

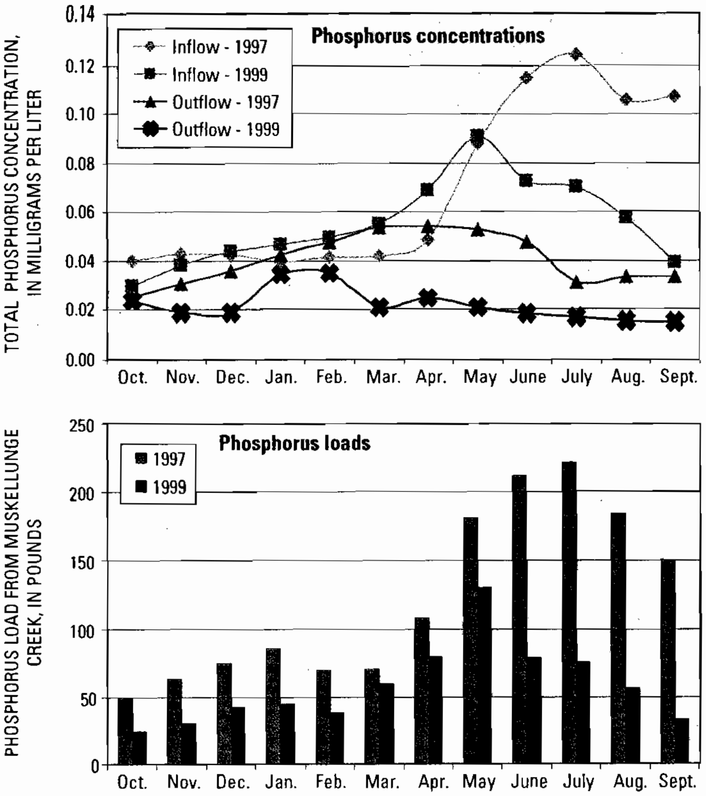

Figure 6. Phosphorus concentrations and loads in the inflow and outflow from Little St. Germain Lake, Wis., and phosphorus loads to the lake from Muskellunge Creek.

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.

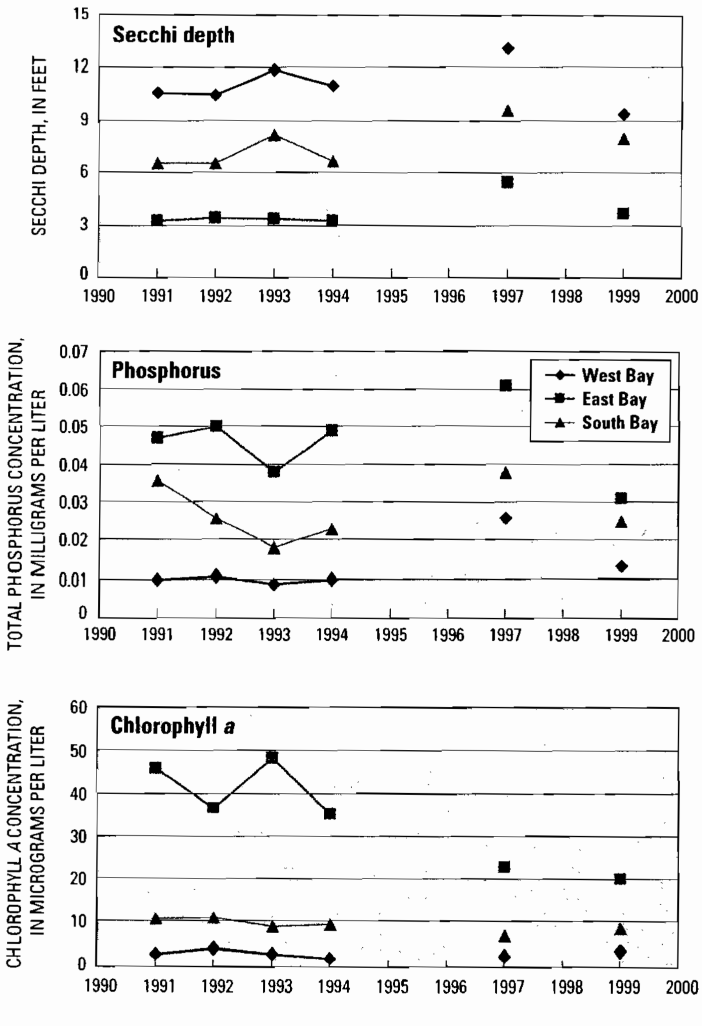

Figure 7. Average summer Secchi depth, and surface concentrations of phosphorus and chlorophyll *a* in the three main basins of Little St. Germain Lake, Wis., by year.

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.

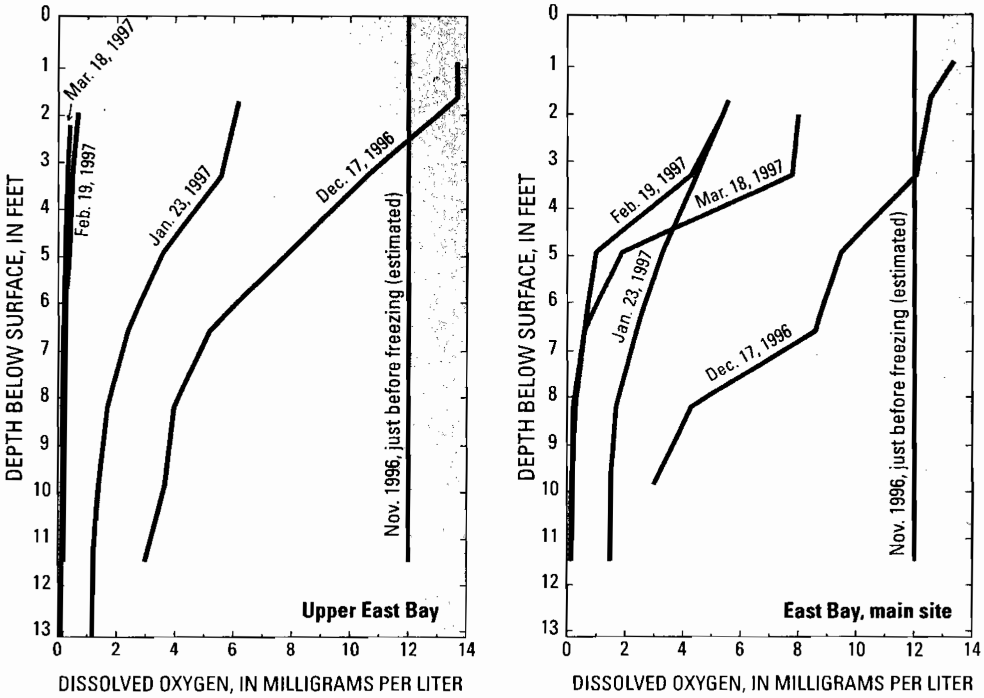

Figure 8. Oxygen distributions in the Upper East and East Bays of Little St. Germain Lake, Wis., during winter 1996–97.

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

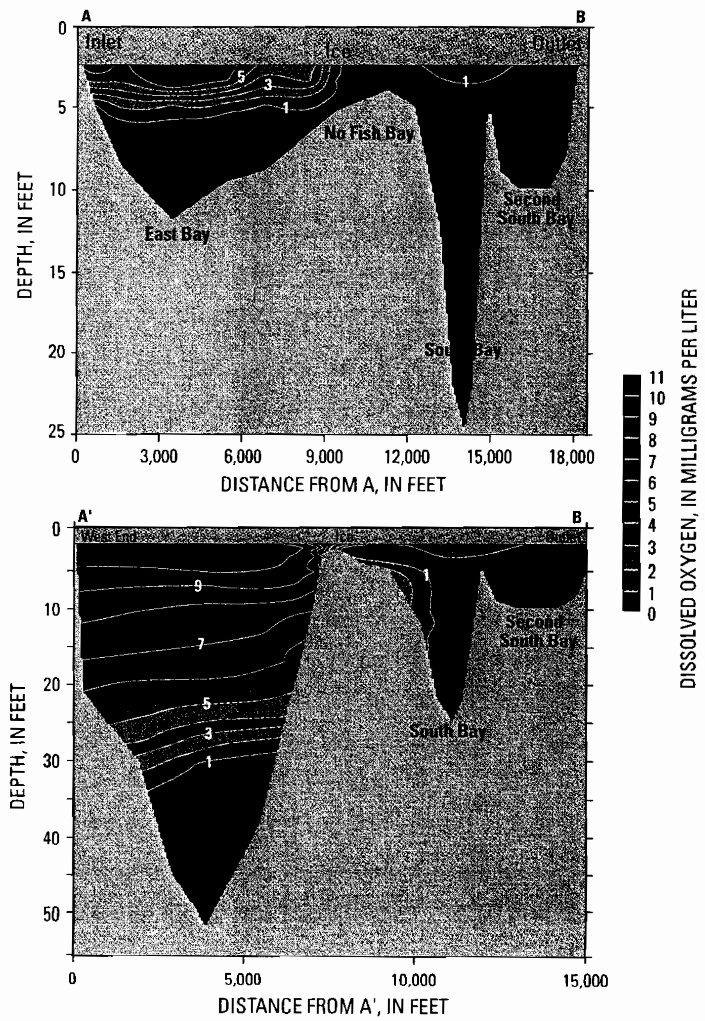

Figure 9. Distributions of dissolved oxygen in Little St. Germain Lake, Wis., March 18, 1997. (Trace of sections are shown in figure 2.)

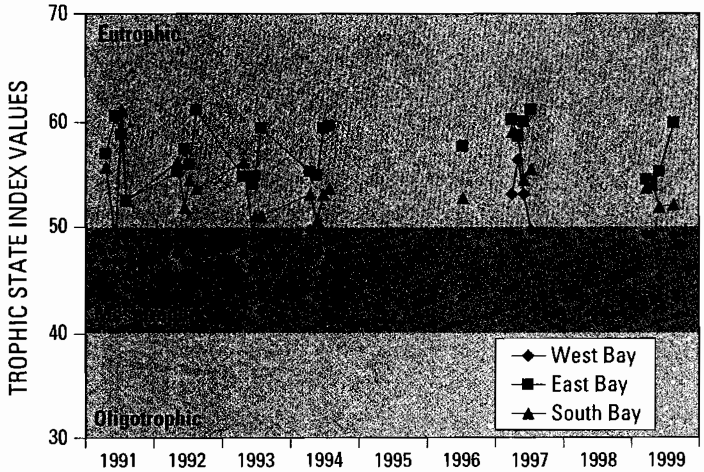

Figure 10. Trophic state indices based on surface total phosphorus concentrations in the West, East, and South Bays of Little St. Germain Lake, Wis., by year.

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 groundwater inflow are considerably uncertain, and further studies would be needed to better quantify the importance of ground water to the lake.

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