Report

Lake Study Summary

Little St. Germain Lake Protection District

Project I.D.: 05L001

Little St. Germain Lake Protection District

May 2006

Lake Study Summary
Little St. Germain Lake Protection District

Contents

1. Sediment Phosphorus Evaluation

Lake studies done by USGS in 2001 and 2005 produced a phosphorus budget for the Little St. Germain Lake. The phosphorus budget included input values for precipitation, stream inflow, groundwater inflow, and septic tanks. USGS identified internal sediment loading as a potential source of phosphorus but had no input values available to use with the phosphorus budget. Internal loading occurs as phosphorus contained in the sediment is released back into the water column. This release takes place under aerobic and anoxic conditions.

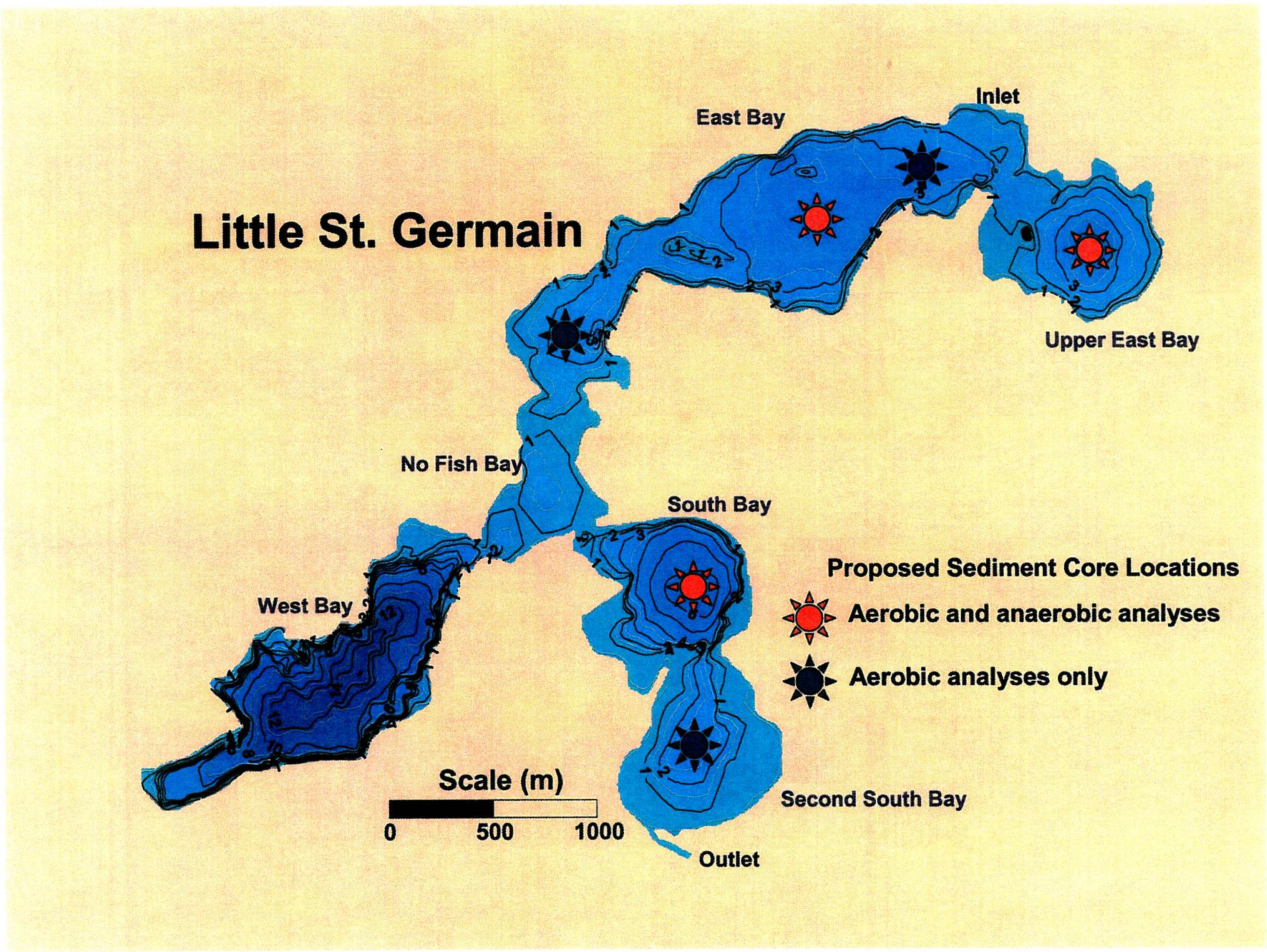
The Little St. Germain Lake Protection District received a WDNR Lake Planning Grant to study internal phosphorus loading to the lake. This work was completed by the United States Geological Survey (USGS) in 2005. The intent of this work was to identify the internal phosphorus loading to the lake and determine if this loading would reduce the effectiveness of chemical treatment to remove phosphorus.

Sediment core samples were collected in the summer of 2005. Figure 1 shows the sample locations. The core samples were sent to the State Lab of Hygiene for analysis. Core samples were incubated under aerobic or anoxic conditions. The water above the sediment cores was sampled for soluble reactive phosphorus on a daily basis. The results were calculated in a phosphorus release rate ($mg/m^2/day$).

The sediment core test results are shown in Attachment 1. USGS found the maximum phosphorus release rate to be 1 $mg/m^2/day$ and occurred under anoxic conditions. This release rate was applied to the upper East Bay in the area that experiences anoxic conditions (below 10 feet water depth). This area is 44,000 square meters. Over a 60 day period (approximately equal to a winter anoxic period) the phosphorus release from the Upper East Bay is estimated at 5.8 pounds. The measured aerobic release rate was near zero.

The result of the study shows that with a total lake phosphorus input budget of over 1,000 pounds of phosphorus per year, the relative input from sediment release is small. With the Upper East Bay as a model for the other three bays that experience anoxic conditions, the total internal phosphorus release is approximately 25 pounds per year.

Based on this study, the internal phosphorus loading is less than 3% of the overall phosphorus loading. Chemical treatment to remove phosphorus in Muskellunge Creek can be effective and internal phosphorus loading will have little impact on the effectiveness of the chemical treatment.


Little St. Germain
East Bay
Inlet
Upper East Bay
No Fish Bay
South Bay
West Bay
Second South Bay
Outlet
Scale (m)
0
500
1000
Proposed Sediment Core Locations
Aerobic and anaerobic analyses
Aerobic analyses only

August 2005
Little St. Germain Lake Phosphorus Release Rate Study
Summary

WSLH #	Sample Description/Core ID	Aerobic or Anerobic	Release Rate mg/m2/day	Regression Fit, r	Average Release mg/m2/day	% Relative Difference
IQ003580	Core S-1	Aerobic	1.534	0.98	1.2255	50%
IQ003581	Core S2	Aerobic	0.917	0.964		
IQ003582	Core S3	Aerobic	1.208	0.934	1.2955	14%
IQ003583	Core S4	Aerobic	1.383	0.997		
IQ003584	Core SS1	Aerobic	0.054	0.827	0.065	34%
IQ003585	Core SS2	Aerobic	0.076	0.954		
IQ003586	Core E1	Aerobic	-0.104	0.794	-0.0015	13667%
IQ003587	Core E2	Aerobic	0.101	0.661		
IQ003588	Core M1	Aerobic	-0.05	0.736	-0.033	103%
IQ003589	Core M2	Aerobic	-0.016	0.322		
IQ003590	Core M3	Anaerobic	1.061	0.956	0.966	20%
IQ003591	Core M4	Anaerobic	0.871	0.951		
IQ003592	Core N1	Aerobic	0.035	0.936	0.0555	74%
IQ003593	Core N2	Aerobic	0.076	0.783		
IQ003594	Core UE1	Aerobic	-0.383	0.969	-0.2885	66%
IQ003595	Core UE2	Aerobic	-0.194	0.798		
IQ003596	Core UE3†	Anaerobic	0.898	0.909	-0.033	5642%
IQ003597	Core UE4†	Anaerobic	-0.964	0.823		
IQ003598	Lake Water Blank*	Aerobic	0.431	0.987	NA	NA
IQ003599	Lake Water Blank*	Anaerobic	0.149	0.984	NA	NA

†The raw data are being re-checked to confirm that the cores were analyzed under the same conditions.

* Blank studies were performed without sediment. Consequently, the rubber stopper was in direct contact with the lake water for the entire experiment. We believe phosphorus leached from the stopper. However, in the actual sediment release studies, the stopper is isolated from the lake water by a layer of sediment. Therefore, the release rates observed in the blank studies may not be used to evalute the sample studies.

	NE Basin	UE Basin			11.4828
Ave. Aerobic	0.007	-0.2885			
Ave Anoxic	0.966	-0.033			
UE/NE Anoxic		0.4665			

	NE Basin	UE Basin	UE Basin		UE Basin
Anoxic Area m2	0	3.5 m - 11.	44000		44000
Days	0	60	60		60
Rate		Low	0.4665	High	1
mgs			1,231,560		2,640,000
kgs			1.23		2.64
lbs			**2.71**		**5.808**

Report

Phosphorus Removal Study

Little St. Germain Lake
Scope I.D.: 00L007

Little St. Germain Lake Protection and Rehabilitation District

November 2004

Foth & Van Dyke

Little St. Germain Lake Protection & Rehabilitation District
Phosphorus Removal Study

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Appendices

1. Introduction

The Little St. Germain Lake Protection and Rehabilitation District (District) completed a Lake Management Plan in January 2001. The report identified Muskellunge Creek as a source of 53% to 61% of the phosphorus input to Little St. Germain Lake on an annual basis. A model was used to evaluate the impact of a reduction in phosphorus from Muskellunge Creek. The model evaluated phosphorus reduction levels in Muskellunge Creek of 50%, 75%, and 100% and the impact on the East Bay of Little St. Germain Lake (the mouth of Muskellunge Creek). The measured total phosphorus concentration in East Bay averages 0.046 mg/l. The model predicted a reduction in total phosphorus of 0.012, 0.019, and 0.021 mg/l respectively in the East Bay. The impact on the lake would be expected to increase the average summer Secchi depth reading by 0.7, 1.0, and 2.0 ft respectively. As a result of the phosphorus reduction, the frequency of blue-green algae blooms was also expected to decrease.

The lake management plan recommended that chemical phosphorus removal from Muskellunge was the best technology but that further evaluation was needed due to the potentially high cost. To accomplish the phosphorus removal evaluation, a lake protection grant was applied for in the spring of 2000. The District was successful in obtaining a Lake Protection Grant from the Wisconsin Department of Natural Resources (WDNR) to do preliminary engineering work related to phosphorus removal.

The preliminary engineering work scope is as follows:

A. Phosphorus Removal Preliminary Design
B. Preliminary Lagoon Design
C. Land Acquisition Assistance
D. Permitting

This report focuses on items A and B. If the preliminary concepts and costs are feasible to the District and upon your authorization, items C and D will be completed.

2. Phosphorus Removal Testing

2.1 Jar Testing for Alum Dosage

Jar testing was done to determine the approximate dosage of alum that could be used to remove phosphorus from Muskellunge Creek water. Jar testing is a chemical simulation of a treatment process. Water samples are placed in jars and chemicals added to provide treatment. Various concentrations are used to determine which concentration would be best. Foth & Van Dyke has facilities in their office to complete the jar testing.

Alum is the common name for aluminum sulfate. This chemical is commonly used in water and wastewater treatment as a coagulant (settling aid) and for phosphorus removal. Many lakes have applied alum to the entire lake for phosphorus removal. Alum separates in water into aluminum ions and sulfate ions. The aluminum reacts with dissolved phosphates to produce a precipitate. This precipitate makes the reacted phosphorus unavailable to plants and algae.

A sample of water from Muskellunge Creek was collected by Foth & Van Dyke. Foth & Van Dyke added varying alum dosages to the test samples. The samples were mixed and allowed to settle. The supernatant (clear liquid above the settled solids) was collected from each jar and analyzed for total phosphorus, dissolved phosphorus and total suspended solids. The results are shown below:

Alum Dose – mg/l	Total P – mg/l	Dissolved P – mg/l	Total Suspended Solids – mg/l
0	0.032	0.022	4
10	0.026	0.014	7
20	0.018	0.008	10
30	ND	0.008	3
40	ND	0.007	6

The results showed that a dose of 20 mg/l had reacted with almost all the dissolved phosphorus and a dose of 30 mg/l had removed almost all the total phosphorus. Note that the raw water sample without the alum dose had a relatively low phosphorus concentration compared to the long term Muskellunge Creek average concentrations of 0.050 mg/l.

The best floc (chemical precipitate) was formed at an alum dose of 30 mg/l or higher. The floc settled to the bottom of the jar with some smaller particles remaining suspended.

2.2 Laboratory Settling Column Testing

A laboratory settling column is a useful tool in determining the speed at which a particle settles and simulates actual conditions more closely than a jar test. The settling column used is 7 feet tall and 8 inches in diameter. The column is clear plastic with sample ports located at one foot increments. Foth & Van Dyke has a settling column at their office and used this apparatus for the test.

Alum was added to the raw water as the water was added to the settling column. This procedure simulated field conditions. Samples were taken after 4 hours, 8 hours, and 24 hours. At each sample collection time, samples were collected at 1 foot intervals for a total of 18 samples per test period.

The first test was conducted at an alum dose of 3 mg/l. The second test was done at a higher concentration of 29 mg/l. The test at 3 mg/l alum dosage was done to see if the larger scale test could demonstrate improved performance at a lower alum dosage.

Each sample was analyzed for total phosphorus and total suspended solids. The complete test results are shown in Appendix A. A summary of the test is shown below:

Test 1 – Alum Addition – 3 mg/l

Sample	Total P – mg/l	Total Suspended Solids – mg/l
Raw Water	0.061	10
Average – 4 hours	0.044	13.0
Average – 8 hours	0.032	10.8
Average – 24 hours	0.025	7.7

Test 2 – Alum Addition – 29 mg/l

Sample	Total P – mg/l	Total Suspended Solids – mg/l
Raw Water	0.061	10
Average – 4 hours	0.019	10.7
Average – 8 hours	0.017	5.3
Average – 24 hours	0.017	3.2

The results show that the alum concentration of 29 mg/l was more effective than the lower dose of 3 mg/l. The alum dose of 29 mg/l removed 72% of the phosphorus after 24 hours while the 3 mg/l dose removed 59%. However, the additional cost of the alum at higher dosages should be considered when evaluating chemical cost versus phosphorus removal effectiveness. The above data is shown in graphical form below.

The results also show that the total suspended solids continued to decline from 4 hours to 24 hours. The floc particles apparently move slowly through the water column and quiescent settling of 24 hours or enhanced settling will be needed to provide good particulate removal. Enhanced settling could be accomplished with the aid of a polymer to form larger particles and speed the particulate settling.

Figure 2-1 Settling Column Phosphorus - 3 mg/l Alum

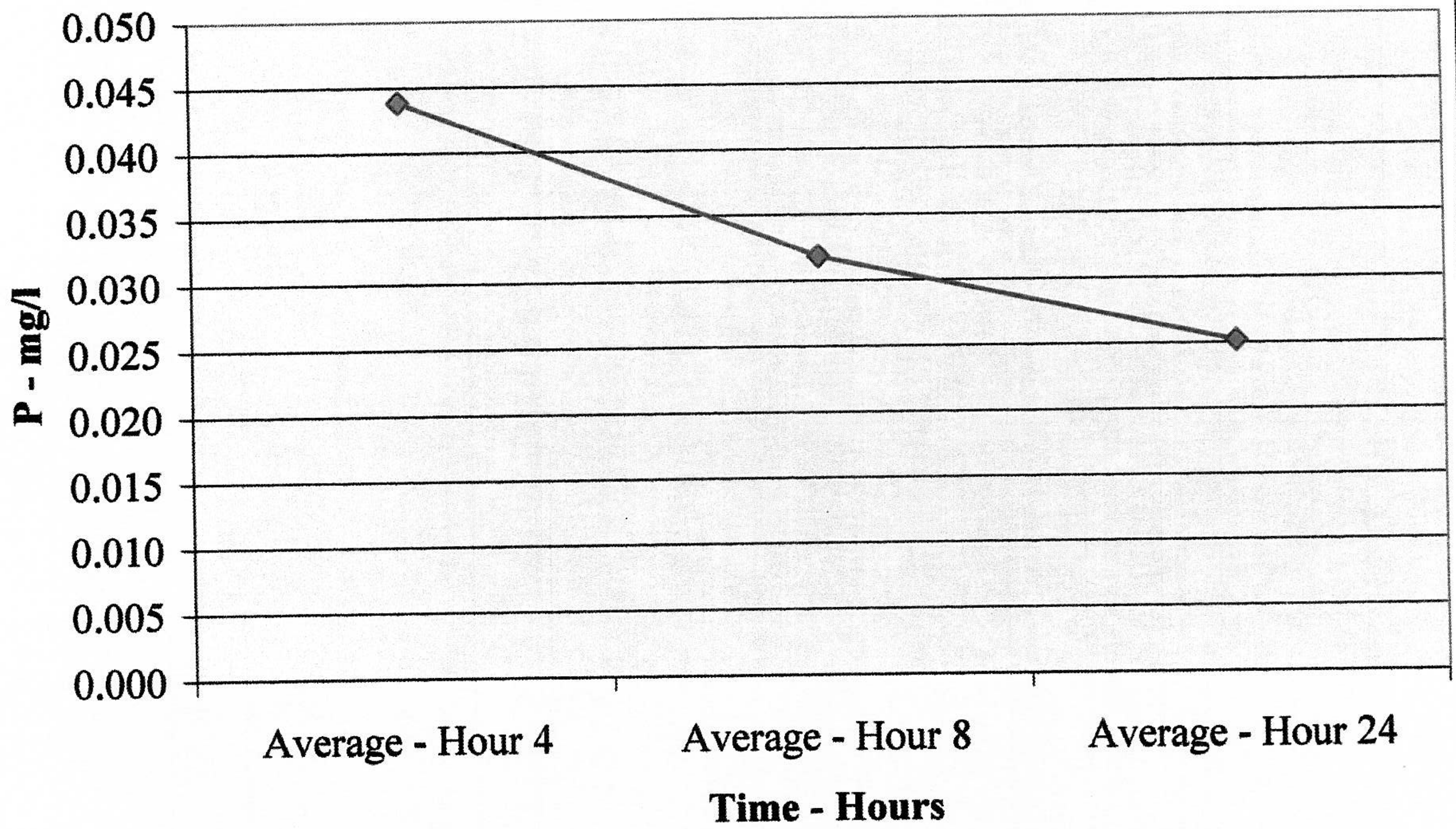


Figure 2-2 Settling Column TSS - 3 mg/l Alum

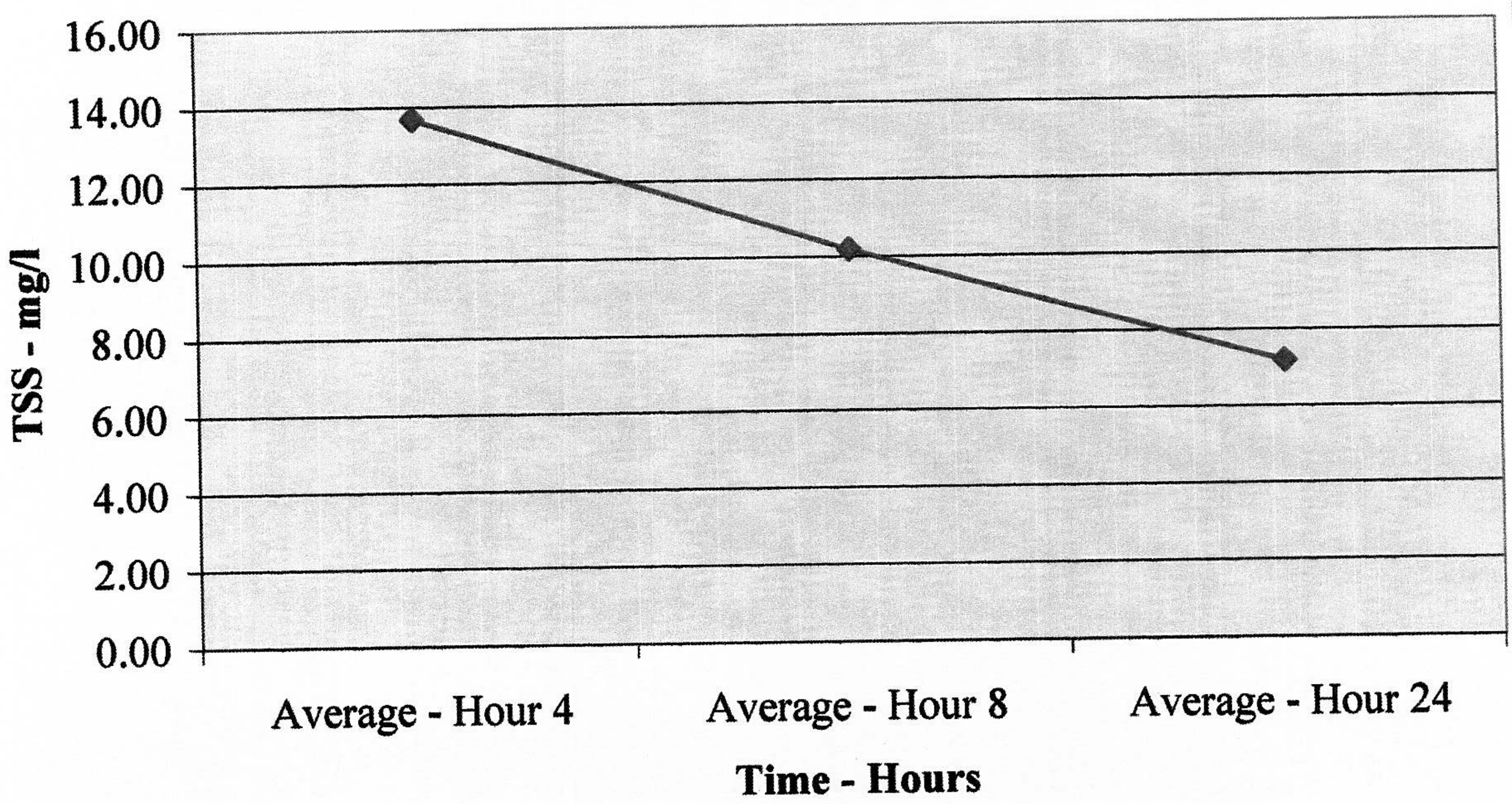


Figure 2-3 Settling Column Phosphorus - 29 mg/l Alum

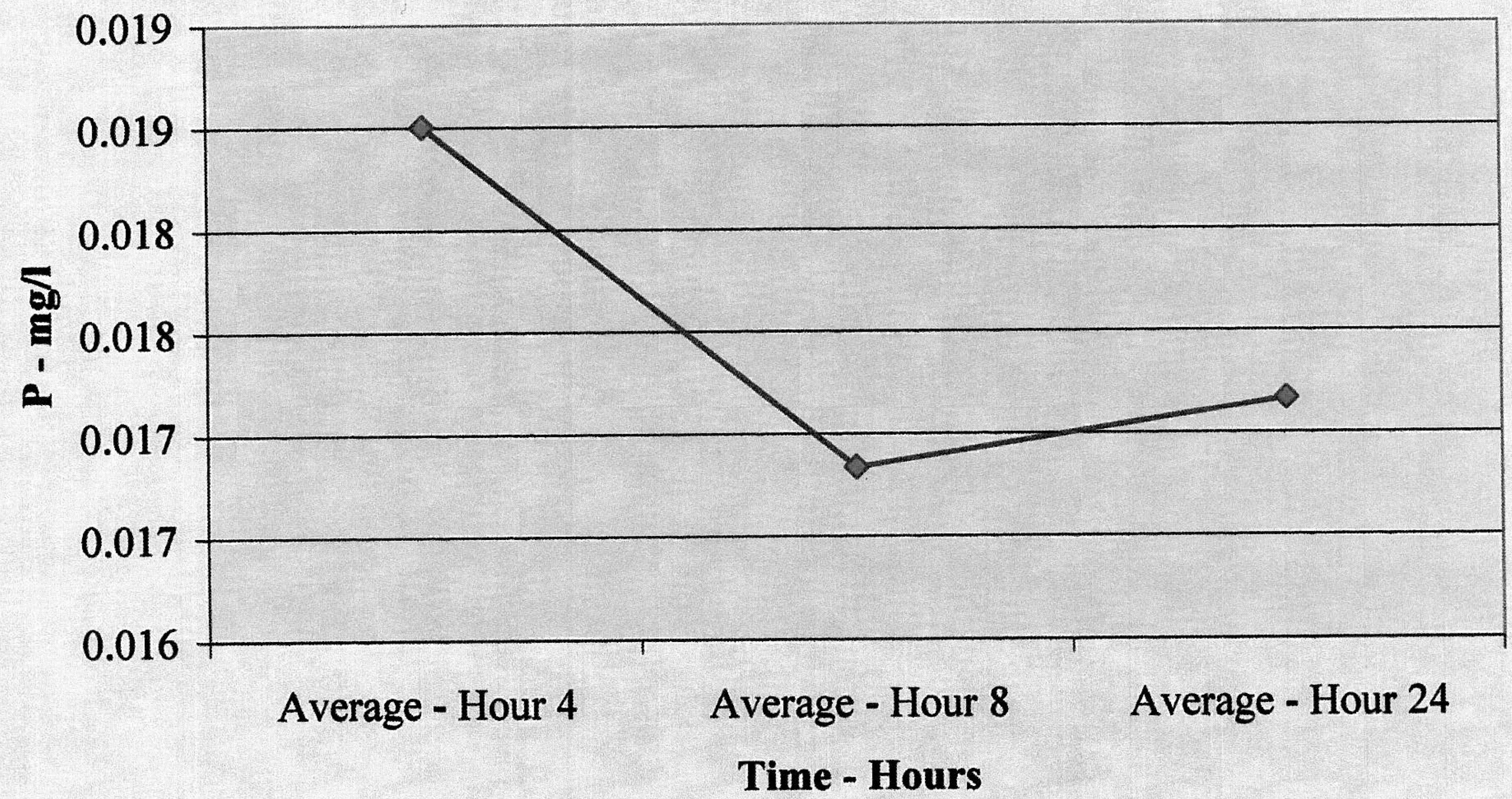
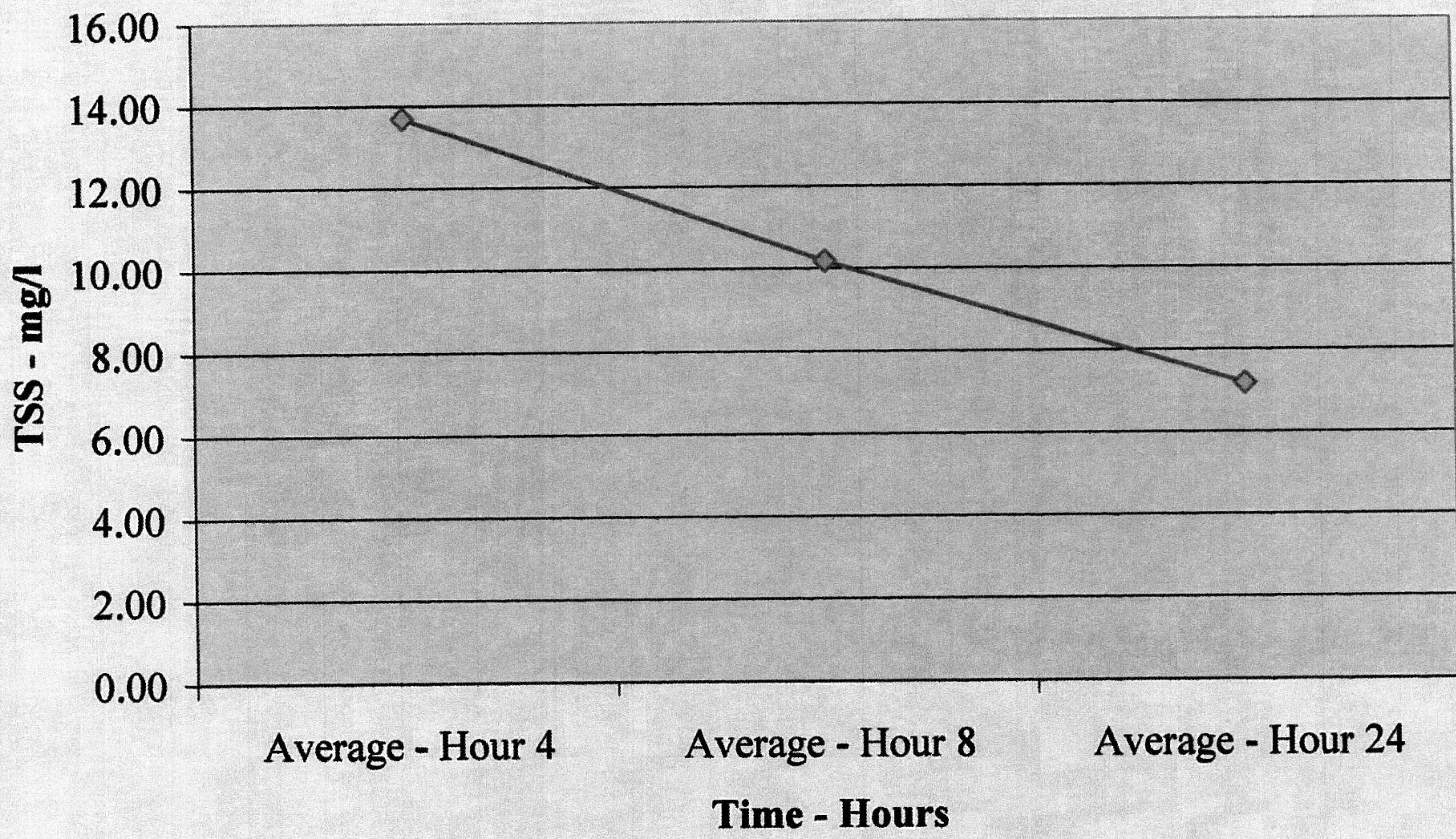


Figure 2-4 Settling Column TSS - 29 mg/l Alum



3. Phosphorus Removal Alternatives

The Lake Management Plan evaluated biological and chemical phosphorus removal alternatives. In the Plan, the biological phosphorus removal alternative was eliminated due to cost, unproven performance, and seasonal operation. Chemical phosphorus removal using alum was considered to be technically feasible. Three options were identified; chemical addition directly to the creek, stream diversion with side stream treatment, and partial lake treatment.

3.1 Direct Chemical Addition to Muskellunge Creek

3.1.1 Process Description

Alum can be applied as a liquid and directly fed to Muskellunge Creek. The alum will react with the phosphorus in the stream to form a precipitate. The precipitate will bind the phosphorus making it unavailable to algae and plants in the lake. Phosphorus precipitate will settle to the bottom of the creek and lake. Figure 3-1 shows sites A and B that are potential sites for adding chemical for phosphorus removal.

3.1.2 Capital Cost

The facilities for this process are relatively simple. A chemical feed system to pump liquid alum into the creek is all that is required. The chemical feed system includes a chemical storage tank and chemical feed pumps. A building will be required to maintain the chemical storage tank above freezing and to protect equipment from the weather and vandalism.

The chemical can be added to the stream through a small diameter pipe (1 inch size). The pipe can be placed on the stream bed and the alum distributed through evenly spaced orifices to get a well mixed process.

3.1.3 Operation Cost

The main operation costs are chemical addition and sludge removal. To determine the cost of these items, an analysis of the processes must be made. The items below describe the potential costs and impacts for each item.

3.1.3.1 Chemical Usage

The settling column test showed 72% of the phosphorus was removed after 24 hours with an alum dose of 29 mg/l. When the alum dose was reduced to 3 mg/l, the test showed 59% of the phosphorus. The USGS report estimated a 50% phosphorus reduction in the stream would decrease the East Bay phosphorus concentration by 0.012 mg/l. A 75% phosphorus reduction would decrease the East Bay phosphorus concentration by 0.019 mg/l. The test results from the settling column were between the two model predictions. Through interpolation, it is estimated that if 59% of the phosphorus were removed from the stream, the impact on East Bay would be a phosphorus reduction of 0.015 mg/l. If 72% of the phosphorus were removed from the stream, the impact on East Bay would be a phosphorus reduction of 0.018 mg/l.

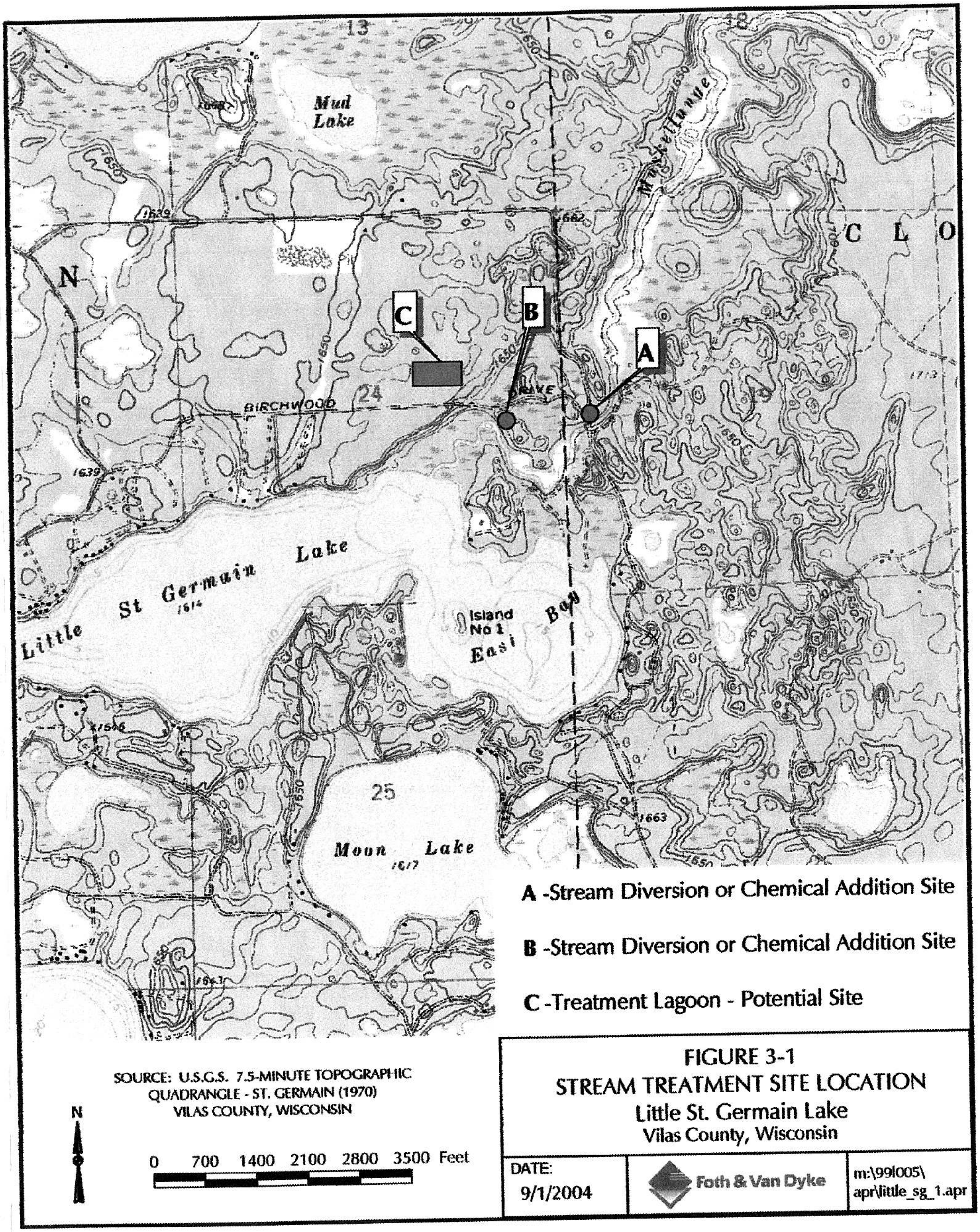


FIGURE 3-1
STREAM TREATMENT SITE LOCATION
Little St. Germain Lake
Vilas County, Wisconsin

DATE:
9/1/2004

Foth & Van Dyke

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apr\little_sg_1.apr

The above analysis shows that a 10-fold increase in chemical addition resulted in a reduction in lake phosphorus concentration of only 17%. The addition of higher amounts of chemical will result in greater phosphorus removal but the additional cost and solids production may outweigh the benefits.

The average stream flow for Muskellunge Creek at the Birchwood Drive road crossing is 7.3 cubic feet per second. This is equivalent to about 4.7 million gallons of water per day. The amount of alum needed to produce 29 mg/l for this amount of water is approximately 227 gallons per day at a concentration of 5 lbs alum/gallon. At a cost of $1.5 per gallon, the daily cost for alum addition is $340 or $124,300 annually.

If the chemical dosage is reduced to 3 mg/l, the amount of liquid alum required is 23.5 gallons per day. The daily cost for this dosage is $34 or $12,900 annually.

3.1.3.2 Solids Production

The use of alum will form a precipitate when it reacts with phosphorus and other compounds in the water. Some of these solids will eventually settle to the bottom of the river but most will settle in the lake. The area where solids will settle will depend on the settling rate of the solids. From the settling column testing, solids settled consistently over a 24 hour period. This leads to a conclusion that the area where solids will settle will be relatively large. Wind, currents, and boating traffic near the mouth of Muskellunge Creek could disperse the light solids formed from alum addition to the creek water. It is estimated that an area of 70 acres (the upper portion of the 336 acre East Bay) may be impacted from solids deposition. Over time the solids that settle will compress and become part of the sediment. The initial solids concentration may be 2% but over time the concentration may increase to 5% to 10%.

The solids production can be estimated from the settling tube testing. When the higher dose of 29 mg/l was added, some solids quickly settled to the bottom of the settling column. The remainder settled slowly over the 24 hour period until a low level of suspended solids remained. It is estimated that 30 mg/l of suspended solids were precipitated in this test. At a concentration of 2% solids, this volume would be 343,000 cubic feet. Over a 70 acre area, the annual increase in sediment would be 0.11 feet (1.3 inches).

The lower dose of alum produced lighter solids that settled slowly. The solids increased to 13.67 mg/l after 4 hours but dropped to 7.17 mg/l by the end of the test. After 24 hours, it is estimated that 6.5 mg/l of suspended solids were precipitated. At a concentration of 2% solids, this volume would be 75,000 cubic feet. Over a 70 acre area, the annual increase in sediment would be 0.025 feet (0.3 inches).

3.1.3.3 Solids Removal

Solids can accumulate in a lake to an extent that causes navigational problems or becomes a nuisance. Dredging is the method used to remove sediment from a lake. The technique for a large body of water is to use a barge and a pump. The pump suction is connected to an auger that removes sediment from the lake bottom. The solids are pumped to shore through a flexible pipe.

Solids disposal can be done in a variety of ways. Liquid sediment can be trucked to a disposal area. Solids can also be dewatered near the dredging site and hauled as a cake to a disposal area.

3.1.4 Risk Issues

While alum has been used extensively in lake rehabilitation and water treatment, there are several unknowns related to continuous use to precipitate phosphorus from a stream. The rate of solids deposition is difficult to predict and could impact the potential of future sediment removal. The area of the lake impacted by the solids deposition is also unknown and will vary depending on the amount of chemical added, the rate at which the chemical settles, and the water movement near the mouth of Muskellunge Creek.

The addition of alum (aluminum sulfate) has no known toxicity issues but the long term affect from aluminum or sulfate is not known. Sulfate has been linked to an increase in mercury concentration by means of chemical reactions in the sediment releasing mercury into the water column. If Little St. Germain Lake has adequate sulfate concentration naturally, then additional sulfate will not cause more mercury release.

3.1.5 Seasonal Operation

A consideration should be made to operating a chemical feed system on a seasonal basis. If an objective of the chemical phosphorus removal is to reduce the weed growth and algae blooms in the East Bay, then reducing the phosphorus concentration in East Bay during the summer growing season may be all that is required.

East Bay is the largest bay in the lake and covers 336 acres. The maximum depth is 16 feet but over half the bay is less than 10 feet deep. It is estimated that the upper half of East Bay is most affected by Muskellunge Creek. If ½ of East Bay is targeted and is calculated to be 170 acres at 10 feet of depth, the volume of this water is 74 million cubic feet. With an average flow rate of 8 cfs, Muskellunge Creek would replace that amount of water in 107 days. If chemical treatment of Muskellunge Creek began at the beginning of March, by early June, much of the upper ½ of East Bay would have been displaced and the phosphorus concentration would be significantly lower. Treatment could continue until late August for a seven month treatment period.

Seasonal treatment may accomplish most goals at a lower operational cost and reduced risk.

3.2 Sidestream Chemical Phosphorus Removal

3.2.1 Process Description

This alternative diverts a portion of Muskellunge Creek to a treatment lagoon where alum is added and the solids settle in the lagoon. The treated water is then returned to Muskellunge Creek before it discharges into Little St. Germain Lake. This process is complex and includes a diversion structure in the creek, a pumping system capable of about 5,000 gpm, a treatment lagoon, and a return flow structure to discharge water back into Muskellunge Creek. Figure 3-1 shows sites A and B as potential for stream diversion locations. Site C is identified as a potential lagoon site for treatment and settling of the solids.

3.2.2 Capital Cost

The facilities for this process are much more extensive than the in-stream chemical addition alternative. A water diversion structure will be required to intercept water from Muskellunge Creek. This structure is proposed to be concrete and be located in the stream channel. Water from Muskellunge Creek will be diverted to a pump station. The pump station will transfer water to the treatment lagoon. The pump station will be sized for about 5,000 gpm and will have controls to allow about 75% of the creek water to be pumped to the lagoon. At high flows, the amount of water bypassing the pumps will be greater.

At the lagoon, alum will be added to the pumped water and discharged into the lagoon. The lagoon will be sized for a minimum retention time of 24 hours. The required volume is 7.2 million gallons with an additional million gallons reserved for sediment storage. The dimensions of the lagoon will be approximately 280 feet by 520 feet with a water depth of about 10 feet. Solids will settle in the lagoon and clear water discharged back to Muskellunge Creek.

A chemical feed system to pump liquid alum into the treatment lagoon will be required. The chemical feed system includes a chemical storage tank and chemical feed pumps. A building will be required to maintain the chemical storage tank above freezing and to protect equipment from the weather and vandalism.

3.2.3 Operation Cost

The main operation costs are chemical addition and solids removal. To determine the cost of these items, an analysis of the processes must be made. The items below describe the potential costs and impacts for each item.

3.2.3.1 Chemical Usage

The settling column test showed 72% of the phosphorus was removed after 24 hours with an alum dose of 29 mg/l. When the alum dose was reduced to 3 mg/l, the test showed 59% of the phosphorus. The USGS report estimated a 50% phosphorus reduction in the stream would decrease the East Bay phosphorus concentration by 0.012 mg/l. A 75% phosphorus reduction would decrease the East Bay phosphorus concentration by 0.019 mg/l. The test results from the settling column were between the two model predictions. Through interpolation, it is estimated that if 59% of the phosphorus were removed from the stream, the impact on East Bay would be a phosphorus reduction of 0.015 mg/l. If 72% of the phosphorus were removed from the stream, the impact on East Bay would be a phosphorus reduction of 0.018 mg/l.

The above analysis shows that a 10-fold increase in chemical addition resulted in a reduction in lake phosphorus concentration of only 17%. The addition of higher amounts of chemical will result in greater phosphorus removal but the additional cost and solids production may outweigh the benefits.

The average stream flow for Muskellunge Creek at the Birchwood Drive road crossing is 7.3 cubic feet per second. This is equivalent to about 4.7 million gallons of water per day. The pump station will pump about 75% of the stream flow (3.5 million gallons per day). The amount of alum needed to produce 29 mg/l for this amount of water is approximately 169 gallons per day at a concentration of 5 lbs alum/gallon. At a cost of $1.5 per gallon, the daily cost for alum addition is $253 or $92,300 annually.

If the chemical dosage is reduced to 3 mg/l, the amount of liquid alum required is 17.5 gallons per day. The daily cost for this dosage is $26 or $9,500 annually.

3.2.3.2 Solids Production

The use of alum will form a precipitate when it reacts with phosphorus and other compounds in the water. These solids will eventually settle to the bottom of the treatment lagoon. From the settling column testing, solids settled consistently over a 24 hour period.

The solids production can be estimated from the settling tube testing. When the higher dose of 29 mg/l was added, some solids quickly settled to the bottom of the settling column. The remainder settled slowly over the 24 hour period until a low level of suspended solids remained. It is estimated that 30 mg/l of suspended solids were precipitated in this test. At a concentration of 2% solids, this volume would be 256,000 cubic feet per year. Over a 3 acre area, the annual increase in lagoon solids would be 2.0 feet.

The lower dose of alum produced lighter solids that settled slowly. The solids increased to 13.67 mg/l after 4 hours but dropped to 7.17 mg/l by the end of the test. After 24 hours, it is estimated that 6.5 mg/l of suspended solids were precipitated. At a concentration of 2% solids, this volume would be 55,000 cubic feet per year. Over a 3 acre area, the annual increase in lagoon solids would be 0.42 feet.

3.2.3.3 Solids Removal

Solids that accumulate in the lagoon will need to be removed on a regular basis. Excessive solids in the bottom of the lagoon can reduce detention time and treatment capacity. Dredging is the method used to remove solids from a lagoon. The technique for a large body of water is to use a barge and a pump. The pump suction is connected to an auger that removes solids from the lagoon bottom. The solids are pumped to shore through a flexible pipe. An alternative to dredging is to drain the lagoon and allow the solids to dry. The solids could then be removed as a dry product. To facilitate operation and removal, the treatment lagoon could be divided into two cells and one cell remains in operation while one cell is drained and the solids removed.

Solids disposal can be done in a variety of ways. Liquid sediment can be trucked to a disposal area. Solids can also be dewatered near the dredging site and hauled as a cake to a disposal area. Solids removed as a cake have a lower disposal cost due to lower transportation costs.

Because dredging or dry solids removal is an expensive process with a large portion of the cost tied up in mobilization, solids removal should be delayed until a large enough amount of solids is in the lagoon

3.2.4 Risk Issues

This alternative reduces the risk issues associated with phosphorus precipitation in the lake. Implementation is a large risk with this alternative for the following reasons:

- WDNR strives to maintain natural streams and navigable waterways. A large diversion structure in the stream bed, while technically feasible, may be difficult to get permitted for construction.

- Land will need to be acquired near Muskellunge Creek and Birchwood Drive. Because the land requirements are quite specific, if the land is not available, is located in an environmentally sensitive area, or is too expensive, there are no other alternatives available to locate a lagoon and treatment system.

- The cost of the system including operation may be prohibitive.

3.3 Partial Lake Chemical Phosphorus Removal

3.3.1 Process Description

This alternative chemically treats the majority of Little St. Germain Lake. This process applies alum to the lake where the water depth is greater than five feet. The phosphorus in the water column is removed and settles to the bottom. In addition, the alum precipitate reacts with phosphorus released from the sediment preventing it from entering the water column.

The alum is applied to the lake through a special barge designed to apply liquid alum to the lake surface or injected below the surface. The barge can carry several thousand gallons of liquid alum at a time.

3.3.2 Capital Cost

There is no capital cost for this alternative. All costs are incurred by contracting with a company for phosphorus treatment.

3.3.3 Operation Cost

The operation cost is the cost for contracting a company to do the phosphorus removal. Preliminary estimates of a cost for treating approximately 650 acres (excluding West Bay and Upper East Bay) are about $60,000. If the West Bay and Upper East Bay are included, the cost would be greater. The question relating to operating cost is the frequency that total lake treatment is needed.

The volume of water in the 650 acres impacted by Muskellunge Creek (between mouth of the creek and the outlet stream) is about 250 million cubic feet. The annual input from Muskellunge Creek and groundwater is about 350 million cubic feet as determined by the USGS hydrology report from October 2000. These numbers show that there is a water exchange of about 260 days. If chemical treatment is applied in June each year, by March of the following year, the water from the creek and groundwater would have replaced the treated lake water. With phosphorus concentrations in the creek and groundwater at levels higher than normal lake water, the chemical treatment will have little impact on lake phosphorus concentrations for more than 12 months. To maintain low levels of phosphorus in the lake, chemical treatment will be required each year.

3.3.3.1 Solids Production

The amount of alum used for partial lake treatment is similar to the option of adding 30 mg/l to Muskellunge Creek. The amount of precipitate will be spread out over 650 acres and will accumulate at a rate of 0.13 inches per year assuming in settles to 2% solids concentration.

3.3.3.2 Solids Removal

Solids can accumulate in a lake to an extent that causes navigational problems or becomes a nuisance. Dredging is the method used to remove sediment from a lake. The technique for a large body of water is to use a barge and a pump. The pump suction is connected to an auger that removes sediment from the lake bottom. The solids are pumped to shore through a flexible pipe.

Solids disposal can be done in a variety of ways. Liquid sediment can be trucked to a disposal area. Solids can also be dewatered near the dredging site and hauled as a cake to a disposal area.

3.3.4 Risk Issues

This alternative includes risk issues associated with phosphorus precipitation in the lake. These issues were discussed in Section 3.1.4. The cost of annually treating the lake for phosphorus may be prohibitive.

3.4 Lake Aeration Impact

Lake aerators are used in winter to provide oxygen to areas of the lake that typically become anoxic. There are three aerator locations in Little St. Germain Lake; South Bay, Upper East Bay and near the mouth of Muskellunge Creek. The aerators are operated for approximately 3 months in winter beginning in January and ending in late March.

Phosphorus precipitation from addition to the stream or lake will settle near the aerators located at the bottom of the lake in South Bay and near the mouth of Muskellunge Creek. Areas near the aerators may have velocities great enough (approximately 1 foot per second) to re-suspend settled particles.. This is true of phosphorus precipitates as well as other lighter sediments. These light particles will settle in other areas of the lake that have less turbulence.

The lake aerators are not operated when the seasonal phosphorus treatment system is operated. This is true for the in-stream treatment alternative and the partial lake treatment alternative. The phosphorus precipitate will settle under natural lake conditions before the lake aerators are started up in winter. The only impact the aerators will have on phosphorus precipitates is in areas adjacent to the aerators where velocities are high enough to suspend light sediment. The total area impacted by the aerators will be less than 1 acre.

4. Phosphorus Removal Cost Analysis

4.1 General

A cost-effectiveness analysis will be performed on the three phosphorus removal alternatives. The cost-effectiveness analysis is based on a 20 year project life. Each phosphorus removal alternative uses the present worth analysis method to compare total costs over a 20-year period. The interest rate used in this evaluation is 6%. The analysis includes capital costs and operation and maintenance costs.

4.2 Direct Chemical Addition to Muskellunge Creek

The capital cost for this alternative includes:

- Chemical feed building
- Chemical feed equipment
- Piping
- Site work
- Electrical
- Land
- Technical, administrative
- Contingency

The estimated project cost is $279,000. Appendix B contains detailed information on the project cost.

The operation cost was calculated for a 12 month operational period and a 6 month operational period. The cost for operation over a 6 month period is $13,700 while the cost of operation over a 12 month period is $24,800. These costs assume an alum feed rate of about 3 mg/l.

4.3 Sidestream Chemical Phosphorus Removal

The capital cost for this alternative includes:

- Stream diversion structure
- Pump Station
- Treatment Lagoon
- Chemical feed building
- Chemical feed equipment
- Piping
- Site work
- Electrical
- Land
- Technical, administrative
- Contingency

The estimated project cost is $1,632,000. Appendix B contains detailed information on the project cost.

The operation cost was calculated for a 12 month operational period and a 6 month operational period. The cost for operation over a 6 month period is $49,100 while the cost of operation over a 12 month period is $98,100. These costs assume an alum feed rate of 3 mg/l.

4.4 Partial Lake Chemical Phosphorus Removal

There are no capital costs for this alternative. The annual operation and maintenance cost is estimated at $60,000 for a chemical application to the main lake channel.

4.5 Present Worth Summary

The following table summarizes the cost-effective analysis for the phosphorus removal alternatives:

Alternative	Capital Cost	Annual O&M Cost	Total Present Worth
In-stream Treatment	$279,200	$13,700	$436,300
Treatment Lagoon	$1,632,000	$49,100	$2,195,000
Partial Lake Treatment	$0	$60,000	$688,200

The above table shows the in-stream treatment alternative to be the most cost-effective. This analysis assumed that seasonal phosphorus removal would be implemented to reduce the annual operation cost.

5. Internal Phosphorus Loading

The USGS report dated October 2000 included a phosphorus budget for Little St. Germain Lake. Sources of phosphorus identified in the report included precipitation, stream inflow, groundwater, and septic tanks.

An additional phosphorus source not previously identified is internal loading. This occurs as phosphorus contained in the sediment is released back into the water column. This release takes place under aerobic and anaerobic conditions.

At this time it is unknown what impact the internal loading has on the overall phosphorus budget in Little St. Germain Lake. Before the District evaluates phosphorus removal alternatives, the impact of internal phosphorus loading should be considered. If the internal loading is a relatively large portion of the phosphorus budget, then chemical treatment of the stream may be less effective in lowering the phosphorus concentration in the lake. Therefore, an analysis of internal phosphorus loading should be done before a decision is made on chemical phosphorus treatment.

6. Conclusions and Recommendations

6.1 Conclusions

- Muskellunge Creek contributes 53% to 61% of the total phosphorus to Little St. Germain Lake.
- Removing phosphorus from Muskellunge Creek will improve water clarity and reduce phosphorus concentrations up to 46%.
- Little St. Germain Lake will remain a eutrophic lake if all the phosphorus is removed from Muskellunge Creek.
- Laboratory tests showed alum can remove phosphorus from Muskellunge Creek.
- A laboratory settling column test showed that significant phosphorus removal (59% removal) occurred with an alum dose of 3 mg/l provided that 24 hours of settling occurred.
- An alum dose of 29 mg/l provided more rapid settling and greater phosphorus removal (72% removal).
- Direct chemical addition to Muskellunge Creek is a feasible alternative with risk issues regarding solids settling in the lake.
- Sidestream chemical addition and treatment will eliminate most solids settling in the lake but has a higher cost and may not be permitted due to impacts on the stream habitat.
- Seasonal chemical treatment should be considered to reduce operational cost and minimize solids build-up.
- Partial lake treatment is a feasible alternative to reducing phosphorus concentrations in the lake. To keep phosphorus concentrations low, partial lake treatment will need to be repeated each year. The water entering the lake from the inlet stream and groundwater has an average residence time of less than one year.
- Internal phosphorus loading has an unknown impact on the lake.
- Lake aeration will have a negligible impact on phosphorus precipitation.

6.2 Recommendations

- Determine the impact of internal phosphorus loading in the summer of 2005. Contact USGS to prepare a work plan and apply for a lake planning grant to conduct the work.
- Evaluate the feasibility of implementing the direct chemical treatment in Muskellunge Creek alternative by doing the following:

A. Determine location of treatment facilities and the possibility of obtaining land and easements.
B. Review permitting issues with WDNR.
C. Consider model of lake phosphorus based on seasonal operation.
D. Prepare financing plan including WDNR Lake Protection Grant.
E. Obtain property owner comments with educational flyer and survey.

Appendix A
Phosphorus Removal Testing

Little St. Germain Lake
Settling Column Testing - Alum Addition

Test Water - Muskellunge Creek

Test 1 - Alum Addition 200 ml in 18 gallons
Concentration = 28.9 mg/l

Sample ID	Total P	TSS
Raw Water	0.061	10
200-4-1	0.017	11
200-4-2	0.017	11
200-4-3	0.02	10
200-4-4	0.019	10
200-4-5	0.017	11
200-4-6	0.021	11
200-8-1	0.015	5
200-8-2	0.016	6
200-8-3	0.016	5
200-8-4	0.017	5
200-8-5	0.02	5
200-8-6	0.017	6
200-24-1	0.029	4
200-24-2	0.014	3
200-24-3	0.014	3
200-24-4	0.016	3
200-24-5	0.021	3
200-24-6	0.009	3
Average - Hour 4	0.019	10.67
Average - Hour 8	0.017	5.33
Average - Hour 24	0.017	3.17

Test 2 - Alum Addition 20 ml in 18 gallons
Concentration = 3 mg/l alum

Sample ID	Total P	TSS
Raw Water	0.061	10
20-4-1	0.043	13
20-4-2	0.043	13
20-4-3	0.047	15
20-4-4	0.041	14
20-4-5	0.045	13
20-4-6	0.044	14
20-8-1	0.033	10
20-8-2	0.032	10
20-8-3	0.033	10
20-8-4	0.031	10
20-8-5	0.032	11
20-8-6	0.03	10
20-24-1	0.026	7
20-24-2	0.025	7
20-24-3	0.026	7
20-24-4	0.028	7
20-24-5	0.023	8
20-24-6	0.023	7
Average - Hour 4	0.044	13.67
Average - Hour 8	0.032	10.17
Average - Hour 24	0.025	7.17

Little St. Germain Lake
Alum Addition

Test Water - Muskellunge Creek

Alum - mg/l	Total P - mg/l	Dissolved P - mg/l	TSS - mg/l
0	0.032	0.022	4
10	0.026	0.014	7
20	0.018	0.008	10
30	ND	0.008	3
40	ND	0.007	6

Appendix B
Project Cost Analysis

Little St. Germain

Cost Estimate for Instream Treatment

Item	Quantity	Unit	Unit Price	Cost
Site Piping	300	ft	$30	$9,000
Chemical Feed Building	480	sq. ft.	$150	$72,000
Chemical Feed Equipment	1	each	$40,000	$40,000
Subtotal				$121,000
Contractor Overhead and Profit				$24,200
Misc Metals				$3,630
Site Preparation				$12,100
Electrical/Instrumentation				$24,200
Subtotal				$64,130
Total Construction				$185,130
Land/Easements				$20,000
Legal/Technical/Admin/Contingency				$74,052
Total				$279,182

Operation and Maintenance Costs
Cost Assumes 6 Months Operation/year

Item	Annual Cost
Power	$1,000
Labor (8 hours/wk - 6 months; $20/hr)	$4,200
Chemical	$6,500
Laboratory	$2,000
Dredging	$0
Total	$13,700

Operation and Maintenance Costs
Cost Assumes 12 Months Operation/year

Item	Annual Cost
Power	$1,500
Labor (8 hours/wk - 12 months; $20/hr)	$8,300
Chemical	$13,000
Laboratory	$2,000
Dredging	$0
Total	$24,800

Little St. Germain

Cost Estimate for Treatment Lagoon

Item	Quantity	Unit	Unit Price	Cost
Earthwork	20000	cu. yd.	$5	$100,000
Rip Rap	213	cu. yd.	$25	$5,325
PVC Liner	162000	sq. ft.	$0.6	$97,200
Geotextile	140000	sq. ft.	$0.4	$56,000
Sand Backfill	5200	cu. yd.	$10	$52,000
Landscaping	30000	sq. ft.	$0.1	$3,000
Fencing	1200	ft	$12	$14,400
Pump Station Concrete	116	cu. yd.	$700	$81,200
Submersible pump	1	each	$30,000	$30,000
Site Piping	2000	ft	$75	$150,000
Chemical Feed Building	480	sq. ft.	$120	$57,600
Chemical Feed Equipment	1	each	$30,000	$30,000
Subtotal				$676,725
Contractor Overhead and Profit				$108,276
Misc Metals				$20,302
Site Preparation				$33,836
Electrical/Instrumentation				$81,207
Subtotal				$243,621
Total Construction				$920,346
Land/Easements				$100,000
Legal/Technical/Admin/Contingency				$368,138
Total				$1,632,105

Operation and Maintenance Costs
Cost Assumes 6 Months Operation/year

Item	Annual Cost
Power	$8,500
Labor (16 hours/wk - 6 months; $20/hr)	$8,300
Chemical	$4,800
Laboratory	$2,500
Dredging	$25,000
Total	$49,100

Operation and Maintenance Costs
Cost Assumes 12 Months Operation/year

Item	Annual Cost
Power	$17,000
Labor (16 hours/wk - 12 months; $20/hr)	$16,600
Chemical	$9,500
Laboratory	$5,000
Dredging	$50,000
Total	$98,100

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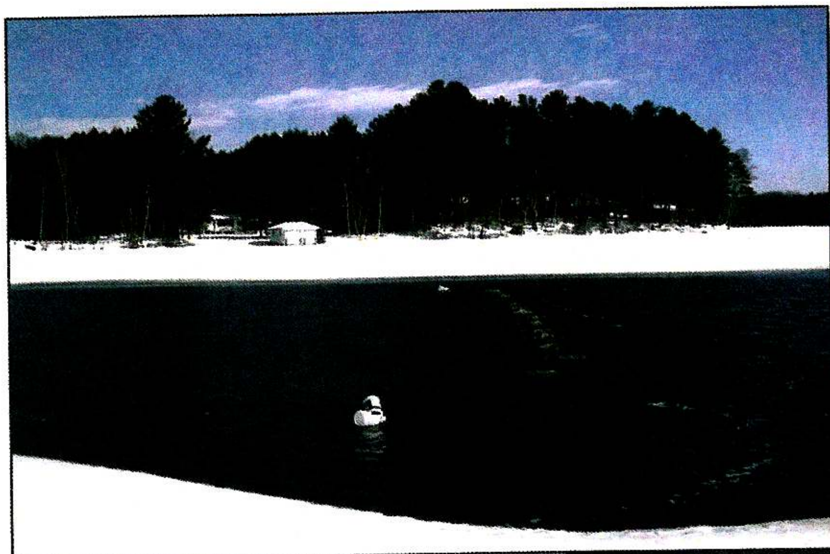
In cooperation with the Little St. Germain Lake District

Water Quality, Hydrology, and Phosphorus Loading to Little St. Germain Lake, Wisconsin, with Special Emphasis on the Effects of Winter Aeration and Ground-Water Inputs



Scientific Investigations Report 2005–5071

U.S. Department of the Interior
U.S. Geological Survey

Water Quality, Hydrology, and Phosphorus Loading to Little St. Germain Lake, Wisconsin, with Special Emphasis on the Effects of Winter Aeration and Ground-Water Inputs

By Dale M. Robertson, William J. Rose, and David A. Saad

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Conversion Factors and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature, in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = [1.8 \times °C] + 32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) – a geodetic datum derived from a general adjustment of the first-order level of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Water Quality, Hydrology, and Phosphorus Loading to Little St. Germain Lake, Wisconsin, with Special Emphasis on the Effects of Winter Aeration and Ground-Water Inputs

By Dale M. Robertson, William J. Rose, and David A. Saad

Abstract

Little St. Germain Lake is a 978-acre, multibasin lake in Vilas County, Wisconsin. In the interest of protecting and improving the water quality of the lake, the Little St. Germain Lake District initiated several cooperative studies with the U.S. Geological Survey between 1991 and 2004 to (1) document the water quality and the extent of winter anoxia in the lake, (2) evaluate the success of aerators at eliminating winter anoxia, (3) develop water and nutrient budgets for the lake, and (4) assess how the water quality of the lake should respond to changes in phosphorus loading. This report presents the results of these cooperative studies with special emphasis on the water quality in the lake since 2000, including the effects of winter aeration and the importance of ground-water contributions of phosphorus to the productivity of the lake.

Measurements collected during these studies indicate that the water quality in Little St. Germain Lake was consistently different among basins. The West Bay consistently had the best water quality, the South Bay had intermediate water quality, and the East and Upper East Bays consistently had the worst water quality. The water quality in each of the basins was relatively stable from 1991 to 2000; however, since 2001, the West Bay has changed from oligotrophic to mesotrophic, the South Bay has changed from mesotrophic to eutrophic, and the East and Upper East Bays have changed from eutrophic to eutrophic/hypereutrophic.

Winter anoxia frequently occurred throughout most of the lake, except in the West Bay and just below the ice in the East Bay. To eliminate winter anoxia, coarse-bubble line aerators were installed and operated in the Upper East, East, and South Bays. The aerators in the Upper East and South Bays were very successful at eliminating winter anoxia; however, the aerator in the East Bay had little impact on the dissolved oxygen concentrations throughout its basin.

Detailed water and phosphorus budgets computed for the lake indicated that inflow from Muskellunge Creek was the major source of phosphorus to the lake and that ground water was the secondary source. Results from a detailed ground-water-flow model indicated that ground water flows into the lake from all sides, except the south sides of the West and Second South Bays. Most of the phosphorus appears to come from natural sources, such as ground water and surface water flowing through relatively undeveloped areas surrounding Little St. Germain Lake and Muskellunge Lake.

Several empirical water-quality models were used to simulate how the East and Upper East Bays of the lake should respond to reductions in phosphorus loading from Muskellunge Creek. Simulation results indicated that reductions in tributary loading could improve the water quality of the East and Upper East Bays. Improving the water quality of these bays would also improve the water quality of the South and Second South Bays because of the flow of water through the lake. However, even with phosphorus loading from Muskellunge Creek completely eliminated, most of the lake would remain borderline mesotrophic/eutrophic because of the contributions of phosphorus from ground water.

Introduction

Little St. Germain Lake, located just northeast of St. Germain in Vilas County, Wisconsin (fig. 1), is one of 21 impoundments operated by Wisconsin Valley Improvement Company (WVIC) to provide storage for power and for recreational use. The level of the lake, which was originally dammed in 1882, has been maintained by the WVIC at about 5 ft above its natural level since 1929, and it is annually drawn down about 1.5 ft from December through March. In the interest of protecting and improving the water quality of the lake, the Little St. Germain Lake District has collaborated with the Wisconsin Department of Natural Resources (WDNR) and the U.S. Geological Survey (USGS) to conduct several water-quality studies. From 1983 to 1985, the WDNR examined the water quality of the lake and various management alternatives (Wisconsin Department of Natural Resources, 1985). Results of the study indicated that, because of relatively high loading of phosphorus to the lake, most of the lake was eutrophic (based on relatively high chlorophyll *a* concentrations), with the possible exception of the West Bay. The results also indicated that monitoring of the lake should continue and that actions should be taken to decrease the nutrient loading to the lake by controlling erosion, fertilizer runoff, and leakage from septic systems.

The lake was monitored in detail during 1991–94 by the USGS as part of a cooperative study with the Little St. Germain Lake District. The study demonstrated variation in water quality among the various basins of the lake and found extensive areas of winter anoxia (absence of oxygen). Further in-depth studies were done by the USGS during 1994–2000 to refine the water and phosphorus budgets of the lake, quantify the effects of annual drawdowns, define the extent of winter anoxia, and provide information needed to develop a comprehensive lake-management plan (Robertson and Rose, 2000). Results of the study indicated that Muskellunge Creek was the dominant source of phosphorus to the lake; however, ground-water contributions (based on limited information) appeared to be important and should be better quantified. The results of the study also indicated extensive areas of winter anoxia in the Upper East, South, and Second South Bays (fig. 2). As a result of that study, aerators were placed in the Upper East Bay, the South Bay, and in the northern end of the East Bay and operated throughout the winter.

The USGS, in cooperation with the Little St. Germain Lake District, continued to study Little St. Germain Lake from 2000 to 2004. The goals of this effort were to (1) continue to document the water quality in the lake, (2) evaluate the success of the aerators at eliminating winter anoxia, (3) refine the nutrient budget of the lake by better quantifying flow and phosphorus contributions from ground water directly entering the lake and entering by way of Muskellunge Creek during November 1, 2000, to October 31, 2001, and (4) assess how the water quality of the lake should respond to changes in phosphorus loading. To better define the contributions from ground water (locations and amounts), a ground-water-flow model was developed for the Little St. Germain area. This report presents the results of the studies since 1991, with special emphasis on the water quality in the lake since 2000–including the effects of winter aeration and the importance of ground-water contributions of phosphorus to the productivity of the lake.

Little St. Germain Lake and its Watershed

Little St. Germain Lake (fig. 1) is a multibasin lake with a total surface area of 978 acres and volume of 11,498 acre-ft (table 1). In this report, the lake is discussed in terms of six basins or "bays" (fig. 2 and table 1): Upper East Bay (119 acres), East Bay (336 acres), No Fish Bay (69 acres), West Bay (213 acres), South Bay (122 acres), and Second South Bay (119 acres). The major tributary to the lake is Muskellunge Creek, which flows about 3 mi from shallow, eutrophic Muskellunge Lake into the north end of the East Bay (fig. 2). Muskellunge Lake was extensively studied by the USGS during 2000–2001 as part of a cooperative study with the Muskellunge Lake Association (Robertson and others, 2003); results from that study are used to further describe the importance of ground water and contributions from natural sources to Little St. Germain Lake. Outflow from the lake is to Little St. Germain Creek, which leaves the south side of the Second South Bay and flows about 1 mi before draining into the Wisconsin River.

The total watershed area of Little St. Germain Lake is 10 mi^2 (not including the lake itself). The watershed is predominantly forest (68 percent), wetland (17 percent), and water (8 percent), although areas of low-density residential development are increasing, especially immediately around the lakes (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).

Methods

Data Collection

Data used to describe the water quality of the lake were collected from April 1991 to March 2004; however, no data were collected from September 1994 to July 1996 and September 1997 to February 1999. Lake water-quality

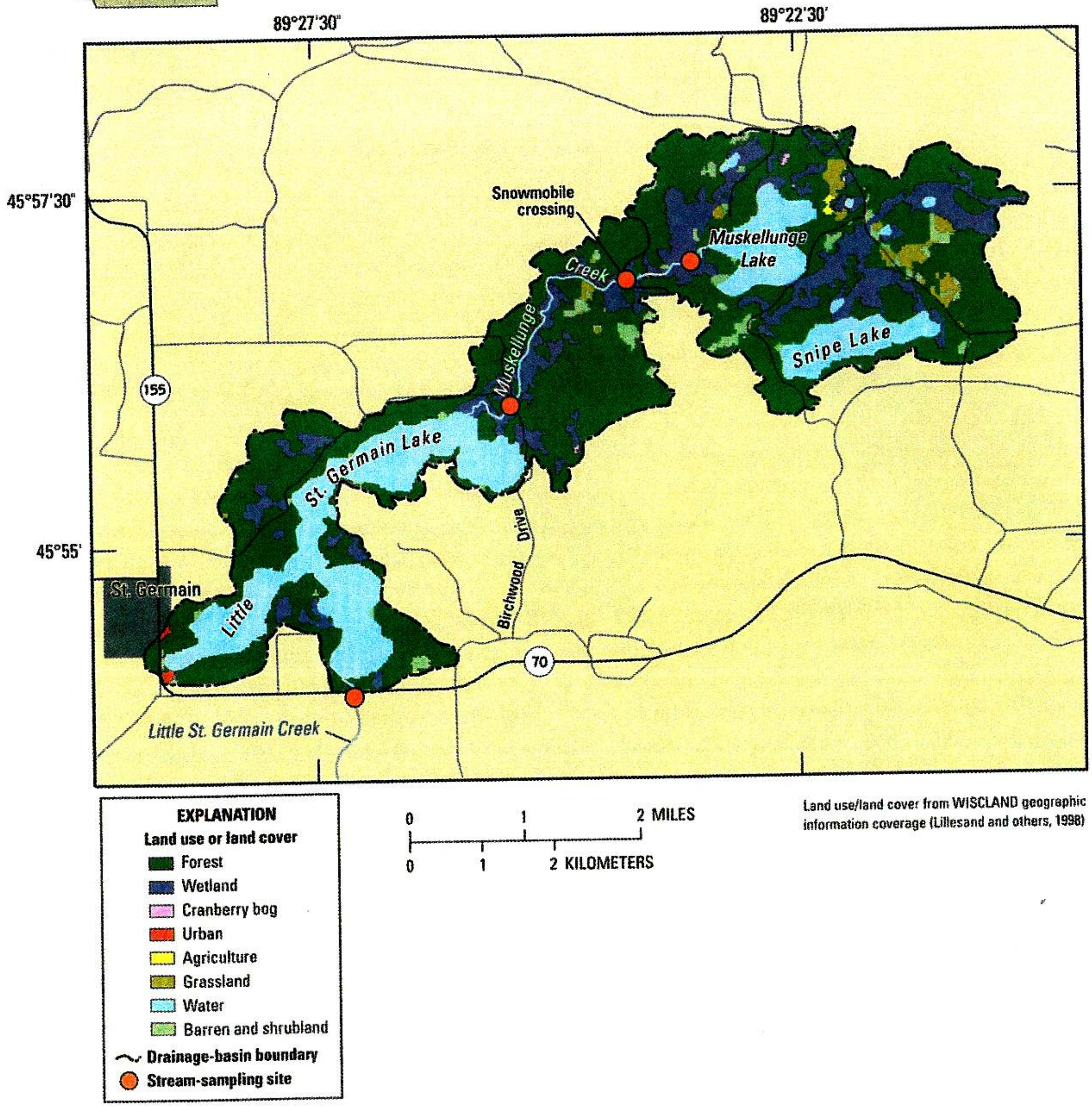

Figure 1. Drainage basin of Little St. Germain Lake, Vilas County, Wis.

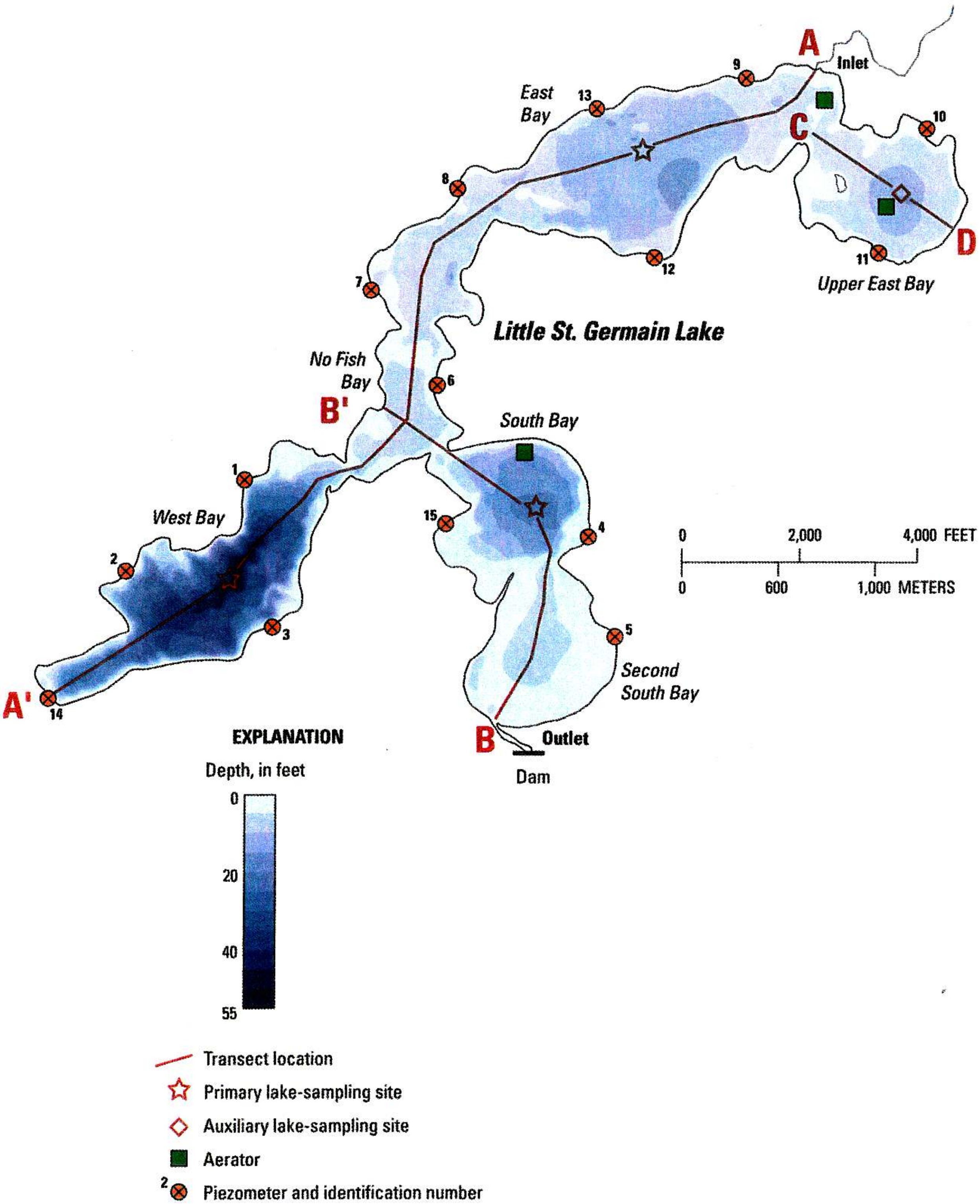

Figure 2. Morphometry of Little St. Germain Lake, Vilas County, Wis.

Table 1. Morphometry of Little St. Germain Lake and each of its basins, Vilas County, Wisconsin.

Basin/Total	Maximum Depth (feet)	Mean Depth (feet)	Area (acres)	Volume (acre-feet)
Upper East	15	7.5	119	893
East	12	8.9	336	2,982
No Fish	6	4.4	69	305
West	53	24.1	213	5,140
South	21	11.6	122	1,417
Second South	9	6.4	119	761
Entire lake	**53**	**11.8**	**978**	**11,498**

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). In addition, water-quality data were collected at the center of the Upper East Bay from 2000 to 2004. 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 (1.5 ft below the surface during open water or just below ice during ice cover) or near bottom (1.5 ft above bottom) with a Van Dorn sampler. Near-surface water samples were analyzed for concentrations of total phosphorus (an indicator of the amount of available nutrients) and chlorophyll *a* (an indicator of the algal population). During ice-free periods, Secchi depths (an indicator of water clarity) also were measured. During spring overturns after ice out in 1991 through 1994, in 2002, and in 2003, surface-water samples were analyzed for a full suite of water-quality constituents in the South and West Bays.

Additional depth-profile measurements of temperature and oxygen were made at various locations during the winters of 1997–2004 to assess the extent and timing of anoxia before and during operation of the aerators. The most extensive set of profiles was collected in the basins in which aerators were placed: Upper East Bay, East, and South Bays (fig. 2).

Inflow and phosphorus loading to the lake were determined from flow measurements and water samples collected approximately monthly in Muskellunge Creek at Birchwood Drive (fig. 1) during October 1996–September 1997, December 1998–January 2000, and November 2000–October 2003. During 1996–97 and 1998–2000, flows between measurements were estimated by linearly interpolating between monthly measurements. Continuous (15-minute intervals) water-elevation measurements were collected at Birchwood Drive and the outlet of Muskellunge Lake from March 2001 through October 2001 to better describe the flow throughout Muskellunge Creek and better estimate the total phosphorus contributions from Muskellunge Creek. The monthly streamflow measurements were used to develop stage-discharge relations, which were then used in conjunction with water-elevation data to compute flow at these locations. During 1996–97, water samples collected at Birchwood Drive were analyzed for total phosphorus concentration. During 1998–99, water temperature and dissolved oxygen also were measured at Birchwood Drive, and the samples also were analyzed for dissolved phosphorus. During 1999–2003, water temperature and dissolved oxygen measurements were measured, and water-quality samples (analyzed for total and dissolved phosphorus) were collected approximately monthly at the Muskellunge Lake outlet (Robertson and others, 2003) and at the snowmobile crossing between the two lakes (fig. 1) to help define the sources of water and phosphorus to Muskellunge Creek.

Surface-water outflow from Little St. Germain Lake was estimated from water-elevation measurements made at the dam at Highway 70 by WVIC. Water levels at the dam on Little St. Germain Creek were monitored almost daily from 1991 to 2003 by the WVIC (U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2004). Additional flow measurements and water samples were collected monthly just below the dam from December 1998 through September 2003 to better describe the outflow from the lake. Water samples were analyzed for total phosphorus. The flow measurements at the dam indicated that low flows were underestimated; therefore, those flows were adjusted accordingly.

Fifteen small, shallow piezometers (small-diameter observation wells) were installed approximately 1 to 3 ft below the water table around the lake (fig. 2) to help define areas contributing ground water to the lake, determine the phosphorus concentrations in the ground water entering the lake, and quantify the phosphorus loading from ground water. Ground-water gradient (determined from water elevation in the piezometer and the water elevation of the lake) and phosphorus concentrations in the ground water in each piezometer were measured two times: May and August 2001.

All chemical analyses of water samples were done by the Wisconsin State Laboratory of Hygiene in accordance with standard analytical procedures described in the "Manual of Analytical Methods, Inorganic Chemistry Unit" (Wisconsin State Laboratory of Hygiene, 1993).

Data collected during this study were published in two annual USGS data report series. Streamflow data were published in "Water Resources Data, Wisconsin–Water Year 2001" (Waschbusch and others, 2002) and lake data in the series "Water Quality and Lake-Stage Data for Wisconsin Lakes, Water Years 1994–2003" (the most recent Little St. Germain Lake data were published in U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2004).

Aerator Design

Coarse-bubble line aerators were installed in the Upper East and East Bays in fall 2001 (fig. 2) and operated during the winters of 2002, 2003, and 2004. (All winters are described in terms of the year in which the ice left the lake.) Each aerator is supplied by 5-horsepower blowers on the nearby shoreline. The air travels through 4-in. pipe out to the aerators, which were constructed of 2-in. pipe with 1/8-in. holes placed about 4 ft apart. The aerator in the East Bay is about 600 ft off the northwest shore at a depth of about 4 ft. This aerator was designed to release 42 ft^3/min of air at 6 psi through two parallel 67-ft lines placed about 100 ft apart; each line has 16 holes. The aerator in Upper East Bay is near the center of the bay at a depth of about 10 to 12 ft. This aerator was designed to release 117 ft^3/min of air at 10 psi through five parallel 75-ft lines about 100 ft apart; each line has 18 holes. A coarse-bubble line aerator was installed into the South Bay in fall 2002 (fig. 2) and operated during the winters of 2003 and 2004. The aerator in the South Bay is about 600 ft off the northwest shore at a depth of about 20 ft. This aerator was designed to release 117 ft^3/min of air at 10 psi through five parallel 75-ft lines placed about 100 ft apart; each line has 18 holes. Each of the aerators is operated from shortly after ice formation until shortly before ice out.

Simulation of Ground-Water Flow

The two-dimensional, analytic-element, steady-state, ground-water-flow model, GFLOW (Haitjema, 1995) was used to define ground-water-source areas around Little St. Germain Lake (and Muskellunge Lake) and to allocate ground-water discharge to shoreline segments represented by the piezometers installed around the lake. A complete description of analytic-element modeling is beyond the scope of this report; however, a brief description is given below. A complete discussion of the methods for applying the model can be found in Strack (1989) and Haitjema (1995).

An infinite aquifer is assumed in analytic-element modeling. In GFLOW, the study area (domain) does not require a grid or involve interpolation between cells. To construct an analytic-element model, features that affect ground-water flow (such as surface-water bodies, aquifer characteristics, and recharge) are entered as mathematical elements or strings of elements (described below). The amount of detail specified for the features depends on the distance from the area of interest. Each element is represented by an analytic solution. The effects of these individual solutions are added together to arrive at a solution for the ground-water-flow system. Because the solution is not confined to a grid, ground-water levels (heads) and flows can be computed anywhere in the study area without averaging values at specific locations in the model (nodal averaging). In the GFLOW model, the analytic elements are two dimensional and are used to simulate only steady-state conditions. Ground-water-flow systems are three dimensional; however, two-dimensional models can provide reasonable approximations of ground-water flowlines when the lengths of the flowlines are long compared to the aquifer thickness (Haitjema, 1995, p. 23). In the study area, most ground water was assumed to move through unconsolidated deposits that have a maximum saturated thickness of 200 ft or less. The lengths of flowlines from recharge areas to discharge areas are typically several thousand feet or more in length.

The GFLOW model for the study area covers an area extending approximately 4 to 7 mi around Little St. Germain Lake (fig. 3). The geometry of the single-layer model includes a bottom elevation set at 1,500 ft and an average aquifer thickness of 200 ft, which were based on well logs for the study area and additional information from Patterson (1989). Recharge was applied to the model area using an inhomogeneity element (an element with different aquifer properties from the rest of the study area). Surface-water features were simulated using several

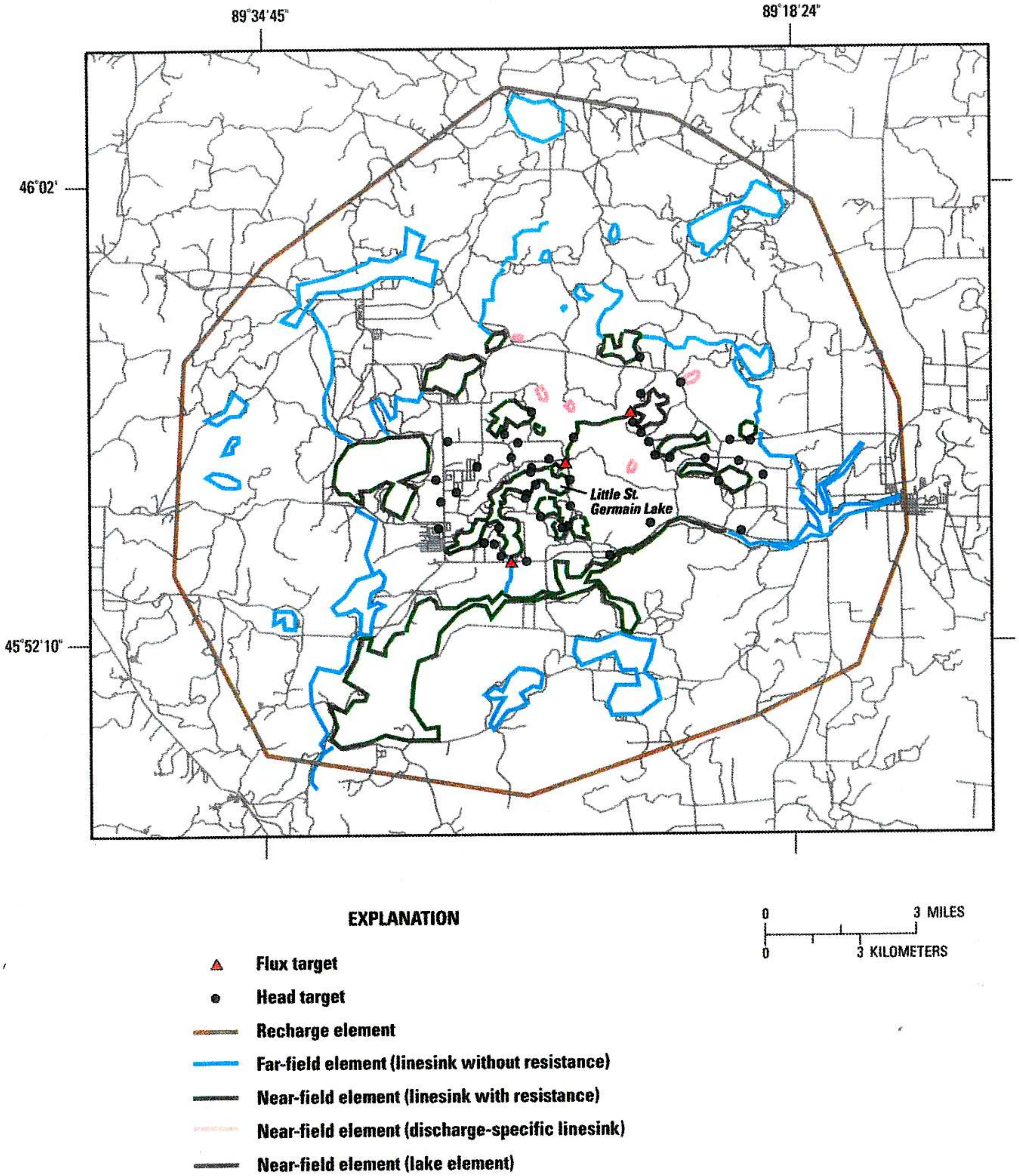

Figure 3. Hydrologic features simulated with GFLOW analytic elements near Little St. Germain Lake, Vilas County, Wis.

types of linesink elements. The model includes "far-field" and "near-field" sources and sinks of water (collectively referred to as linesinks; fig. 3). The far-field area surrounds the near-field area of interest. In the far field, streams are simulated as coarse linesinks having little or no resistance between the surface-water feature and the ground-water-flow system. The purpose of simulating the far field is to have the model explicitly define the regional ground-water-flow field near the area of interest. The near field represents the area of interest and includes Little St. Germain and Muskellunge Lakes and other adjacent lakes and streams (fig. 3). Base flows in near-field streams (Muskellunge Creek and Little St. Germain Creek near the lake outlet) were used to calibrate the model (flux calibration); flows in far-field streams were not. Near-field streams and lakes, in good connection with the ground-water-flow system, were included as linesinks with resistance.

A constant value for stage was used for Little St. Germain Lake even though there was an annual stage fluctuation of about 1.5 ft. Cyclic fluctuations of this magnitude should have minimal effect on regional ground-water flow, and the net gains and losses to the ground-water-flow system immediately adjacent to the lake should be approximated by steady-state conditions on an annual basis. Muskellunge Lake was simulated with a special type of linesink with resistance, called a lake element, by use of the methodology described by Hunt and others (2003). The lake element solves for lake stage on the basis of simulated surface-water inflows and estimated surface-water outflows from the lake.

In analytic-element modeling, resistance is computed by dividing the bed-sediment thickness by the vertical hydraulic conductivity. For this model, resistance was set equal to 0.3 day for near-field streams, and 1.0 day for near-field lakes. These values are similar to sediment-resistance values used in other nearby GFLOW models (Hunt and others, 1998; Graczyk and others, 2003). Assigned stream widths ranged from 10 to 40 ft. The leakage length for near-field lakes was set equal to 64 ft and calculated by use of methods described by Hunt and others (2003). Perched or mounded lakes (such as Pincherry and Honeysuckle Lakes) were included as discharge-specified linesinks. The value assigned to discharge-specified linesinks limits the amount of water that can be added to the ground-water-flow system from perched lakes. The amount of discharge assigned to this type of linesink (8.9 in/yr) was computed from the long-term precipitation for the area (Hunt and others, 1998) minus evaporation (estimated in the section entitled "Water and Phosphorus Loading to Little St. Germain Lake", page 19).

Lake-Water Quality and the Effects of Winter Aeration

Water quality in Little St. Germain Lake was consistently different among basins, except for a few water-quality characteristics (specific conductance and pH) that were similar throughout the lake but varied seasonally. Specific conductance ranged from about 75 μS/cm in summer to about 90 μS/cm in winter, and pH ranged from about 7 (in standard units) in winter to about 8 in summer.

Water Clarity

Water clarity, based on Secchi-depth readings, was highly variable and ranged from about 1.5 ft in the East and Upper East Bays to more than 15 ft in the West Bay. The West Bay consistently had the greatest water clarity, which ranged from 5 to 15 ft (average summer, June through August, clarity ranged from 8.6 to 13.1 ft). The South Bay had intermediate clarity that ranged from 1.6 to 14 ft (average summer clarity from 3.9 to 9.6 ft). The East and Upper East Bays consistently had the least water clarity, which ranged from 1.6 to 8 ft (average summer clarity from 2.8 to 5.5 ft) (fig. 4). In the West Bay, water clarity was usually greatest in late summer; however, in the East and South Bays, it was usually greatest in early summer. The summer average water clarities in East, Upper East, and South Bays were less in 2002 and 2003 than in any other year measured. Water clarity in these basins in summer 2004 was comparable to 2002 and 2003 water clarity (Ron Mackowski, Little St. Germain Lake District, written commun., 2004).

Distribution of Water Temperature and Dissolved Oxygen, and the Effects of Winter Aeration

The extent of thermal stratification differed among basins because of differences in the morphometries of the basins and limited circulation between basins. The West Bay, being relatively deep, consistently became strongly stratified during summer, with bottom temperatures remaining around 7–9 °C. The South Bay, being moderately deep, became stratified during summer; however, in some years, stratification was frequently broken down by wind mixing. Because of the frequent deep mixing, bottom temperatures in the South Bay usually increased as summer progressed. Most of the rest of the lake is relatively shallow, which resulted in stratification being very weak in

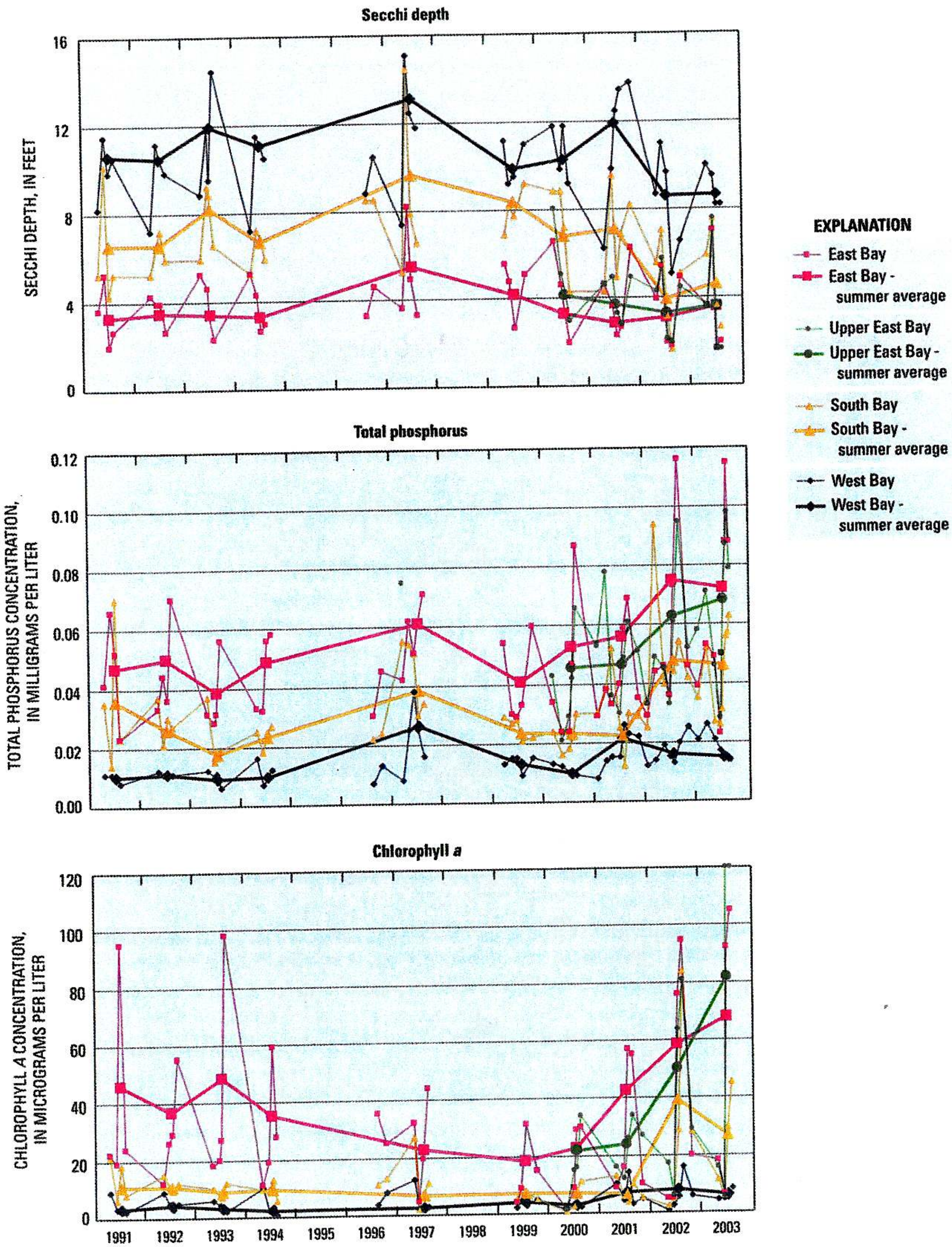

Figure 4. Measured Secchi depths, total phosphorus and chlorophyll *a* concentrations, and summer average (June through August) values for the various basins in Little St. Germain Lake, Vilas County, Wis., 1991–2003.

these areas, with seldom more than 2 or 3°C of stratification. During winter and without aeration, thermal stratification was weak but present throughout the entire water column in each of the basins. With aeration in the Upper East Bay and South Bay, little if any thermal stratification existed above the depth of the aerators; however, limited thermal stratification occurred below the depths of the aerators. The aerator in the East Bay, owing to its shallow depth, appeared to have little effect on the winter stratification in the center of the basin.

Thermal stratification during summer, which primarily occurred in the West and South Bays, 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 and other organic matter that settled from the surface and the biochemical oxygen demand of the sediment. Water below about 25–30 ft in the West Bay usually became anoxic in late June and stayed anoxic throughout summer. In the South Bay, the variable strength of thermal stratification resulted in anoxia in the deepest water during summers when stratification was extensive and low oxygen concentrations during summers when mixing was more frequent. Anoxia seldom occurred in the other bays during summer because of frequent mixing.

Before freezing, the entire water column of most lakes is nearly saturated with oxygen; however, after a lake freezes and snow cover increases as winter progresses, oxygen can be quickly consumed, especially in shallow, productive lakes. This was the case in Little St. Germain Lake, especially in the shallower basins when aeration was not used. 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 the ice cover and because the snow cover reduced light penetration and therefore limited oxygen-producing photosynthesis. To demonstrate the spatial extent of oxygen depletion, transects of 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 (fig. 5) and March 1999. Detailed transects were collected in March because this was near to when oxygen depletion was expected to be most severe. Anoxia occurred in each of the basins, and by mid-March only small areas of the lake were habitable by most warm-water fish (areas with dissolved oxygen concentrations greater than about 2 mg/L, Barton and Taylor, 1996). These habitable areas include water down to depths of about 30 ft in the West Bay and down to about 5 ft in the East Bay. Without aeration, in most years, oxygen was almost completely consumed by mid-February in the Upper East, No Fish, South, and Second South Bays.

Water entering from Muskellunge Creek apparently may help alleviate the extent of late-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 when parts of Muskellunge Creek are free of ice (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. This increase appears to be associated with cold, highly oxygenated water originating from Muskellunge Creek propagating across the basin (fig. 5). 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 ft of water (just below the ice) throughout the East Bay could be replaced by water from Muskellunge Creek in about 30 days.

Aerators were operated in the East and Upper East Bays in the winters of 2002, 2003, and 2004, and operated in the South Bay in 2003 and 2004 to eliminate winter anoxia and the associated fish kills and odor problems near the outlet. Winter fish kills (referred to as "winterkills") usually result when dissolved oxygen concentrations throughout the lake drop below a critical concentration (usually considered below 2 mg/L; Wetzel, 1983). The success of the aerators at eliminating winter anoxia and the potential for fish kills can be evaluated by comparing oxygen profiles collected at the center of the basins (fig. 6) and oxygen transects collected across the basins (figs. 7 and 8) in late winter (March) in years with and without aeration. Each of the three years which the aerators were operated had distinct characteristics: 2002 had ice cover form later than normal, 2003 had very little snowfall, and 2004 had a more typical freeze date and relatively heavy snowfall. In 2002, the late ice formation should have resulted in delayed dissolved oxygen depletion. In 2003, there was very little snowfall, which resulted in thick clear ice that enabled light to penetrate into the water throughout most of the winter. This should have resulted in oxygen being depleted at a much slower rate than what typically occurs in Little St. Germain Lake because of oxygen production associated with algal and macrophyte productivity. Therefore, it is difficult to evaluate the effectiveness of the aerators at eliminating winter anoxia in 2003. The earlier freeze date and more snowfall in 2004 should have resulted in the most severe oxygen depletion and the best

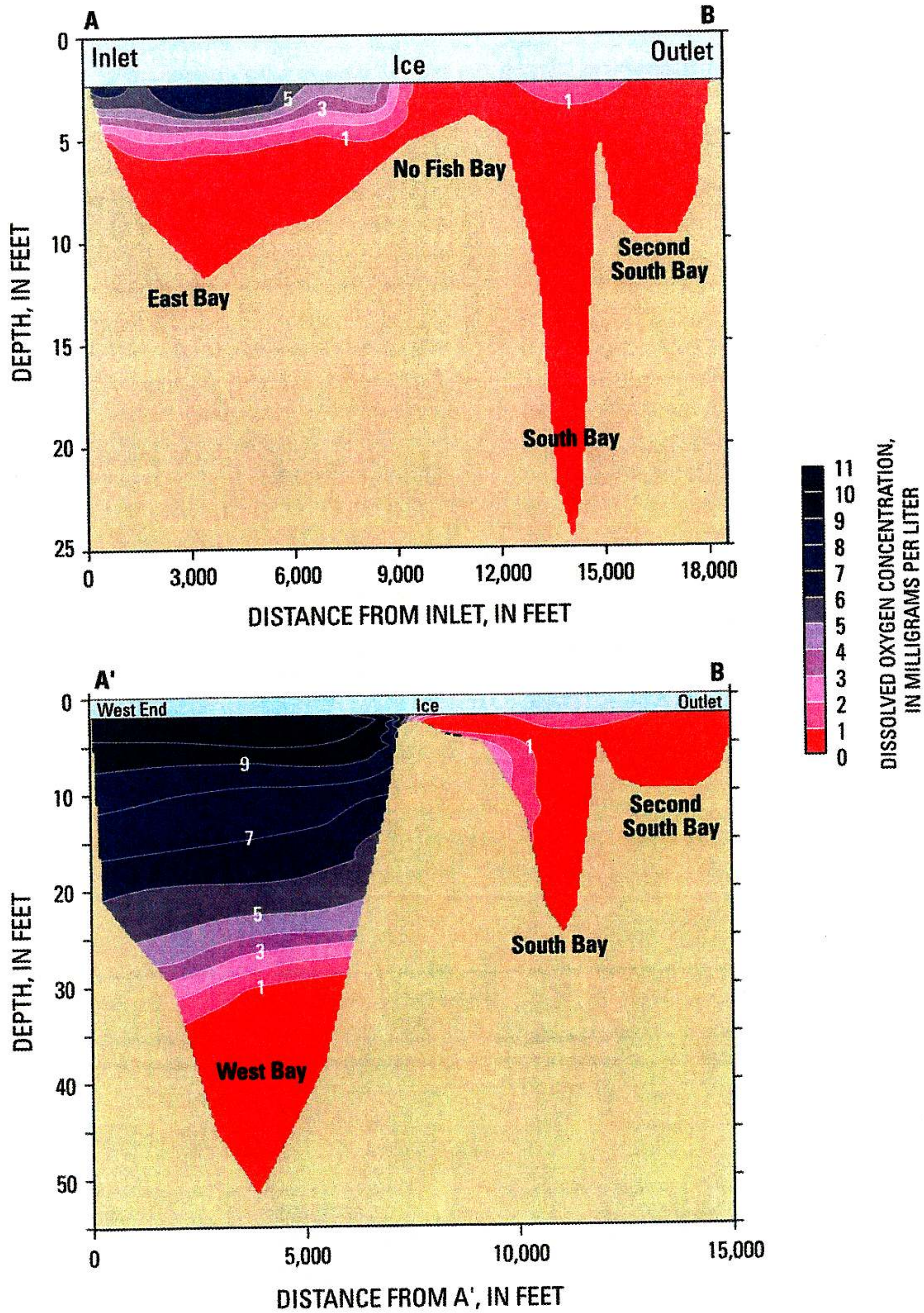

Figure 5. Distribution of dissolved oxygen in Little St. Germain Lake, Vilas County, Wis., March 18, 1997, without aeration.

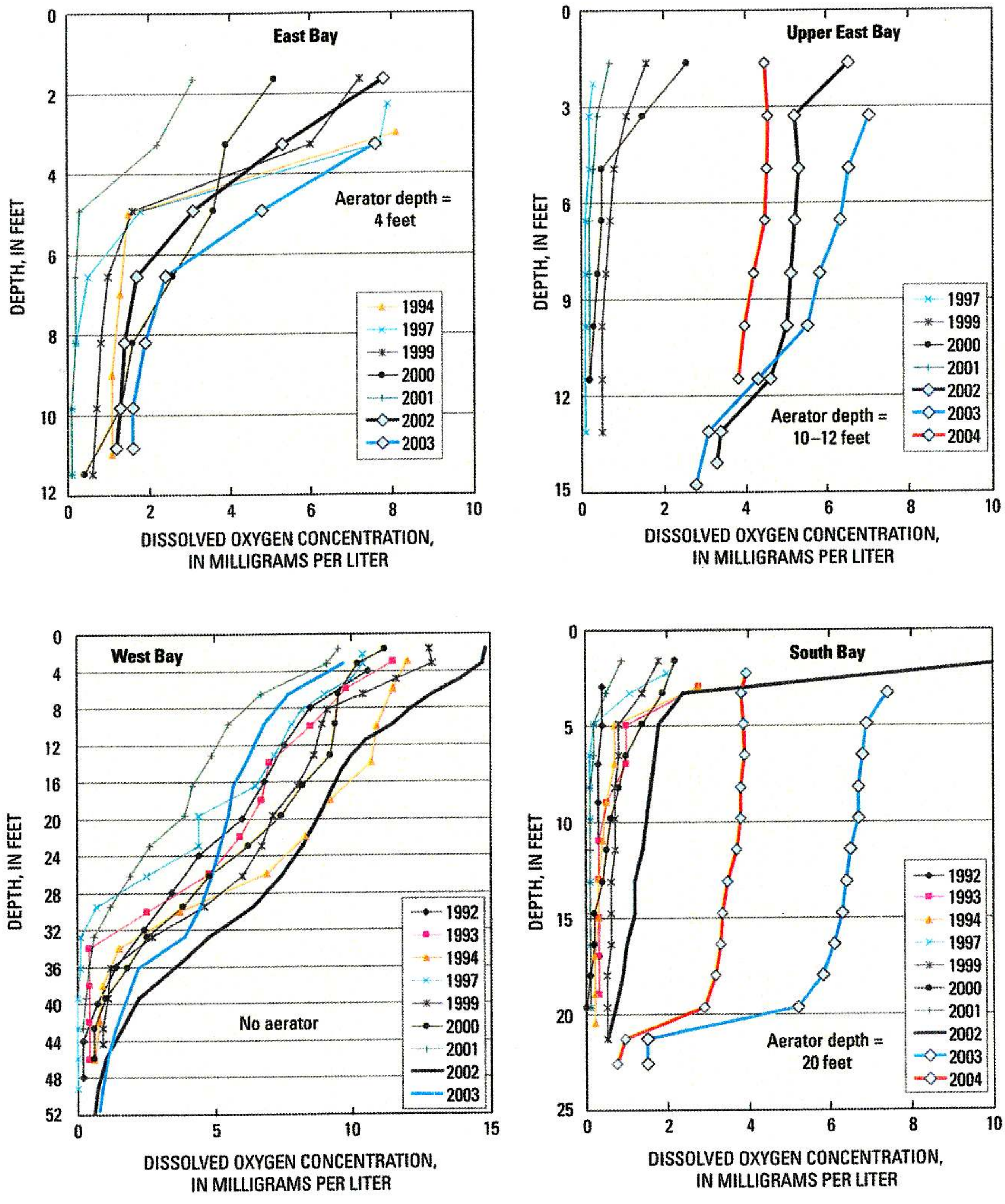

Figure 6. Late winter vertical distribution of dissolved oxygen (February, 1992–94 and March, 1997–2004) in Little St. Germain Lake, Vilas County, Wis., 1992–2004. Years in which aeration was used are identified by diamond symbols.

evaluation of the aerators during harsh winter conditions. More winterkills in nearby lakes were reported in 2004 than in most other years.

The aerator in the East Bay appeared to have minimal effect on the dissolved oxygen concentrations throughout the basin. The dissolved oxygen profile collected in 2002 at the center of the basin was very similar to those measured in 1994 and 2000 when aerators were not operated (fig. 6). The slightly higher dissolved oxygen concentrations in 2003 than in other years may have resulted from the very little snowfall that year. The ineffectiveness of the aerators may have been caused by being placed in water that was too shallow (approximately 4 ft) and (or) the aerator releasing too little air given the size of the East Bay.

The aerator in the Upper East Bay was very successful at eliminating winter anoxia and possible winterkills. In all three years of operation, dissolved oxygen concentrations remained above 3.5 mg/L throughout almost the entire water column, except below the depth of the aerators (fig. 6). Relatively high dissolved oxygen concentrations were found throughout the basin (fig. 7). Even during 2004, dissolved oxygen concentrations were above 4 mg/L throughout most of the water column. These concentrations were below the Wisconsin state standard of 5 mg/L for dissolved oxygen in warm-water lakes (Shaw and others, 1993) but were above the 2-mg/L critical concentration for most fish.

The aerator in the South Bay was very successful at eliminating winter anoxia and possible winterkills in the South and Second South Bays. In both years of operation, dissolved oxygen concentrations remained above 3 mg/L throughout almost the entire water column in the South Bay, except below the depth of the aerators where concentrations diminished sharply (fig. 6). Relatively high dissolved oxygen concentrations were found throughout most of the basin, but concentrations did diminish near the sediment surface (fig. 8). Even during the harsh winter of 2004, dissolved oxygen concentrations were above 3 mg/L throughout most of the water column. The movement of water with low dissolved oxygen concentrations from No Fish Bay to the South Bay resulted in lower dissolved oxygen concentrations on the northwest side of the South Bay, especially near the bottom (fig. 8).

The positive effects of the aerator in the South Bay were propagated downstream into the Second South Bay. The movement of water with relatively high dissolved oxygen concentrations from the South Bay into the Second South Bay increased dissolved oxygen concentrations in the water above the depth of the sill separating the two basins (fig. 8). The cooler, less dense water from the South Bay flowed over the warmer and more dense water below the sill depth in the Second South Bay. This resulted in a zone of oxygenated water (greater than 2 mg/L) just below the ice in the Second South Bay.

Nutrient Concentrations

Phosphorus and nitrogen are essential nutrients for plant growth and are the nutrients that usually limit algal growth in Midwestern lakes. High nutrient concentrations can cause high algal populations (blooms) and can therefore be the cause of accelerated eutrophication (that is, accelerated aging and increased productivity) of lakes. The ratio of near-surface concentrations of total nitrogen to total phosphorus is often used to indicate which of these nutrients should potentially limit algal productivity in a lake. The specific value of this ratio that determines which nutrient is potentially limiting varies under different conditions such as water temperature, light intensity, and nutrient deficiencies (Corell, 1998); however, a ratio greater than about 12:1, by weight, usually indicates that phosphorus is the potentially limiting nutrient. Total nitrogen was measured only during spring overturn in the South and West Bays and once at the four main sampling sites in 2002; therefore, the nitrogen to phosphorus ratio could only be quantified at a few times. In July 2002, the nitrogen-to-phosphorus ratio ranged from about 10:1 in the East and Upper East Bays, to about 17:1 in the South Bay, to about 50:1 in the West Bay. These ratios are similar to those measured in the South and West Bays at spring overturn in 2002 and other years. Therefore, phosphorus should usually be the nutrient limiting algal growth in most of the lake (possibly co-limiting in the East and Upper East Bays) and the nutrient to focus on when considering management efforts to improve water quality.

Phosphorus concentrations at the surface ranged from 0.006 mg/L (West Bay) to 0.116 mg/L (East Bay) (fig. 4). The West Bay consistently had the lowest concentrations, which ranged from 0.006 to 0.038 mg/L (average summer concentrations from 0.009 to 0.026 mg/L; fig. 4). The South Bay had intermediate concentrations, which ranged from 0.012 to 0.094 mg/L (average summer concentrations from 0.018 to 0.048 mg/L). The East and Upper East Bays consistently had the highest concentrations, which ranged from 0.023 to 0.116 mg/L (average summer concentrations from 0.038 to 0.075 mg/L). Phosphorus concentrations were usually highest in late summer in the East and Upper East Bays; however, no consistent seasonal patterns were evident in the South and West Bays. The highest phosphorus concentrations were measured in 2002 and 2003 in all locations but the West Bay.

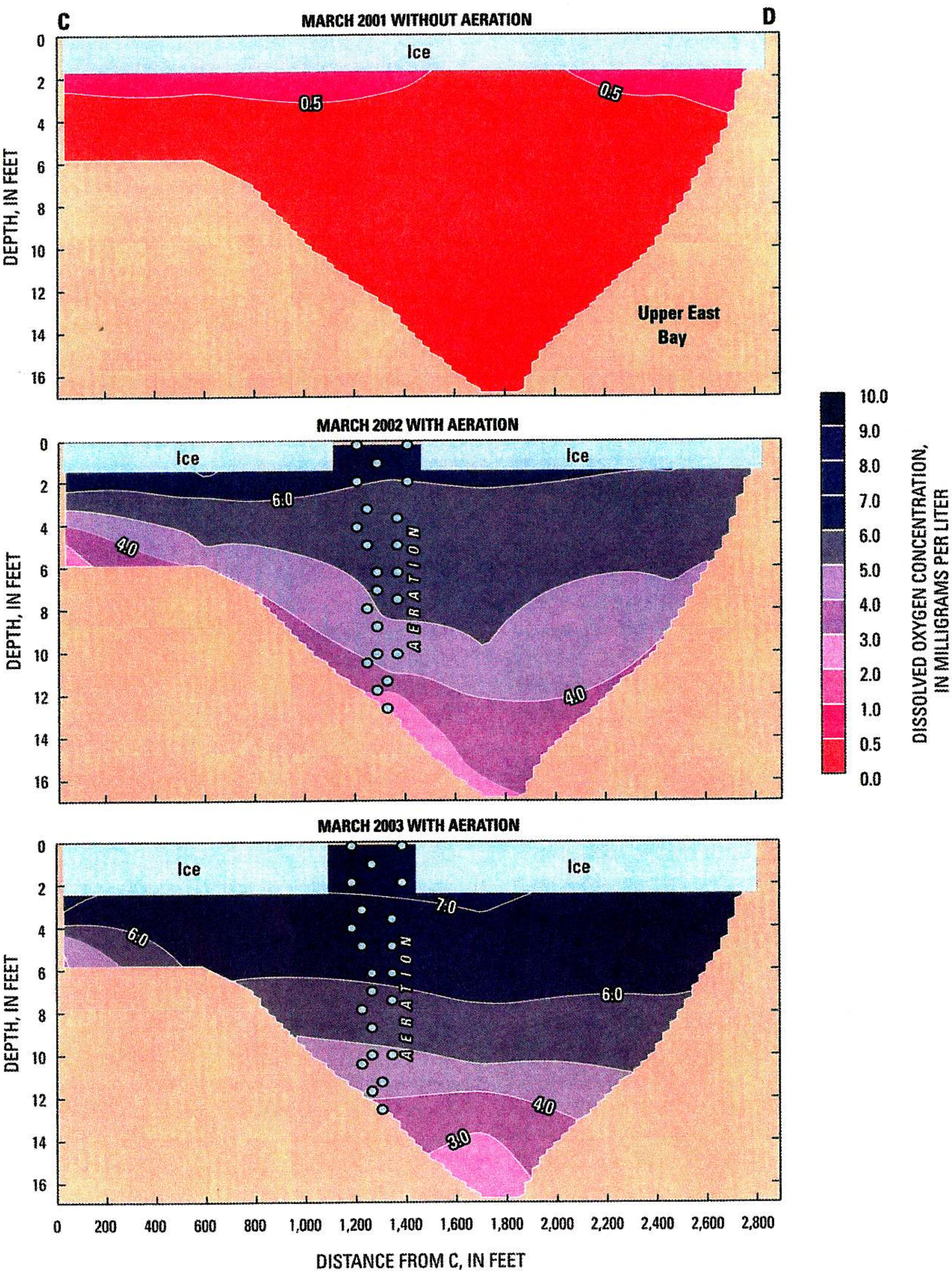

Figure 7. Distribution of dissolved oxygen in the Upper East Bay of Little St. Germain Lake, Vilas County, Wis., with and without aeration.

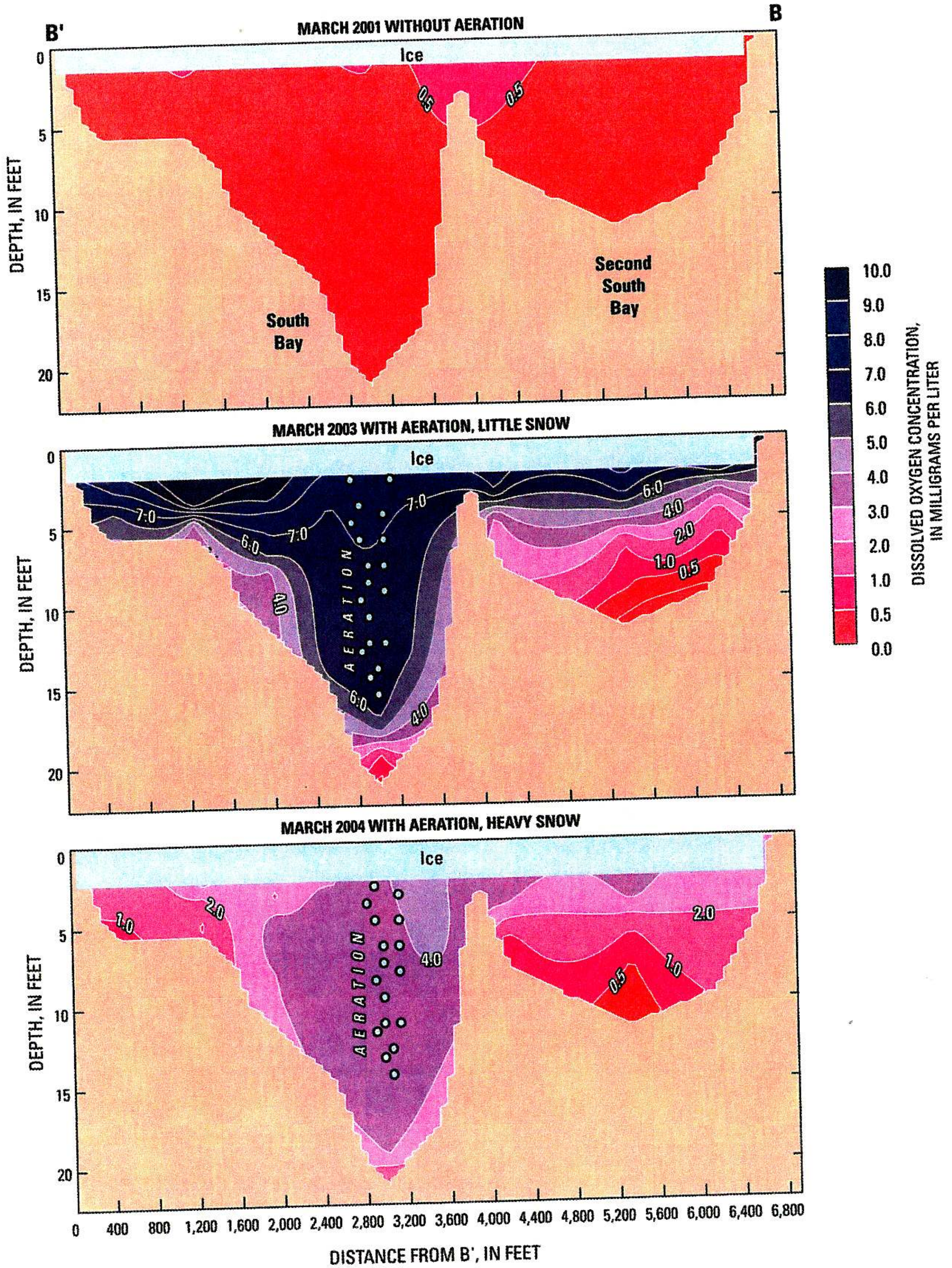

Figure 8. Distribution of dissolved oxygen in South and Second South Bays of Little St. Germain Lake, Vilas County, Wis., with and without aeration.

Phosphorus can be released from lake sediments, especially during periods of anoxia. Increased phosphorus concentrations just above the sediments primarily were observed in the West Bay during late summer, when the deep water was anoxic. Phosphorus concentrations typically reached 0.2–0.3 mg/L just above the bottom in late summer in the West Bay. Because of the variable strength of stratification in the South Bay and variable lengths of time with anoxia near the bottom, the buildup of phosphorus in the deep water was variable. In 2003, phosphorus concentrations were greater than 0.6 mg/L in August; however, in most years, phosphorus concentrations were similar to those measured near the surface because of mixing. Anoxia was seldom measured in the other bays during summer because of frequent and extensive mixing events, and therefore near-bottom phosphorus concentrations were very similar to those measured at the surface. Although anoxia was common under the ice, near-bottom phosphorus concentrations were not as great as during summer anoxia. Near-bottom concentrations of about 0.2 mg/L were measured in each of the basins, but only in the absence of aeration.

Chlorophyll *a* Concentrations

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. In the northern part of Wisconsin, concentrations greater than 15 μg/L are usually considered to be high and are usually associated with algal blooms. Chlorophyll *a* concentrations ranged from less than 1 μg/L (West Bay) to greater than 100 μg/L (East and Upper East Bays) (fig. 4). Differences in chlorophyll *a* concentrations among basins directly coincided with the differences in the phosphorus concentrations among basins. Concentrations were commonly greater than 15 μg/L in the East and Upper East Bays and occasionally greater than 15 μg/L in the South Bay, but only once was a concentration greater than 15 μg/L observed in the West Bay. Average summer concentrations were highest in the East and Upper East Bays (from 18 to 82 μg/L), moderate in the South Bay (from 6 to 39 μg/L), and lowest in the West Bay (from 2 to 8 μg/L) (fig. 4). Chlorophyll *a* concentrations increased dramatically in all of the basins in 2002 and 2003, but especially in the South Bay.

Trophic State Indices

One method of classifying the water quality or productivity of lakes is by computing Trophic State Indices (TSIs). These indices, based on near-surface concentrations of total phosphorus and chlorophyll *a* and on Secchi depths (Carlson, 1977), place these three characteristics on similar scales. Oligotrophic lakes (TSIs 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 (TSIs 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 (TSIs 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 TSIs 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 and Upper East Bays were eutrophic and often hypereutrophic, especially during 2002 and 2003 (fig. 9). For these basins, the average summer TSIs based on surface phosphorus ranged from 56 to 64, based on surface chlorophyll *a* ranged from 58 to 67, and based on Secchi depth ranged from 53 to 63. All three indices indicated that the South Bay was mesotrophic to eutrophic from 1991 to 2001 and eutrophic to hypereutrophic in 2002 and 2003 (average summer TSIs based on surface phosphorus, 45 to 60; based on surface chlorophyll *a*, 47 to 61; and based on Secchi depth, 45 to 60). All three indices indicated that the West Bay was usually oligotrophic prior to 2001 and mesotrophic from 2001 to 2003 (the average summer TSIs based on surface phosphorus, 35 to 50; based on surface chlorophyll *a*, 36 to 48; and based on Secchi depth, 40 to 47). Based on the indices, all of the basins were more eutrophic in 2002 and 2003 than in any of the other years monitored.

Streamflow and Stream-Water Quality

Streamflows for the three sites on Muskellunge Creek and the outlet from Little St. Germain Lake are shown in figure 10. Flow increases in Muskellunge Creek from the Muskellunge Lake outlet, to the snowmobile crossing, to

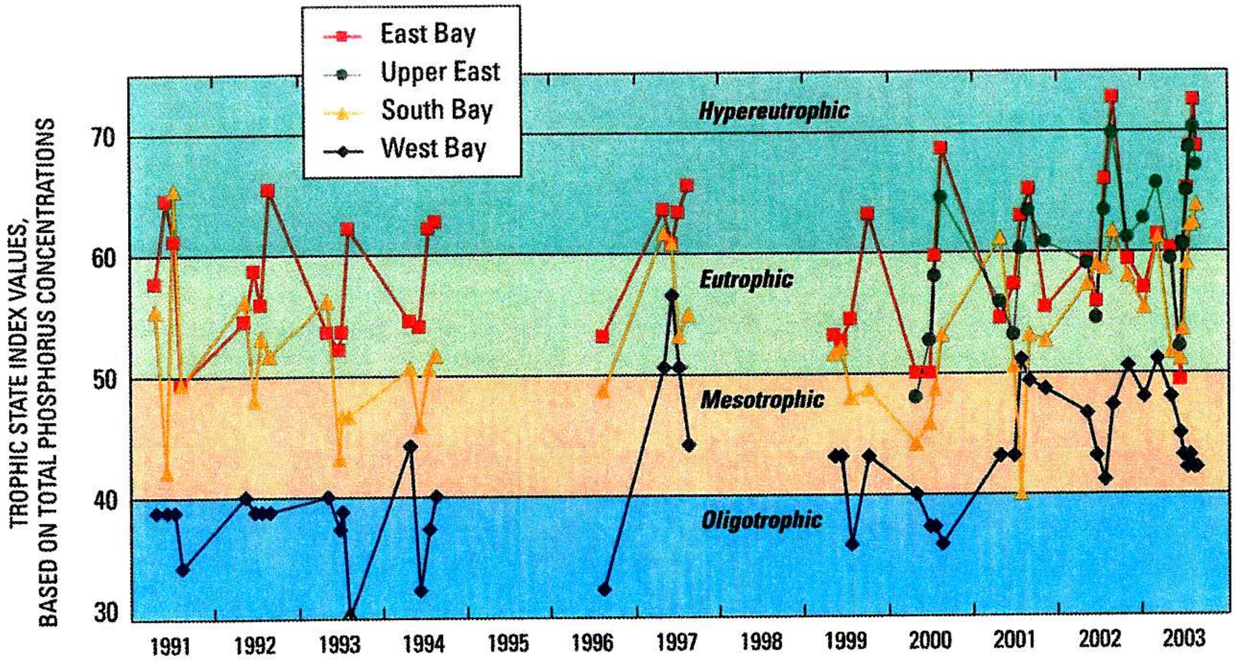

Figure 9. Trophic state indices based on total phosphorus concentrations for the various basins in Little St. Germain Lake, Vilas County, Wis., 1991–2003.

Birchwood Drive. During 2001, the only year with true daily data from March through October, average streamflow increased from 3.1 ft^3/s at the Muskellunge Lake outlet to 7.0 ft^3/s at Birchwood Drive. There was little daily variability in Muskellunge Creek during 2001, which indicated that the interpolation between monthly measurements should be a relatively accurate means of computing daily flows for the other years for which daily data were not available. The average annual flow at Birchwood Drive in 2001 computed using the daily flows interpolated between the approximately monthly calibration data was 7.2 ft^3/s compared to 7.0 ft^3/s computed using daily measurements. Measurements throughout 1999 to 2003 indicate similar differences among sites. During 2001, the flow at the Little St. Germain Lake outlet was 9.7 ft^3/s. Average annual flows into the lake (at Birchwood Drive) and out of the lake were highest in 1997 and were relatively similar in all other years. Flows were highest in Muskellunge Creek during spring; however, flow out of the lake was highest during the fall and early winter drawdown of the lake.

Phosphorus concentrations in Muskellunge Creek consistently increased from the Muskellunge Lake outlet to Birchwood Drive (figs. 10 and 11). Concentrations at all of the sites were highest during summer and lowest during winter. Phosphorus concentrations at the Muskellunge Lake outlet ranged from about 0.009 mg/L in the winter to about 0.06 mg/L in summer. Phosphorus concentrations at Birchwood Drive ranged from 0.016 mg/L in winter of 2000 to 0.14 mg/L during summer 1997. Phosphorus concentrations at the snowmobile crossing were between those of these two sites, but generally were more similar to those at the Muskellunge Lake outlet. Phosphorus concentrations at Birchwood Drive were much higher in 1997 than during any other time, especially in midsummer to late summer. The high concentrations in 1997 may have been due to effects of beaver activity on Muskellunge Creek. Ponding of water behind beaver dams may have resulted in a high release of phosphorus from the organic-rich wetland sediments that are not otherwise inundated with water.

Concentrations at the Little St. Germain Lake outlet usually were lower than those entering the lake and ranged from 0.013 to 0.081 mg/L. The highest concentrations were measured in 2002 and 2003, coinciding with the high concentrations in the South Bay. The average total phosphorus concentration for 1999 to 2003 (fig. 11) increased from 0.036 mg/L at the Muskellunge Lake outlet, to 0.045 mg/L at the snowmobile crossing, to 0.053 mg/L at Birchwood Drive. Phosphorus concentrations in Muskellunge Creek are high considering that most of the watershed of Little St. Germain Lake is relatively pristine (fig. 1). The

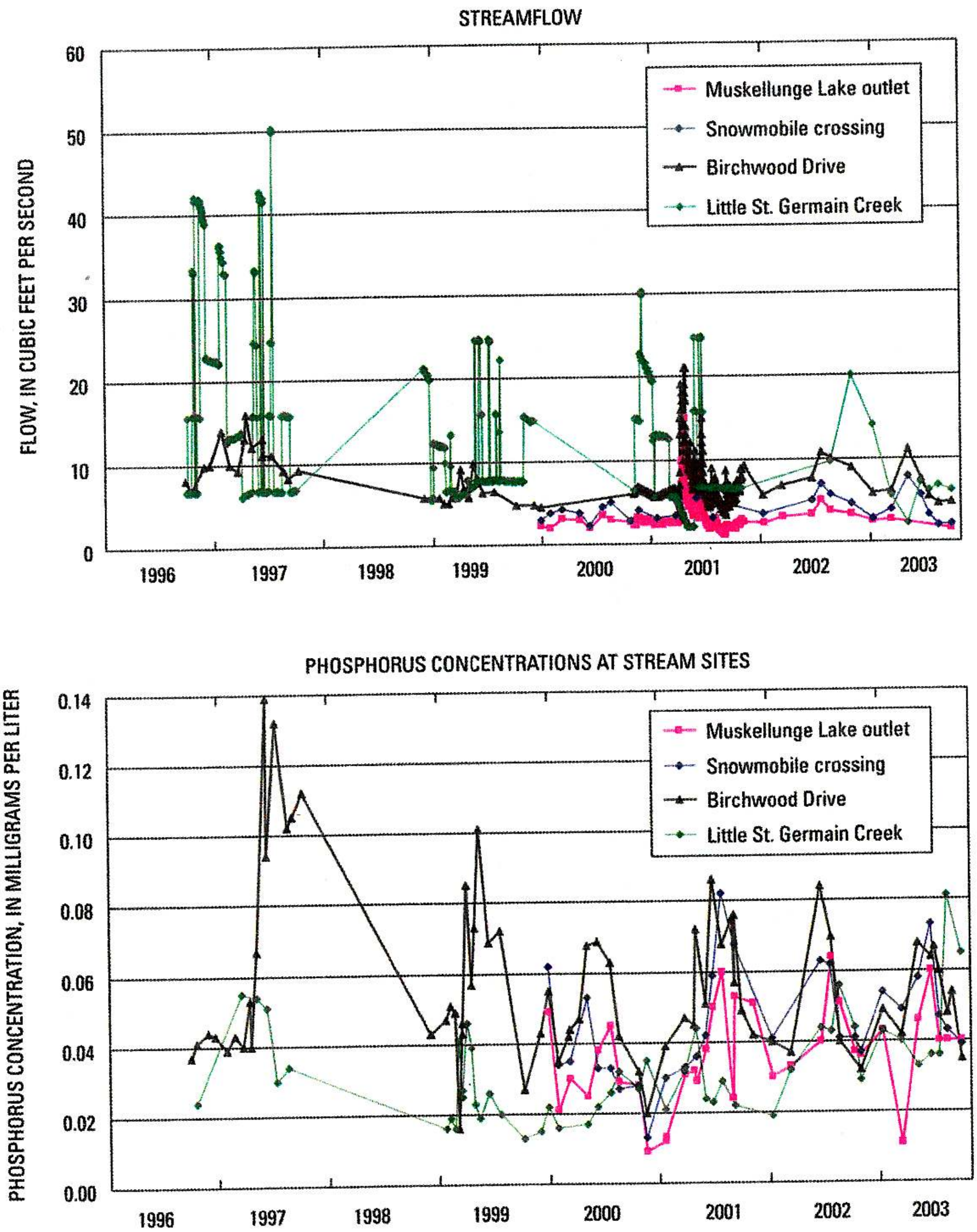

Figure 10. Flow and total phosphorus concentrations in Muskellunge Creek and Little St. Germain Creek, Vilas County, Wis., 1996–2003.

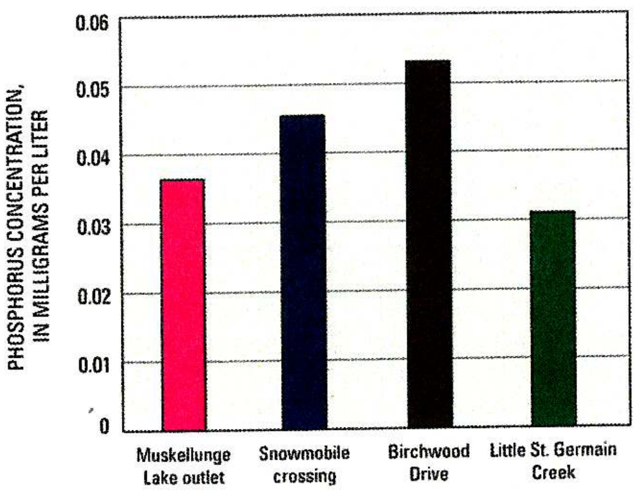

Figure 11. Average total phosphorus concentrations in Muskellunge Creek and Little St. Germain Creek, Vilas County, Wis., 1999–2003.

high concentrations may be the result of leaching from the soils that are thought to be rich in phosphorus in this area (Wisconsin Department of Natural Resources, 1985). The average total phosphorus concentration of the water leaving the lake during this period was 0.031 mg/L.

From 1999 through 2003, the dissolved phosphorus concentrations in Muskellunge Creek ranged from 0.013 to 0.045 mg/L, representing about 55 percent of the phosphorus in the creek. The average dissolved phosphorus concentration at Birchwood Drive was 0.027 mg/L. The average dissolved phosphorus concentration at this site during May through August was 0.033 mg/L, representing about 53 percent of the phosphorus.

Water and Phosphorus Loading to Little St. Germain Lake

Because the productivity in Little St. Germain Lake should potentially be limited by the input of phosphorus (based on nitrogen-to-phosphorus ratios), reduction in phosphorus input to the lake would be a logical management goal. Most phosphorus that enters lakes is associated with the input of water. Therefore, to determine where the water and phosphorus originates and how changes in phosphorus loading should affect the trophic status of the lake, the water and phosphorus budgets of the lake were quantified. Water and phosphorus budgets were computed on a monthly basis for three different annual periods: the period from October 1, 1996, to September 30, 1997 (referred to as monitoring year 1997; MY1997); the period from December 1, 1998, to November 30, 1999 (referred to as MY1999); and the period from November 1, 2000, to October 31, 2001 (referred to as MY2001). Water and phosphorus budgets were constructed as part of the earlier study on the lake (Robertson and Rose, 2000). That study indicated that phosphorus from Muskellunge Creek was the dominant source of phosphorus; however, ground-water contributions also were important and needed to be better quantified. Therefore, the water and phosphorus budgets for 2001 were computed with greater detail, especially regarding the inputs from ground water. This information was used to refine the budgets of the earlier study.

Water Loading

The hydrology of Little St. Germain Lake can be described in terms of components of its water budget (fig. 12). The water budget for the lake may be represented by the equation

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

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 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}).

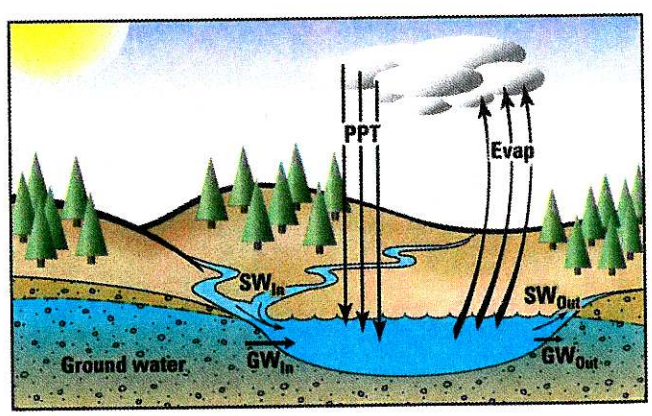

Figure 12. Schematic of the components of the water budget for Little St. Germain Lake, Vilas County, Wis. (abbreviations are described in text).

Changes in Storage

Changes in lake volume were determined from water elevations monitored at the outlet dam near Highway 70 (fig. 1) and the morphometry of the lake, assuming a constant surface area of the lake. Lake stage fluctuated from a minimum elevation of 1,611.9 ft to a maximum of 1,614.0 ft (fig. 13). Typically, the lake stage was relatively stable from May through mid-November, lowered about 1.5 ft 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 MY1997 was similar to that at the beginning of the period; therefore, the change in storage was only 59 acre-ft (table 2). The lake stage at the end of MY1999 was about 0.6 ft higher than at the beginning of that year and resulted in a change in storage of 529 acre-ft. The lake stage at the end of MY2001 period was about 0.3 ft higher than at the beginning of that year and resulted in a change in storage of 326 acre-ft.

Precipitation and Evaporation

Precipitation was measured by a weather observer near St. Germain, Wis. (fig. 13). During these three periods, precipitation (in inches) ranged from 33.2 in MY2001, to 34.8 in MY1997, to 37.3 in MY1999 (table 2). Evaporation from the lake was estimated from average monthly evaporation-pan data from 7 years of data collected at the Rainbow Flowage, which is about 15 mi west of Little St. Germain Lake. Monthly lake/pan coefficients computed as part of a study on Vandercook Lake, Vilas County (Wentz and Rose, 1991), were then used to adjust the pan evaporation rates to obtain total lake evaporation. These coefficients ranged from 0.75 in May to 1.17 in October. No evaporation was assumed to occur when the lake was ice covered. About 22 in. of water (1,825 acre-ft) was estimated to have evaporated from the lake during each period (table 2), most of this during summer. It was assumed that the monthly evaporation was the same each year.

Surface-Water Inflow

Surface-water inflow to the lake was measured at Birchwood Drive on Muskellunge Creek (fig. 13). It was assumed that there was no surface-water inflow to the lake downstream from Birchwood Drive. Any surface-water inflow downstream from this point was incorporated into ground-water inflow. Daily average flows at Birchwood Drive were computed by linearly interpolating between monthly measurements in MY1997 and MY1999. In MY2001, daily average flows were computed by linearly interpolating between monthly measurements from November through February and from the 15-minute flow data for March through October. Average annual inflow ranged from 10.6 ft^3/s (7,722 acre-ft) in MY1997, to 7.0 ft^3/s (5,084 acre-ft) in MY2001, to 6.0 ft^3/s (4,383 acre-ft) in MY1999. Inflow to the lake in MY1997 was about 1.8 times that in MY1999 even though there was less precipitation in MY1997. This demonstrates that the flow in Muskellunge Creek is driven by long-term changes in precipitation and ground-water inflow rather than short-term fluctuations.

Surface-Water Outflow

The average flow out of the lake was 17.3 ft^3/s (12,552 acre-ft) in MY1997, 10.3 ft^3/s (7,445 acre-ft) in MY1999, and 9.7 ft^3/s (7,034 acre-ft) in MY2001 (table 2). Outflow from the lake in MY1997 also was higher than in MY1999 even though there was less precipitation in MY1997, which again demonstrates that long-term changes in precipitation and ground-water inflow are important to the hydrology of Little St. Germain Lake. In all three years, outflow from the lake was about 1.4 to 1.7 times greater than the input from Muskellunge Creek.

Ground-Water Inputs and Outputs

After converting all of the hydrologic components in the water budget equation (eq. 1) into acre-ft and solving for net ground-water input ($GW_{In} - GW_{Out}$), it was estimated that there was a net ground-water input to Little St. Germain Lake of about 3,900 acre-ft (5.3 ft^3/s) in MY1997, 2,400 acre-ft (3.3 ft^3/s) in MY1999, and 1,400 acre-ft (1.9 ft^3/s) in MY2001 (table 2). In order to better define the contributions from ground water (locations and input and output amounts) a ground-water-flow model was developed for the Little St. Germain Lake watershed based on the flow conditions in MY2001.

Ground-water gradients from the 15 piezometers installed around the lake (fig. 2), water levels in wells and lakes in the area, flows at the Muskellunge Lake outlet, Birchwood Drive, and the Little St. Germain Lake outlet were used to calibrate the ground-water-flow model, GFLOW (Haitjema, 1995). The model was then used to define ground-water-source areas around Little St. Germain Lake (and Muskellunge Lake) and to allocate ground-water discharge to the shoreline segments represented by the piezometers.

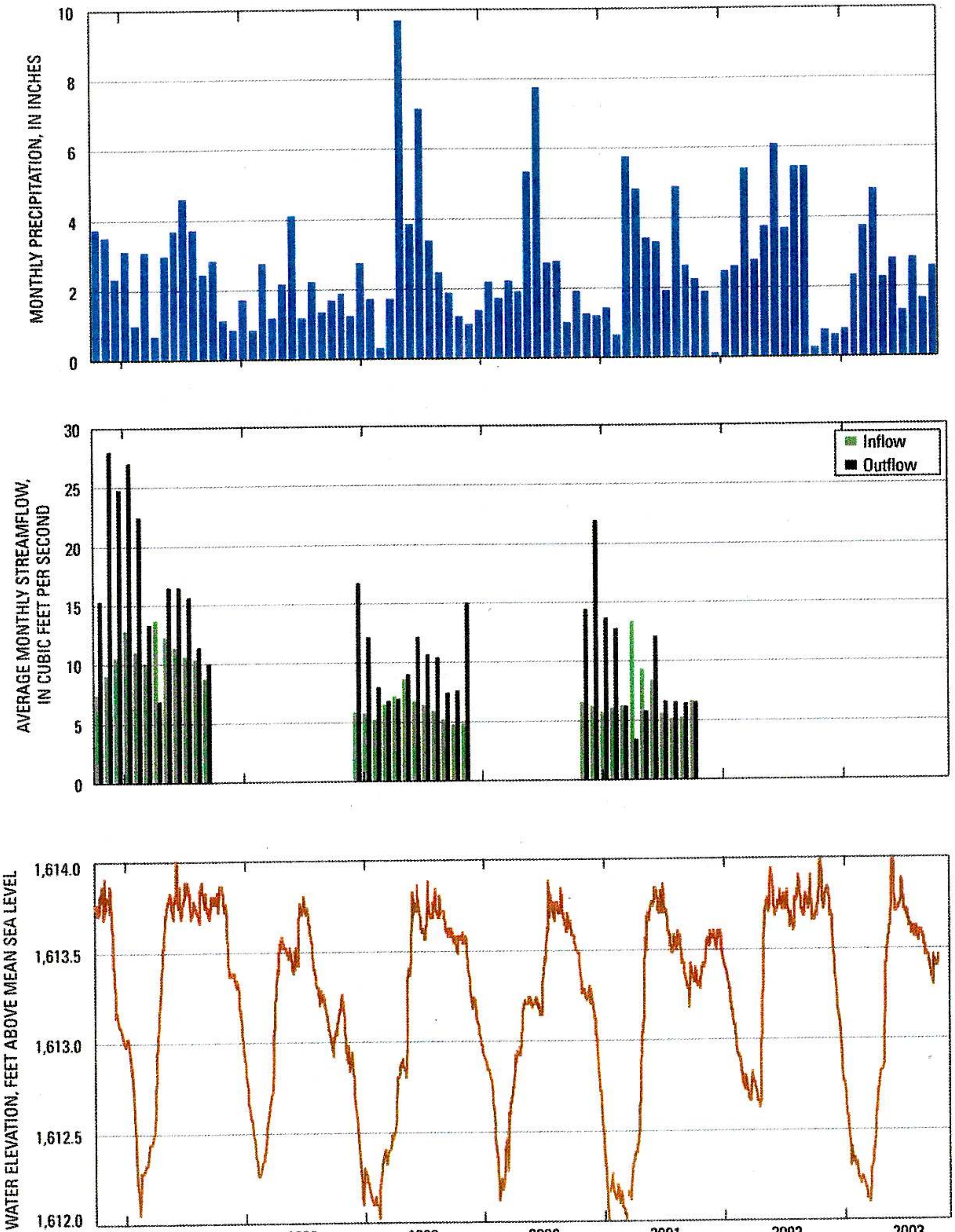

Figure 13. Monthly precipitation, inflow, outflow, and daily average water elevations for Little St. Germain Lake, Vilas County, Wis.

Table 2. Monthly water budget for Little St. Germain Lake, for October 1, 1996, to September 30, 1997; December 1, 1998, to November 30, 1999; and November 1, 2000, to October 31, 2001.

[ft^3/s, cubic feet per second. Numbers may not add exactly to totals due to rounding. Totals for rates in ft^3/s are means.]

Month	Precipitation		Evaporation		Muskellunge Creek input		Change in storage	Net ground-water input		Ground-water input	Ground-water output	Outlet	
	inches	acre-feet	inches	acre-feet	ft^3/s	acre-feet	acre-feet	ft^3/s	acre-feet	acre-feet	acre-feet	ft^3/s	acre-feet
October 1, 1996, to September 30, 1997 (MY1997)													
Oct.	3.7	305	1.9	153	7.4	456	39	6.1	375	425	49	15.3	944
Nov.	3.5	287	0.4	33	9.0	539	-431	7.5	443	502	58	28.0	1,668
Dec.	2.3	189	0.0	0	10.5	647	-343	5.7	348	393	46	24.8	1,527
Jan.	3.1	255	0.0	0	12.8	789	-500	2.0	123	139	16	27.0	1,666
Feb.	1.0	79	0.0	0	11.0	613	-176	6.9	382	433	50	22.5	1,250
Mar.	3.1	252	0.0	0	10.0	614	305	4.2	260	294	34	13.3	821
Apr.	0.7	56	1.0	83	13.7	816	949	9.6	570	645	75	6.9	410
May	3.0	243	3.8	310	12.3	756	196	8.5	521	589	68	16.5	1,015
June	3.7	300	4.3	350	11.4	679	20	6.3	372	421	49	16.5	982
July	4.6	376	4.4	361	10.6	654	-39	4.2	256	290	34	15.7	965
Aug.	3.7	302	3.7	305	10.4	640	59	2.0	126	142	17	11.4	704
Sept.	2.4	199	2.8	230	8.7	519	-20	1.6	92	104	12	10.1	600
Total	**34.8**	**2,844**	**22.4**	**1,825**	**10.6**	**7,722**	**59**	**5.3**	**3,869**	**4,377**	**508**	**17.3**	**12,552**
December 1, 1998, to November 30, 1999 (MY1999)													
Dec.	1.2	100	0.0	0	5.8	358	-372	3.3	203	230	27	16.8	1,033
Jan.	2.7	224	0.0	0	5.7	352	-176	-0.4	-27	0	27	11.8	725
Feb.	1.7	140	0.0	0	4.6	285	284	6.3	348	394	46	7.9	489
Mar.	0.3	26	0.0	0	6.5	400	127	1.9	118	134	16	6.8	418
Apr.	1.7	139	1.0	83	6.9	426	313	3.7	219	248	29	6.3	388
May	9.7	790	3.8	310	8.5	526	862	6.7	413	467	54	9.3	573
June	3.8	314	4.3	350	6.5	401	-157	3.4	205	232	27	11.5	711
July	7.2	585	4.4	361	6.4	393	274	5.2	319	361	42	10.7	661
Aug.	3.4	274	3.7	305	5.9	361	-196	1.6	98	111	13	8.9	547
Sept.	2.5	202	2.8	230	5.0	307	-78	1.7	101	115	13	8.7	536
Oct.	1.9	153	1.9	153	4.7	290	20	3.3	201	227	26	7.7	472
Nov.	1.2	98	0.4	33	4.6	285	-372	2.9	172	194	23	14.5	893
Total	**37.3**	**3,045**	**22.4**	**1,825**	**6.0**	**4,383**	**529**	**3.3**	**2,371**	**2,712**	**341**	**10.3**	**7,445**
November 1, 2000, to October 31, 2001 (MY2001)													
Nov.	1.9	155	0.4	33	6.3	389	-202	2.5	148	167	19	14.0	861
Dec.	1.3	104	0.0	0	6.2	382	-846	0.3	21	24	3	22.0	1,353
Jan.	1.2	100	0.0	0	5.7	352	49	7.2	441	499	58	13.7	843
Feb.	1.4	117	0.0	0	5.5	337	-215	0.7	40	45	5	11.5	709
Mar.	0.6	53	0.0	0	6.2	381	411	5.8	358	405	47	6.2	381
Apr.	5.7	469	1.0	83	12.9	795	1,136	2.6	157	178	21	3.3	202
May	4.8	394	3.8	310	9.2	570	215	-1.3	-79	0	79	5.8	359
June	3.4	281	4.3	350	8.1	499	-78	3.6	215	243	28	11.7	722
July	3.3	270	4.4	361	5.6	343	-176	-0.3	-19	0	19	6.6	409
Aug.	1.9	156	3.7	305	5.2	318	-215	0.3	21	24	3	6.6	405
Sept.	4.9	398	2.8	230	5.0	311	0	-1.5	-92	0	92	6.3	387
Oct.	2.6	216	1.9	153	6.6	409	248	2.9	178	201	23	6.5	402
Total	**33.2**	**2,713**	**22.4**	**1,825**	**7.0**	**5,084**	**326**	**1.9**	**1,389**	**1,786**	**397**	**9.7**	**7,034**

The GFLOW model was calibrated by varying horizontal hydraulic conductivity and ground-water recharge within an expected range until there was a reasonable match between measured and simulated ground-water levels and base flows for streams in the near field. Areal recharge to the ground-water-flow system was set equal to 8.9 in/yr, and horizontal hydraulic conductivity was set equal to 28 ft/d for the calibrated model. These values are similar to those used by Hunt and others (1998). For 46 water-level targets (fig. 3), the calibrated model had a mean difference between measured and simulated water levels of 0.1 ft and mean absolute difference of 3.6 ft (fig. 14).

Simulated cumulative net ground-water discharges were within 0.4 ft^3/s of independently determined cumulative net ground-water discharges at the Muskellunge Lake outlet, at Muskellunge Creek at Birchwood Drive, and at Little St. Germain Creek at Highway 70 in MY2001 (table 3). Net ground-water discharge to Muskellunge Lake was determined as the residual in the water-budget equation (2.46 ft^3/s; 1.87 ft^3/s from eq. 1 plus 0.59 ft^3/s, the estimated ground-water discharge to the southeast tributary of Muskellunge Lake that was included in the discharge simulated by the ground-water-flow model; Robertson and others, 2003). The total net ground-water discharge at Birchwood Drive (5.69 ft^3/s) was estimated by adding the ground-water discharge to Muskellunge Creek (3.23 ft^3/s, estimated by subtracting the daily outflow from Muskellunge Lake from the total flow measured at Birchwood Drive and by use of a graphical base-flow separation analysis on the difference between these two sites to determine surface runoff) to that estimated at the Muskellunge Lake outlet. The total net ground-water discharge at Highway 70 was estimated by adding the net ground-water input to Little St. Germain Lake from table 2 (1.9 ft^3/s) to the net ground-water discharge at Birchwood Drive. Simulated net ground-water discharges in table 3 were obtained by removing precipitation minus evaporation on the surfaces of Muskellunge Lake (0.28 ft^3/s) and Little St. Germain Lake (1.004 ft^3/s) from the model estimates.

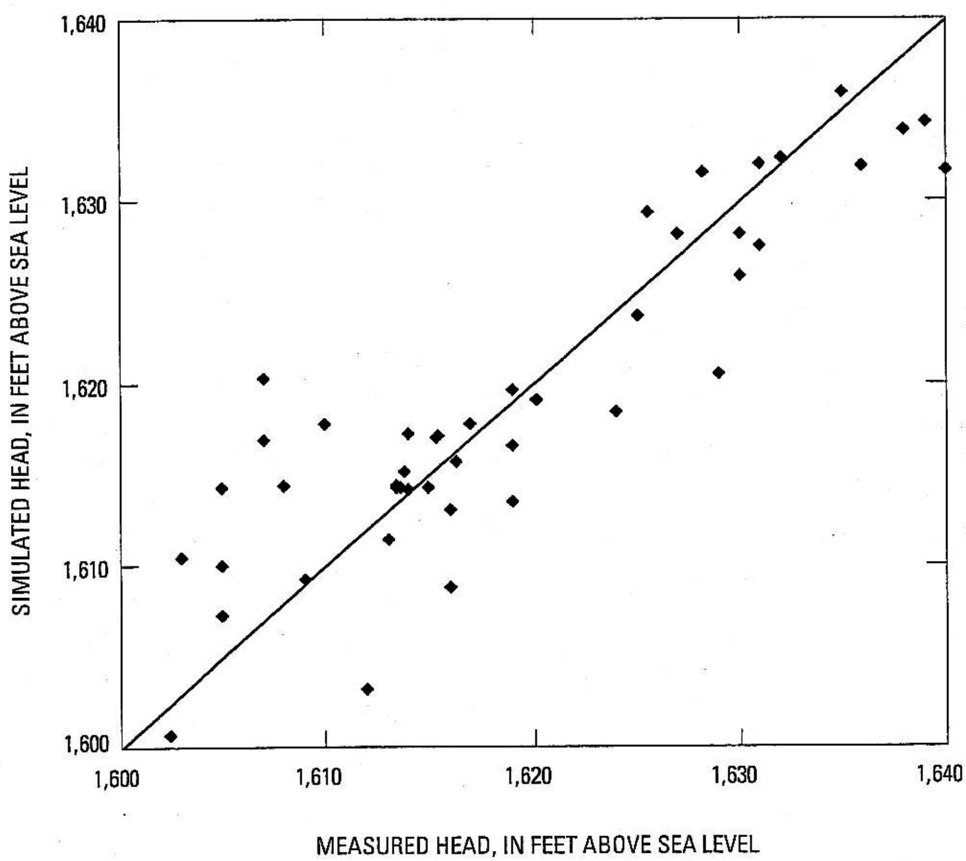

Figure 14. Measured and simulated head for the calibrated GFLOW model for the area near Little St. Germain Lake, Vilas County, Wis.

Table 3. Measured and simulated cumulative net ground-water discharge values for the calibrated GFLOW model.

[ft^3/s, cubic feet per second; in/yr, inches per year; MY, monitoring year]

Comparison site	Cumulative net ground-water discharge (ft^3/s)	
	Independently determined values for MY2001	Model-simulated values*
Muskellunge Lake at the outlet	2.46	2.20
Muskellunge Creek at Birchwood Drive	5.69	5.32
Little St. Germain Lake outlet at Highway 70	7.79	8.12

* Simulated net ground-water discharge values from the lakes were modified from the actual model output by subtracting precipitation minus evaporation (8.9 in/yr) applied to the lake surfaces. For Muskellunge Lake and Muskellunge Creek, 0.28 ft^3/s was subtracted, and for the Little St. Germain Lake outlet at Highway 70, 1.284 ft^3/s was subtracted.

The ground-water contributing area for Little St. Germain Lake was delineated using particle tracking techniques in GFLOW. The area contributing ground water to the lake (14.1 mi^2) is different and slightly larger than the area contributing surface water (10 mi^2; 11.5 mi^2 if the lake surface is included)(fig. 15). The model results indicated that ground water discharges into the lake from all sides except for two small areas at the south ends of the Second South and West Bays. Water levels (heads) measured in piezometers indicated that some parts of the lake alternate between contributing and losing ground water at different times of the year. During May and June 2001, water levels measured at 13 piezometers indicated that ground water flowed into the lake on all sides except the south side of West Bay, where it was leaving the lake. During August and September 2001, water-level measurements at 15 piezometers indicated that ground-water discharged into all sides of the lake except the south side of the West Bay, the northeast side of the South Bay, and the south side of the East Bay. No piezometers were installed near the outlet of the lake in an area simulated as losing water. Most of the urban development around the southwest part of the West Bay and along Highway 70 is in areas that do not contribute ground water to the lake.

The simulated ground-water fluxes into and out of the lake were calculated for 16 shoreline segments. The segment lengths correspond to the length of shoreline halfway between adjacent piezometers installed around the lake (fig. 2), except for the segment representing the south end of the South Bay. No piezometers were installed in this area; therefore, the segment between piezometers in the South and Second South Bays was divided into two segments, one of which represents the shoreline near the lake outlet that was simulated to lose water to the ground-water-flow system. The amount of ground water entering the lake through each shoreline segment is shown in figure 15 by the thickness of the segment lines around the lake. The ground-water flux into the lake ranged from 0.4 ft^3/day per foot of shoreline (West Bay near piezometer 3, close to where water is lost to the ground-water-flow system) to 12.6 ft^3 per day per foot of shoreline (near piezometer 13, along the north shore of East Bay). Ground-water fluxes out of the lake ranged from 2.5 to 7.4 ft^3 per day per foot of shoreline, in the West and Second South Bays, respectively.

The total annual simulated ground-water flow into Little St. Germain Lake (GW_{In}) was 2.65 ft^3/s (based on summing contributions of shoreline segments contributing ground water to the lake), and the total annual simulated loss from the lake to the ground-water-flow system (GW_{Out}) was 0.30 ft^3/s (based on summing shoreline segments gaining water from the lake). The net annual ground-water flow to Little St. Germain Lake was 2.35 ft^3/s, which is similar to the total annual net ground-water input estimated from the MY2001 water budget (1.9 ft^3/s, table 2). This results in the total ground-water inflow to the lake being about 13 percent higher than net inflow. In the earlier study (Robertson and Rose, 2000), total ground-water inflow was assumed to be 50 percent higher than net inflow. Therefore, less ground water enters the lake than assumed in the earlier study.

Based on the similarity between the model output and the base flows in Muskellunge Creek and Little St. Germain Creek (table 3) and the annual net ground-water input from the water budget in MY2001 (table 2), the model appears to accurately simulate the ground-water flow near Little St. Germain Lake. In the model, ground-water flow to the lake is assumed to be uniform throughout the year, although in reality there is seasonal variation caused by variable recharge and seasonal regulation of stage in Little St. Germain Lake. The monthly distribution of net ground-water input to the lake was obtained directly from the

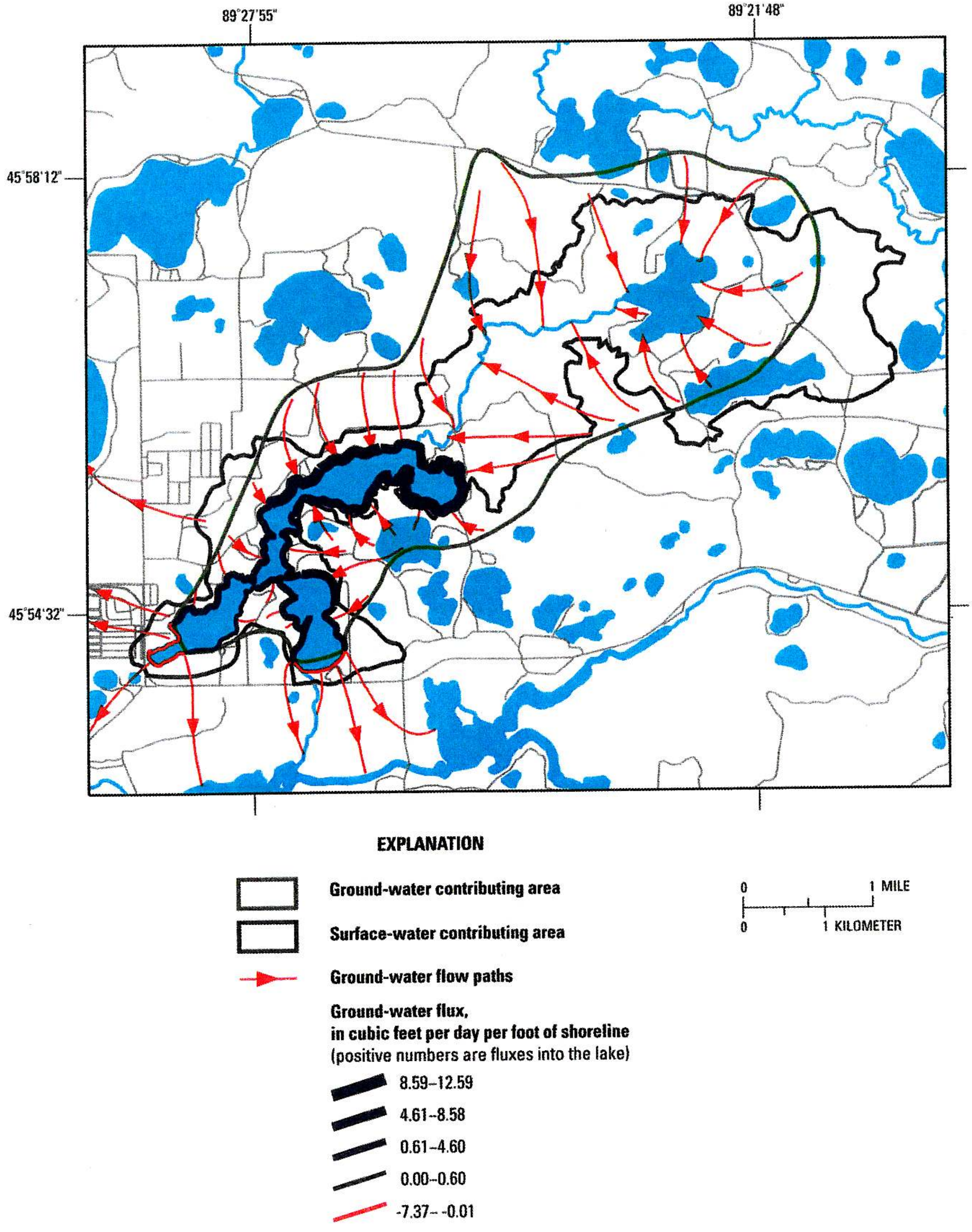

Figure 15. Surface-water contributing area, simulated ground-water contributing area and flow direction, and ground-water flux for Little St. Germain Lake, Vilas County, Wis.

water budget (table 2), and the monthly inputs and outputs to the lake were obtained based on the assumption that the ratio of inputs to outputs was similar to that estimated by the ground-water-flow model for the entire year. The annual net ground-water inputs for MY1997 and MY1999 were estimated directly from the water budgets for the respective years, and the monthly distribution of inputs and outputs for those years (table 2) was again obtained based on the assumption that the ratio of inputs to outputs was similar to that found with the ground-water-flow model. The ground-water inputs to the lake were estimated to be about 4,380 acre-ft in MY1997, 2,710 acre-ft in MY1999, and 1,790 acre-ft in MY2001.

Water Budget

The complete water budget (table 2 and fig. 16) indicated that the major source of water to the lake is from surface-water inflow from Muskellunge Creek, which represented about 43 percent (MY1999) to 53 percent (MY2001) of the total water input to the lake. Ground water and precipitation each contributed between 19 and 30 percent of the total water input. During a dry year after an extended dry period (such as prior to MY1999), direct precipitation and ground water contribute almost as much water as Muskellunge Creek (about 40 percent from Muskellunge Creek and about 30 percent from both precipitation and ground water). The major loss of water from the lake is through the outlet (ranging from 76 percent of the total water loss in MY2001 to 84 percent MY1997). About 12 to 20 percent of the water lost from the lake is through evaporation, and about 3 to 4 percent is lost to the ground-water-flow system.

Phosphorus Loading

To help define where the phosphorus in Little St. Germain Lake originates and how much may be controllable, a detailed phosphorus budget was computed for each of the three monitoring years. Sources of phosphorus to the lake include precipitation, surface- and ground-water inflow, and contributions from septic systems. Phosphorus is removed from the lake through surface- and ground-water outflow and deposition to the lake sediments.

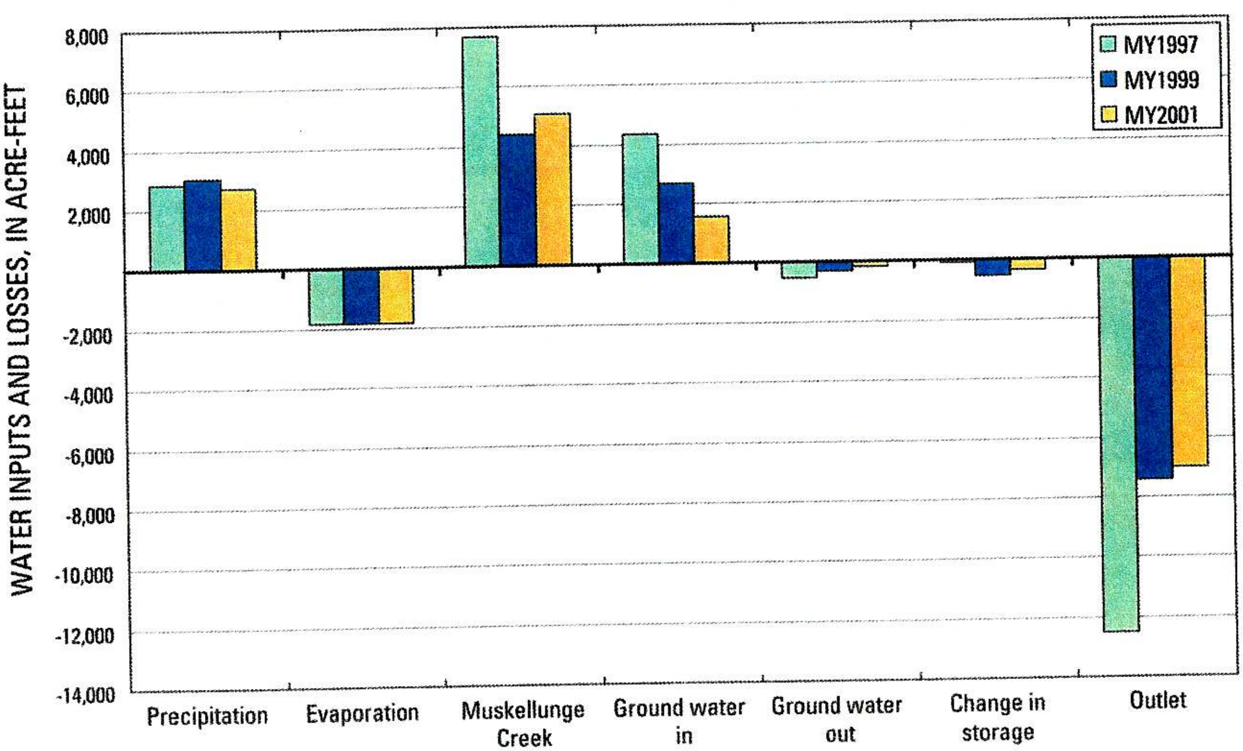

Figure 16. Water budgets for Little St. Germain Lake, Vilas County, Wis. for monitoring years MY1997, MY1999, and MY 2001.

Precipitation

The phosphorus concentration in precipitation was assumed to be constant at 7 μg/L, a value suggested by Rose (1993) for northern Wisconsin. Therefore, direct precipitation contributed between about 52 lb (MY2001) and 58 lb (MY1999) of phosphorus to the lake during each study year (table 4).

Surface-Water Inflow

During each monitoring year, phosphorus concentrations were measured approximately monthly in Muskellunge Creek at Birchwood Drive (fig. 10). Daily concentrations for each monitoring year were obtained by linearly interpolating between each measurement. The amount of phosphorus delivered to the lake was then computed by multiplying the daily phosphorus concentrations by the daily inflow volumes. The total input of phosphorus from Muskellunge Creek was estimated to be about 1,470 lb (MY1997), 690 lb (1999), and 710 lb (2001) (table 4). About 50 percent of the phosphorus loading from surface-water inflow occurred between May and August. Because dissolved phosphorus represents about 50 percent of the total phosphorus at this site (throughout the year and during May through August), the total annual load of dissolved phosphorus ranged from about 350 lb (MY1999 and MY2001) to 750 lb (MY1997), of which about 175 lb (MY1999 and MY2001) to about 375 lb (MY1997) were delivered from May through August.

Ground-Water Inputs and Outputs

Dissolved phosphorus concentrations were measured twice in 13 of the 15 piezometers installed around the lake (fig. 2). Concentrations were not measured if the ground-water head gradient at a location was away from the lake (such as at piezometers 3 and 14). Ground-water simulations indicated that the gradient along most of the shoreline near piezometer 3 should be towards the lake; therefore, the concentration in piezometer 3 was assumed to be the average of that measured in piezometers 1 and 2. Ground water was leaving the lake at piezometer 14; therefore, a concentration was not measured. Phosphorus concentrations varied only slightly between measurements at each location. The median overall phosphorus concentration from all piezometers was 0.019 mg/L. All average concentrations were less than 0.035 mg/L, except in piezometers 4 (0.076 mg/L), 6 (0.303 mg/L), and 7 (0.386 mg/L) near No Fish Bay and the South Bay (fig. 2). Phosphorus input was then computed by multiplying the average phosphorus concentration in each piezometer by the monthly ground-water flux computed for each shoreline segment. The input of phosphorus from each shoreline segment is shown in figure 17 (for MY2001) by the thickness of the segment line. Most phosphorus enters the middle part of the lake represented by piezometers 6 and 7, where the phosphorus concentrations were highest. Ground water was estimated to contribute about 740 lb (MY1997), 460 lb (MY1999), and 300 lb (MY2001) of phosphorus during the various monitoring years (table 4).

The amount of phosphorus leaving the lake with ground-water outflow was estimated by multiplying the monthly ground-water outflow (table 2; proportioned between piezometers 5 and 14 based on the model output for MY1999) by the monthly average in-lake, near-surface phosphorus concentration estimated for the South and West Bays, respectively. Ground-water outflow was estimated to have removed about 46 lb (MY1997), 20 lb (MY1999), and 23 lb (MY2001) of phosphorus during the various monitoring years (table 4). About 80 percent of the phosphorus removed with ground-water outflow was from the South and Second South Bays.

Septic Systems

The input of phosphorus from septic systems (M) was estimated by use of equation 2 (Reckhow and others, 1980):

$$M = E_S * (\text{Number of capita years}) * (1 - S_R) \qquad (2)$$

where M is a function of an export coefficient, E_S, and a soil retention coefficient, S_R. In applying equation 2, it was assumed that the most likely value for E_S was 1.5 lb of phosphorus per capita per year and the most likely value for S_R was 0.85. Typical export coefficients range from 1.1 lb per capita per year (Reckhow and others, 1980; Panuska and Kreider, 2002) to 1.8 lb per capita per year (Garn and others, 1996). The total number of capita years was estimated to be 330. This value was obtained on the basis of the assumptions that 300 of the 415 lake-front dwellings were in areas where ground water flowed toward the lake, 40 percent of these dwellings had 2 permanent residents (240 capita years), 30 percent of these dwellings had 3 residents living on the lake for 3 months (68 capita years), and 30 percent of these dwellings had 3 residents living on the lake for 1 month (22 capita years) (Ted Ritter, Little St. Germain Lake District, oral commun., 2004). This estimate includes all residents on the lake except those on the west part of the West Bay and the southern part of the

Table 4. Monthly phosphorus budget, in pounds, for Little St. Germain Lake, for October 1, 1996, to September 30, 1997; December 1, 1998, to November 30, 1999; and November 1, 2000, to October 31, 2001.

[MY, monitoring year. Numbers may not add exactly to totals due to rounding.]

Month	Precipitation	Muskellunge Creek	Ground-water input	Ground-water output	Septic systems	Outlet	Total input	Total output	Gain in lake
				October 1, 1996, to September 30, 1997 (MY1997)					
Oct.	5.8	50.1	72.0	2.7	7.4	65.0	135.3	67.7	67.6
Nov.	5.5	63.3	85.1	3.1	7.4	140.2	161.2	143.3	18.0
Dec.	3.6	75.2	66.7	3.0	7.4	149.7	152.9	152.8	0.2
Jan.	4.8	85.6	23.5	1.3	7.4	194.4	121.5	195.6	-74.2
Feb.	1.5	69.6	73.4	4.6	7.4	162.8	151.9	167.5	-15.5
Mar.	4.8	70.4	49.8	3.5	7.4	120.2	132.5	123.8	8.7
Apr.	1.1	108.4	109.4	8.3	7.4	60.6	226.3	68.9	157.4
May	4.6	181.8	99.9	8.1	7.4	146.0	293.8	154.1	139.7
June	5.7	211.9	71.4	6.1	7.4	127.9	296.4	134.0	162.4
July	7.2	221.6	49.2	2.6	7.4	82.1	285.3	84.6	200.7
Aug.	5.7	184.7	24.1	1.2	7.4	64.4	222.0	65.6	156.4
Sept.	3.8	151.3	17.7	0.9	7.4	55.3	180.2	56.3	123.9
Total	**54.1**	**1,473.9**	**742.3**	**45.5**	**89.1**	**1,368.6**	**2,359.3**	**1,414.1**	**945.2**
				December 1, 1998, to November 30, 1999 (MY 1999)					
Dec.	1.9	42.9	38.9	1.7	7.4	53.5	91.1	55.1	36.0
Jan.	4.2	44.7	0.0	1.7	7.4	68.0	56.4	69.7	-13.2
Feb.	2.7	38.4	66.8	2.9	7.4	47.0	115.3	49.9	65.4
Mar.	0.5	60.2	22.7	1.0	7.4	23.9	90.9	24.9	66.0
Apr.	2.6	80.0	42.1	1.8	7.4	26.0	132.2	27.8	104.3
May	15.0	130.3	79.2	3.3	7.4	33.2	232.0	36.5	195.4
June	6.0	79.4	39.3	1.7	7.4	36.4	132.1	38.1	94.0
July	11.1	75.3	61.2	1.9	7.4	30.9	155.1	32.8	122.3
Aug.	5.2	56.7	18.8	0.6	7.4	23.5	88.1	24.2	63.9
Sept.	3.8	33.0	19.4	0.7	7.4	22.2	63.7	22.9	40.7
Oct.	2.9	23.8	38.5	1.7	7.4	30.8	72.7	32.4	40.2
Nov.	1.9	29.6	33.0	1.4	7.4	47.2	71.9	48.6	23.3
Total	**57.9**	**694.4**	**459.9**	**20.3**	**89.1**	**442.7**	**1,301.3**	**463.0**	**838.3**
				November 1, 2000, to October 31, 2001 (MY 2001)					
Nov.	2.9	23.9	28.4	1.2	7.4	77.7	62.6	78.9	-16.3
Dec.	2.0	30.2	4.1	0.2	7.4	104.3	43.7	104.5	-60.7
Jan.	1.9	36.4	84.6	3.6	7.4	52.0	130.2	55.7	74.6
Feb.	2.2	38.9	7.7	0.3	7.4	49.7	56.2	50.0	6.2
Mar.	1.0	47.4	68.7	3.0	7.4	31.7	124.6	34.6	90.0
Apr.	8.9	102.5	30.1	1.3	7.4	21.1	149.0	22.4	126.6
May	7.5	96.2	0.0	4.9	7.4	29.3	111.1	34.2	76.9
June	5.3	95.9	41.2	1.8	7.4	46.2	149.8	47.9	101.9
July	5.1	69.1	0.0	0.8	7.4	29.7	81.7	30.6	51.1
Aug.	3.0	62.0	4.0	0.1	7.4	28.1	76.4	28.3	48.1
Sept.	7.6	52.4	0.0	4.7	7.4	23.2	67.4	27.9	39.5
Oct.	4.1	50.8	34.2	1.5	7.4	24.0	96.5	25.5	71.0
Total	**51.6**	**705.7**	**302.9**	**23.4**	**89.1**	**517.0**	**1,149.2**	**540.5**	**608.8**

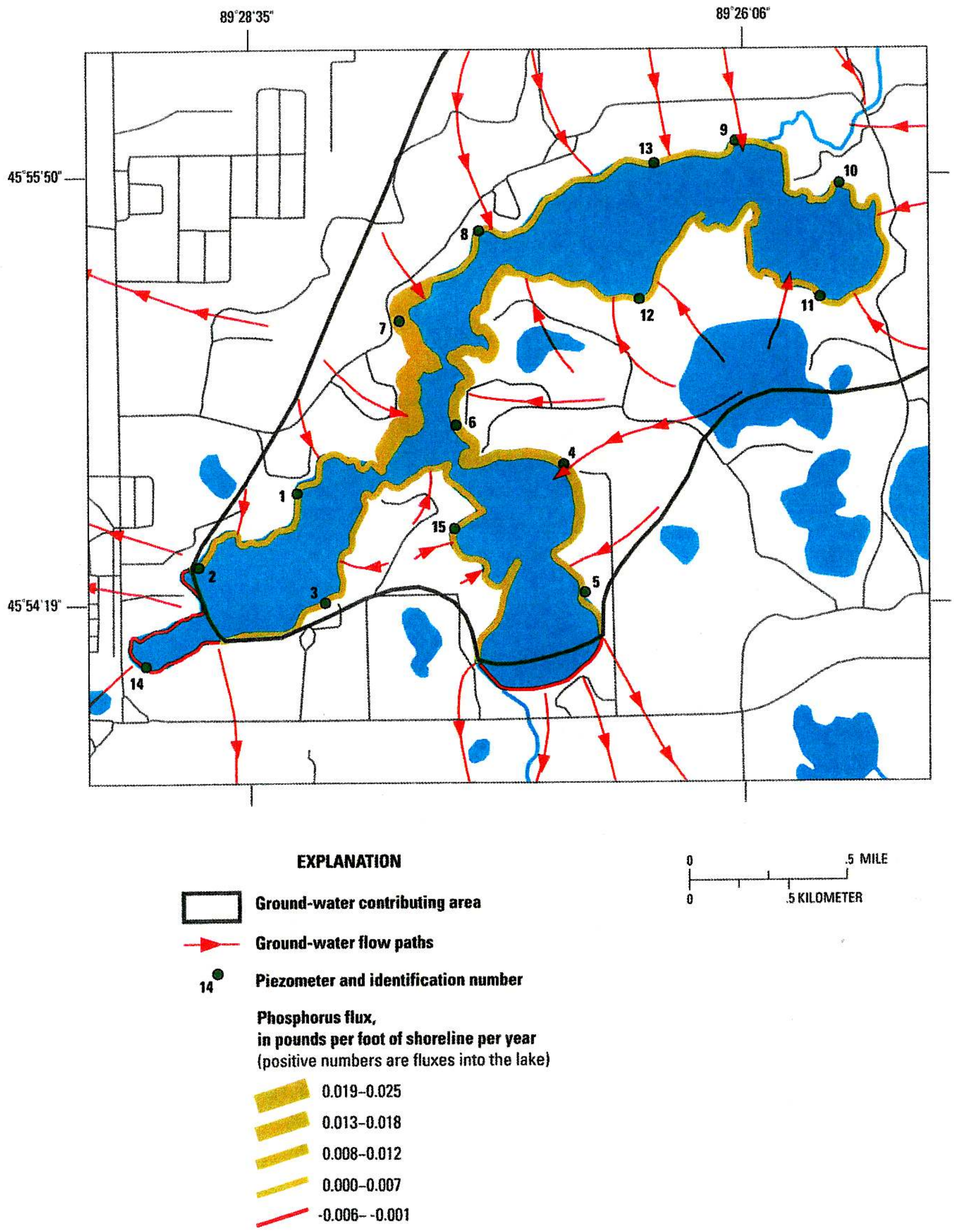

Figure 17. Phosphorus loading into and out of Little St. Germain Lake, Vilas County, Wis., from ground water, by shoreline segment for monitoring year 2001.

Second South Bay where ground water was flowing away from the lake. The total input from septic systems was then computed to be 89 lb per year and was aassumed to be uniformly distributed throughout each year. This estimate is twice that estimated by Robertson and Rose (2000) because the ground-water-flow model indicated that much more of the lake had areas contributing ground water than previously estimated. By applying low and high estimates for E_S (1.1 and 2.2 lb of phosphorus per capita per year, respectively) and S_R (0.9 and 0.5, respectively), low and high estimates of phosphorus from septic systems were computed to be 36 and 363 lb, respectively.

Surface-Water Outflow

The phosphorus leaving the lake's outlet was computed for each monitoring year by multiplying the daily outflow volumes by the measured or estimated daily concentrations. Estimated concentrations were obtained by linearly interpolating between the measurements in figure 10. The total amount of phosphorus in surface-water outflow was estimated to be about 1,370 lb (MY1997), 440 lb (MY1999), and 520 lb (MY2001) (table 4). The larger load in MY1997 than those estimated for the other two years was due to a combination of higher concentrations and higher flows than in the other two years. About 35 to 45 percent of the phosphorus load leaving the lake occurred between November and January when the lake was being drawn down.

Phosphorus Budget

The total phosphorus input to the lake was about 2,360 lb in MY1997, 1,300 lb in MY1999, and 1,150 lb in MY2001 (table 4). The phosphorus budget (fig. 18) indicates that inflow from Muskellunge Creek was the major source of phosphorus to the lake (53 to 62 percent) and ground water was the secondary source (26 to 35 percent). Phosphorus from precipitation and septic systems each accounted for less than 8 percent of the total input. With the worst assumptions regarding input from septic systems, they would contribute between 14 percent (MY1997) to 26 percent (MY2001) of the total phosphorus input. Approximately 34 to 58 percent of the total phosphorus input to the lake (463 lb in MY1999 and 1,414 lb in MY1997) was exported out of the lake through Little St. Germain Creek. The remaining 32 to 66 percent of the phosphorus input (about 610 lb in MY2001 to 950 lb in MY1997) was deposited in the bed sediment of the lake. The overall phosphorus loading from MY1997 and MY1999 is very similar to that estimated by Robertson and Rose (2000). In the earlier study, the total phosphorus input in MY1997 was estimated to be 2,410 lb (compared to 2,360 lb in this study) and in MY1999 was estimated to be 1,310 lb (compared to 1,300 lb in this study). The primary differences in the phosphorus budgets were that phosphorus input from septic systems increased by about 45 lb and phosphorus input from ground water decreased by 93 and 52 lb, in MY1997 and MY1999, respectively, compared to the earlier study.

Effects of Phosphorus Reductions

The total phosphorus input to the lake was estimated to be about 2,360 lb in MY1997, 1,300 lb in MY1999, and 1,150 lb in MY2001. Most of this phosphorus is input into the East and Upper East Bays and results in the water quality in these basins being poorer than other parts of the lake. One way to determine how much of the phosphorus loading to these basins would need to be reduced to improve their water quality 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; Panuska and Kreider, 2002) relate the hydrology and phosphorus loading to in-lake phosphorus concentrations. Four of these models were applicable to the East and Upper East Bay of Little St. Germain Lake (table 5). These two basins were modeled as a single lake because of the mixing between the two basins and their similar water quality. Therefore, the morphometry (based on data from table 1), hydrology (based on data from table 2), and phosphorus loading (based on data from table 4) to these basins for the three monitoring years and various phosphorus-reduction scenarios were input into these models within WiLMS and near-surface phosphorus concentrations and changes in their phosphorus concentrations were simulated. In computing the total phosphorus load to these two basins, loading from precipitation was computed for only the surface area of these two basins (46 percent of the total), loading from ground water was only the portion contributed to these basins, and the loading from septic systems were based on only 150 of the 300 dwellings contributing phosphorus to the lake. Therefore, the total loading for MY1997 was 2,031 lb, for MY1999 was 1,068 lb, and for MY2001 was 973 lb.

The models within WiLMS that were applied to the East and Upper East Bays use annual hydrologic and

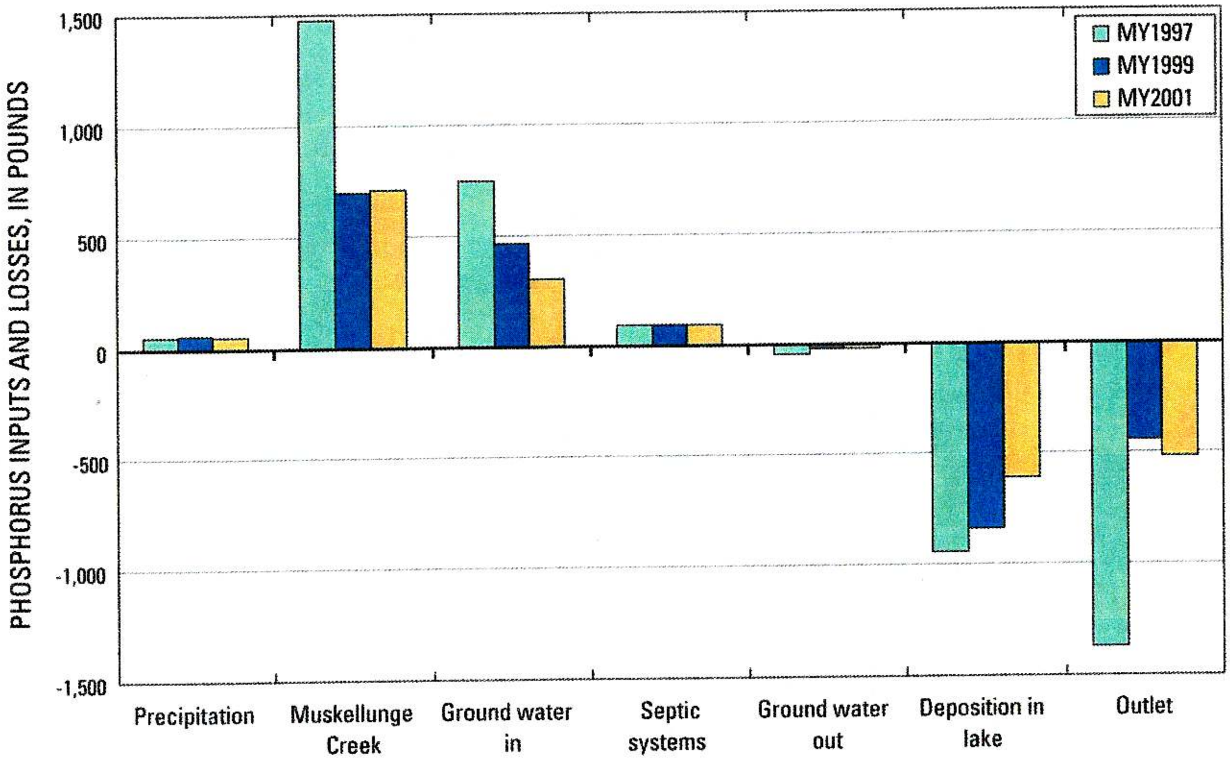

Figure 18. Phosphorus budgets for Little St. Germain Lake, Vilas County, Wis., for monitoring years MY1997, MY1998 and MY1999.

phosphorus loadings but simulate the water quality for the growing season (June through September); therefore, output from the model simulations was compared with the summer-average data for MY1997, MY1999, and MY2001 (table 5). Data were available for only the East Bay for MY1997 and MY1999; therefore, all comparisons including MY2001 were done with measured East Bay data only. There are no calibration factors in WiLMS; however, the output can be adjusted to account for model biases by only interpreting the results as a percentage change from some base condition.

The average phosphorus concentration predicted by the models for the three years was 0.039 mg/L, which is 26 percent lower than that measured in the East Bay (0.053 mg/L) (table 5). For MY1997, the average simulated concentration was 0.047 mg/L compared to 0.061 mg/L measured in the East Bay. For MY1999, the average simulated concentration was 0.037 mg/L compared to 0.041 mg/L measured in the East Bay. For MY2001, the average simulated concentration was 0.032 mg/L compared to 0.056 mg/L measured in the East Bay. The models consistently underestimated the phosphorus concentrations in the East Bay. This difference between simulated and measured concentrations may be the result of the release of phosphorus from the sediments of Little St. Germain Lake being higher than the sediment releases in the lakes that were used to develop the models used in WiLMS. The models were then applied with the data for various phosphorus-reduction scenarios: 25-, 50-, 75-, and 100-percent reduction in tributary loading from Muskellunge Creek; phosphorus contributions from all of the other sources were maintained at their present levels. The models predicted that these reductions in tributary loading would cause the average phosphorus concentration in these two basins to decrease 14 percent in response to a 25-percent reduction, by 29 percent in response to a 50-percent reduction, by 45 percent in response to a 75-percent reduction, and by 62 percent in response to a 100-percent reduction in tributary loading. If it is assumed that these percentages of change apply to the summer-average concentration measured in these bays, then a 25-percent reduction in tributary loading would result in a summer average concentration of 0.045 mg/L, a 50-percent decrease would result in 0.037 mg/L, a 75-percent reduction would result in 0.029 mg/L, and a 100-percent decrease in loading would result in 0.020 mg/L. Therefore, a 75- to 100-percent reduction in tributary loading would be needed for these parts of the lake to have a summer average phosphorus concentration of 0.024 mg/L and be classified as borderline mesotrophic/eutrophic.

Table 5. Simulated changes in average June through August near-surface total phosphorus concentrations in the East and Upper East Bays of Little St. Germain Lake, Vilas County, Wisconsin, in response to reductions in tributary loading.

[All concentrations are in milligrams per liter; %, percent; MY, monitoring year; ft/yr, feet per year]

MY1997

	Measured	Simulated tributary-load reductions				
		Base (0%)	25%	50%	75%	100%
Phosphorus loading (pounds)		2,031	1,662	1,294	925	557
Model						
Walker, 1987	0.061	0.045	0.039	0.033	0.026	0.018
Canfield and Bachman, 1981 Natural Lakes	0.061	0.049	0.042	0.034	0.026	0.017
Canfield and Bachman, 1981 Artificial Lakes	0.061	0.042	0.036	0.030	0.024	0.016
Reckhow, 1977, Water load less than 164 ft/yr	0.061	0.051	0.042	0.032	0.023	0.014
Average of models	**0.061**	**0.047**	**0.040**	**0.032**	**0.025**	**0.016**

MY1999

	Measured	Simulated tributary-load reductions				
		Base (0%)	25%	50%	75%	100%
Phosphorus loading (pounds)		1,068	894	720	547	373
Model						
Walker, 1987	0.041	0.039	0.035	0.030	0.025	0.019
Canfield and Bachman, 1981 Natural Lakes	0.041	0.039	0.034	0.029	0.023	0.017
Canfield and Bachman, 1981 Artificial Lakes	0.041	0.034	0.030	0.026	0.021	0.016
Reckhow, 1977, Water load less than 164 ft/yr	0.041	0.036	0.030	0.024	0.018	0.013
Average of models	**0.041**	**0.037**	**0.032**	**0.027**	**0.022**	**0.016**

MY2001

	Measured	Simulated tributary-load reductions				
		Base (0%)	25%	50%	75%	100%
Phosphorus loading (pounds)		973	797	620	444	267
Model						
Walker, 1987	0.056	0.034	0.030	0.025	0.020	0.013
Canfield and Bachman, 1981 Natural Lakes	0.056	0.034	0.029	0.024	0.018	0.012
Canfield and Bachman, 1981 Artificial Lakes	0.056	0.030	0.026	0.022	0.017	0.012
Reckhow, 1977, Water load less than 164 ft/yr	0.056	0.031	0.025	0.020	0.014	0.008
Average of models	**0.056**	**0.032**	**0.028**	**0.023**	**0.017**	**0.011**

Average of three years

		Simulated tributary-load reductions				
Year	**Measured**	**Base (0%)**	**25%**	**50%**	**75%**	**100%**
1997	0.061	0.047	0.040	0.032	0.025	0.016
1999	0.041	0.037	0.032	0.027	0.022	0.016
2001	0.056	0.032	0.028	0.023	0.017	0.011
Average of years	0.053	0.039	0.033	0.027	0.021	0.015
Percent reduction			14	29	45	62
Predicted concentration with load reduction		**0.053**	**0.045**	**0.037**	**0.029**	**0.020**

Empirical relations have also been developed that predict summer average chlorophyll *a* concentrations and Secchi depths from near-surface phosphorus concentrations. Empirical relations developed for Wisconsin lakes by Lillie and others (1993) for nonstratified impoundments, also contained within WiLMS, were applied to determine how the various reductions in phosphorus loading from Muskellunge Creek (tributary loading) should affect near-surface, summer average chlorophyll *a* concentrations and Secchi depths in the East and Upper East Bays (table 6). These models predicted that with the measured summer average phosphorus concentration of 0.053 mg/L, the East and Upper East Bays should have a chlorophyll *a* concentration of 18.5 µg/L (compared to 25.8 µg/L measured in the East Bay for these three years) and a Secchi depth of 3.3 ft (compared to 4.3 ft measured). The predicted average summer phosphorus concentrations from table 5 were then input into the empirical relations. With a near-surface phosphorus concentration of 0.045 µg/L (based on a 25-percent reduction in tributary loading), the models predicted a chlorophyll *a* concentration of 16.5 µg/L (an 11-percent reduction from 18.5 µg/L predicted for 0.053 mg/L of phosphorus) and a Secchi depth of 3.28 ft (no change from that predicted for 0.053 mg/L of phosphorus)(table 6). With a near-surface phosphorus concentration of 0.020 mg/L (based on a 100-percent decrease in tributary loading), the models predicted a chlorophyll *a* concentration of 9.4 µg/L (a 49-percent decrease from that predicted for 0.053 mg/L of phosphorus) and a Secchi depth of 4.3 ft (a 30-percent increase from that predicted for 0.053 mg/L of phosphorus). If it is assumed that these percentages of change again apply to the average summer conditions measured in the East Bay, then a 25-percent reduction in tributary loading would result in a summer average chlorophyll *a* concentration of 23.0 µg/L and a summer average Secchi depth of 4.3 ft, a 50-percent reduction would result in a summer average chlorophyll *a* concentration of 20.1 µg/L and a summer average Secchi depth of 4.7 ft, a 75-percent reduction would result in a summer average chlorophyll *a* concentration of 16.9 µg/L and a summer average Secchi depth of 4.7 ft, and a 100-percent reduction would result in a summer average chlorophyll *a* concentration of 13.1 µg/L and a summer-average Secchi depth of 5.6 ft. Therefore, although phosphorus-load reductions would reduce phosphorus and chlorophyll *a* concentrations and increase water clarity, even with a 100-percent removal of phosphorus from Muskellunge Creek, the East and Upper East Bays would still be classified as eutrophic.

Large reductions in phosphorus loading from Muskellunge Creek could have a significant effect on the water quality of not only the East and Upper East Bays, but

Table 6. Simulated changes in June through August near-surface chlorophyll *a* concentrations and Secchi depths in the East and Upper East Bays of Little St. Germain Lake, Vilas County, Wisconsin, in response to reductions in tributary loading.

[%, percent; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent – summer average	Measured	Base (0%)	25%	50%	75%	100%
		Tributary-load reduction				
				Simulated values		
Total phosphorus (mg/L)	0.053	0.053	0.045	0.037	0.029	0.020
Chlorophyll *a* (µg/L)	25.8	18.5	16.5	14.4	12.1	9.4
Secchi depth (feet)	4.3	3.3	3.3	3.6	3.6	4.3
				Percent reduction		
Chlorophyll *a*		0%	11%	22%	35%	49%
Secchi depth		0%	0%	-10%	-10%	-30%
				Predicted response to tributary-load reduction (based on simulated percent reductions)		
Total phosphorus (mg/L)	0.053	0.053	0.045	0.037	0.029	0.020
Chlorophyll *a* (µg/L)	25.8	25.8	23.0	20.1	16.9	13.1
Secchi depth (feet)	4.3	4.3	4.3	4.7	4.7	5.6

also the South and Second South Bays because of the net flow of water through the lake. A reduction in phosphorus concentrations in these basins would also protect the water quality of the West Bay. However, because of the substantial contributions of phosphorus to the lake estimated from ground water, even with phosphorus loading from Muskellunge Creek completely eliminated, most of the lake would still be classified as borderline mesotrophic/eutrophic.

Summary

In the interest of protecting and improving the water quality of Little St. Germain Lake, the Little St. Germain Lake District initiated several cooperative studies with the U.S. Geological Survey between 1991 and 2004 to (1) document the water quality and the extent of winter anoxia in the lake, (2) evaluate the success of aerators at eliminating winter anoxia, (3) develop water and nutrient budgets for the lake, and (4) assess how the water quality of the lake should respond to changes in phosphorus loading.

Water quality in Little St. Germain Lake consistently varied among basins. The West Bay consistently had the greatest water clarity and lowest total phosphorus and chlorophyll *a* concentrations, the South Bay had intermediate clarity and intermediate phosphorus and chlorophyll *a* concentrations, and the East and Upper East Bays had the least water clarity and highest phosphorus and chlorophyll *a* concentrations. The summer average water quality in the lake was relatively stable from 1991 to 2000; however, water quality appears to have degraded since 2001. The West Bay has changed from oligotrophic to mesotrophic, the South Bay has changed from mesotrophic to eutrophic, and the East and Upper East Bays have changed from eutrophic to eutrophic/hypereutrophic.

Before aerators were installed and operated in the lake, winter anoxia frequently occurred throughout most of the lake, except in the West Bay and just below the ice in the East Bay. To eliminate winter anoxia, coarse-bubble line aerators were installed and operated in the Upper East, East, and South Bays. The aerator in the East Bay appeared to have little effect on dissolved oxygen concentrations throughout its basin. The ineffectiveness of the East Bay aerator may have been caused by the aerator being placed in water that was too shallow and (or) the aerator releasing too little air given the size of the East Bay. The aerators in the Upper East and South Bays were very successful at eliminating winter anoxia, and they maintained dissolved oxygen concentrations above 3.5 mg/L throughout almost the entire water column, except below the depth of the aerators.

Based on nitrogen-to-phosphorus ratios measured in the lake, the productivity in the lake is potentially limited by the supply of phosphorus. Detailed water and phosphorus budgets constructed for the lake indicated that the total phosphorus input to the lake was about 2,360 lb in monitoring year (MY)1997, 1,300 lb in MY1999, and 1,150 lb in MY2001. They also indicated that inflow from Muskellunge Creek was the major source of phosphorus to the lake (53 to 62 percent) and that ground water was the secondary source (26 to 35 percent). Precipitation and septic systems each accounted for less than 8 percent of the total phosphorus input. Results from a detailed ground-water-flow model indicated that ground water flows into the lake from all sides, except the south sides of West and Second South Bays. Simulated total ground-water inflow to the lake is about 13 percent higher than net inflow rather than 50 percent higher than net inflow as assumed in an earlier study by Robertson and Rose (2000). Therefore, compared to what was estimated in the earlier study, there was less ground-water input into the lake (and less phosphorus), but more input from septic systems. The net result was very little change in the phosphorus budget from the earlier study. Most of this phosphorus appears to come from natural sources—ground water and surface water flowing through relatively undeveloped areas surrounding Little St. Germain Lake and Muskellunge Lake.

Several empirical models within the Wisconsin Lakes Modeling Suite (WiLMS) were used to simulate how the water quality of East and Upper East Bays of the lake should respond to specific reductions in phosphorus loads from Muskellunge Creek. Simulation results indicated that large reductions in tributary loads could improve the water quality of the East and Upper East Bays. A 75- to 100-percent reduction in tributary loading would be needed for these parts of the lake to be classified as borderline meso-trophic/eutrophic. Improving the water quality of these bays would also improve the water quality of the South and Second South Bays because of the net flow of water through the lake. However, even with phosphorus loading from Muskellunge Creek completely eliminated, most of the lake would still be classified as borderline mesotrophic/eutrophic because of the contributions of phosphorus from ground water.

References Cited

Barton, B.A., and Taylor, B.R., 1996, Oxygen requirements in northern Alberta Rivers with a general review of the adverse effects of low dissolved oxygen, Water Quality Research Journal of Canada, v. 31, no. 2, p. 361–409.

Canfield, D.E., and Bachmann, R.W., 1981, Prediction of total phosphorus concentrations, chlorophyll *a*, and Secchi depths in natural and artificial lakes: Canadian Journal of Fisheries Aquatic Sciences, v. 38, p. 414–423.

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

Corell, D.L., 1998, The role of phosphorus in the eutrophication of receiving waters–A review: Journal of Environmental Quality, v. 27, p. 261–266.

Garn, H.S., Olson, D.L., Seidel, T.L., and Rose, W.J., 1996, Hydrology and water quality of Lauderdale Lakes, Walworth County, Wisconsin, 1993–94: U.S. Geological Survey Water-Resources Investigations Report 96–4235, 29 p.

Graczyk, D.J., Hunt, R.J., Greb, S.R., Buchwald, C.A., and Krohelski, J.T., 2003, Hydrology, nutrient concentrations, and nutrient yields in nearshore areas of four lakes in northern Wisconsin, 1999–2001: U.S. Geological Survey Water-Resources Investigations Report 03–4144, 64 p.

Haitjema, H.M., 1995, Analytic element modeling of ground-water flow: San Diego, Calif., Academic Press, 394 p.

Hunt, R.J., Anderson, M.P., and Kelson, V.A., 1998, Improving a complex finite-difference ground water flow model through the use of an analytic element screening model: Ground Water, v. 36, no. 6., p. 1011–1017.

Hunt, R.J., Haitjema, H.M., Krohelski, J.T., and Feinstein, D.T., 2003, Simulating lake-ground water interactions—Approaches and insights: Ground Water, v. 41, no. 2, p. 227–237.

Lillesand, T., Chipman, J., Nagel, D., Reese, H., Bobo, M., and Goldman, R., 1998, Upper Midwest GAP analysis image processing protocol: Onalaska, Wis., U.S. Geological Survey, Environmental Management Technical Center, EMTC 98–G00, 25 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.

Panuska, J.C., and Kreider, J.C., 2002, Wisconsin lake modeling suite program documentation and user's manual, Version 3.3 for Windows: Wisconsin Department of Natural Resources PUBL–WR–363–94, 32 p. [Available online through the Wisconsin Lakes Partnership: accessed December 29, 2004, at URL *http://www.dnr.state.wi.us/org/water/fhp/lakes/laketool.htm*]

Patterson, G.L., 1989, Water resources of Vilas County, Wisconsin: Wisconsin Geological and Natural History Survey Miscellaneous Paper 89–1, 46 p.

Reckhow, K.H., 1977, Phosphorus models for lake management: Ph.D. dissertation, Harvard University, Cambridge, Massachusetts, Catalog No. 7731778, University Microfilms International, Ann Arbor, Michigan.

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.

Robertson, D.M., and Rose, W.J., 2000, Hydrology, water quality, and phosphorus loading of Little St. Germain Lake, Vilas County, Wisconsin: U.S. Geological Survey Water Resources Investigations Report 00–4209, 8 p.

Robertson, D.M., Rose, W.J., and Saad, D.A., 2003, Water quality and the effects of changes in phosphorus loading to Muskellunge Lake, Vilas County, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 03–4011, 18 p.

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.

Shaw, Byron, Mechenich, Christine, and Klessig, Lowell, 1993, Understanding lake data: Madison, Wis., University of Wisconsin Extension Report G3582, 19 p.

Strack, O.D.L., 1989, Groundwater mechanics: Englewood Cliffs, N.J., Prentice-Hall, 732 p.

U.S. Geological Survey, Wisconsin District Lake-Studies Team, 2004, Water-quality and lake-stage data for Wisconsin lakes, water year 2003: U.S. Geological Survey Open-File Report 2004–1087, 158 p.

Walker, W.W., Jr., 1987, Empirical methods for predicting eutrophication in impoundments, Report no. 4, Phase III, Applications manual: U.S. Corps of Engineers Waterways Experimental Station Technical Report no. E–81–9, Vicksburg, Miss., 305 p.

Waschbusch, R.J., Olson, D.L., Ellefson, B.R., and Stark, P.A., 2002, Water-resources data, Wisconsin, water year 2001: U.S. Geological Survey Water-Data Report WI–01–1, 610 p.

Wentz, D.A., and Rose, W.J., 1991, Hydrology of Lakes Clara and Vandercook in north-central Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 89–4204, 24 p.

Wetzel, R.G., 1983, Limnology, second edition, Saunders College Publishing, Philadelphia, Pa., 767 p.

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

Wisconsin State Laboratory of Hygiene, Environmental Sciences Section, 1993, Manual of analytical methods, inorganic chemistry unit: Wisconsin State Laboratory of Hygiene, revised November 1993 [variously paged].

Report

Lake Managment Plan

Little St. Germain Lake

Scope ID: 99L005

Little St. Germain Lake Protection District

January 2001

Foth & Van Dyke

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

Contents

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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.

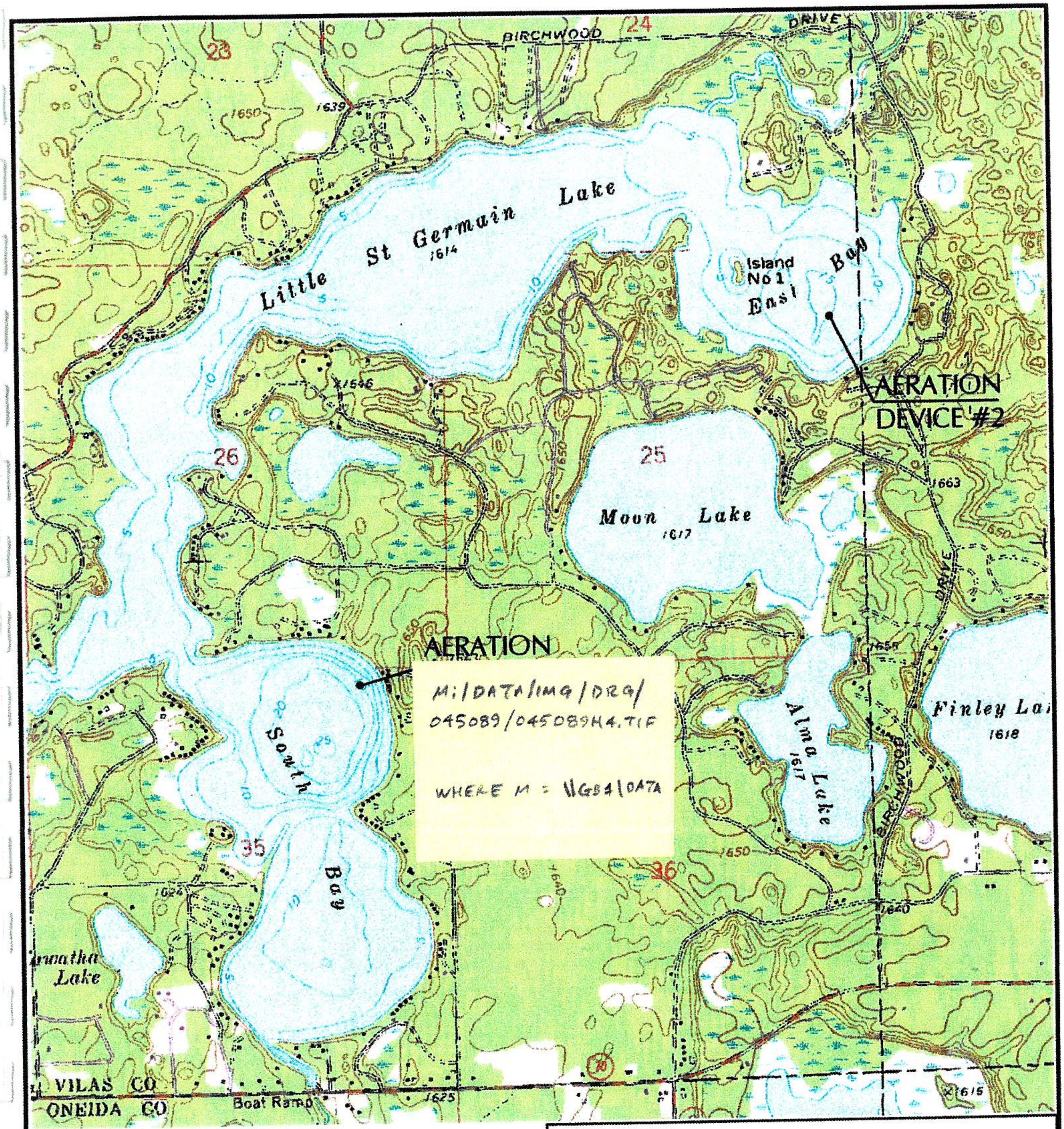
The cost for each on-shore aeration system is estimated at $170,000. Operation costs including power costs for a typical three month aeration season would be approximately $5,000. The large motor size (30 - 40 hp) will require three phase electrical power which may need to be brought in from a long distance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

Appendix A

USGS Report

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.

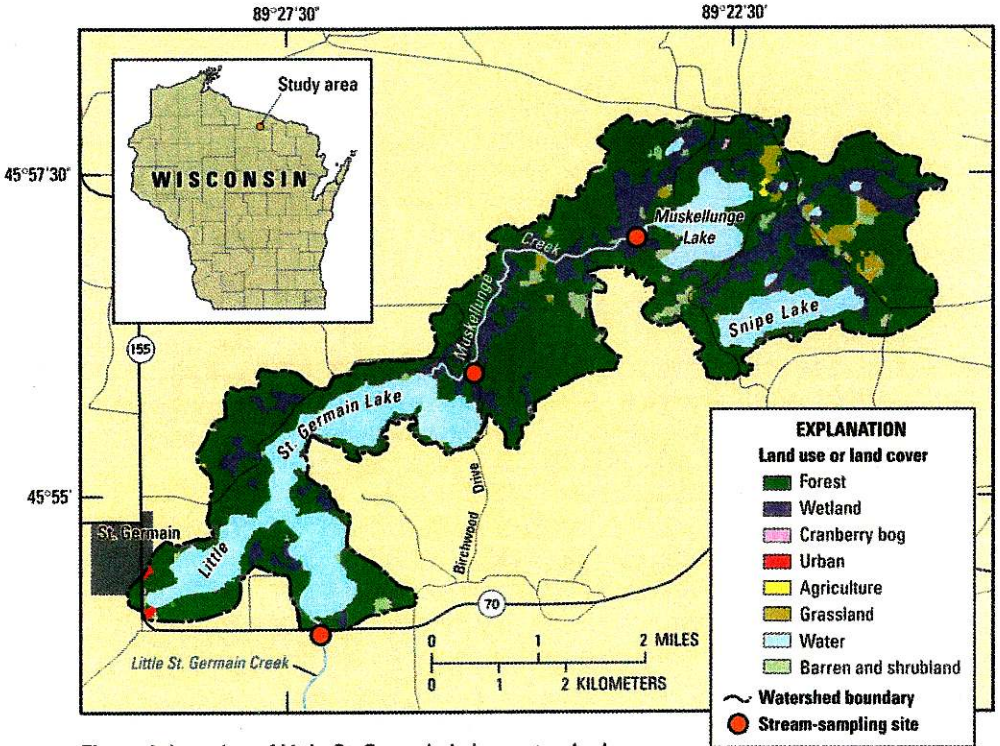


Figure 1. Location of Little St. Germain Lake, watershed characteristics, and location of stream-sampling sites.

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.

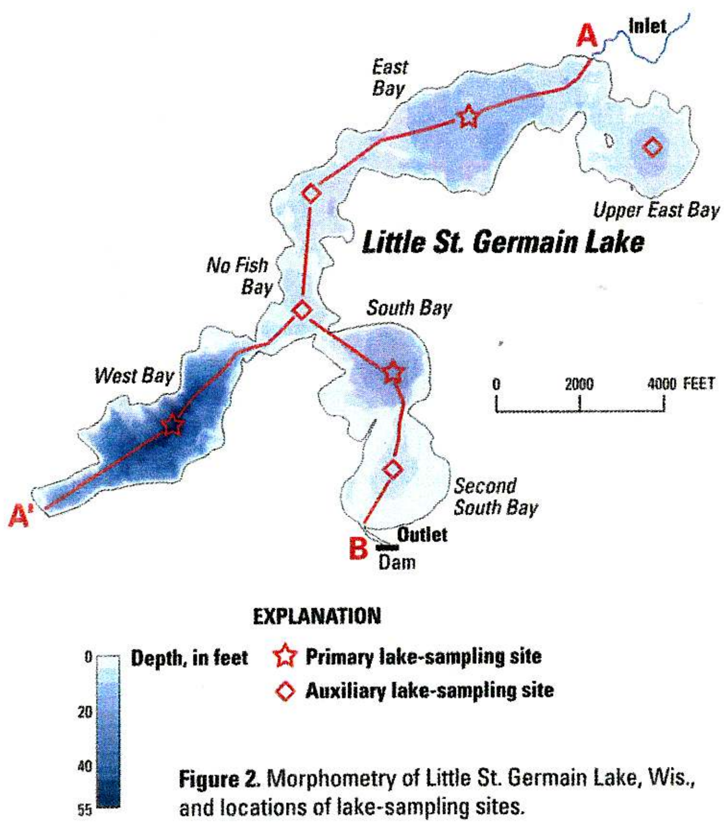


Figure 2. Morphometry of Little St. Germain Lake, Wis., and locations of lake-sampling sites.

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

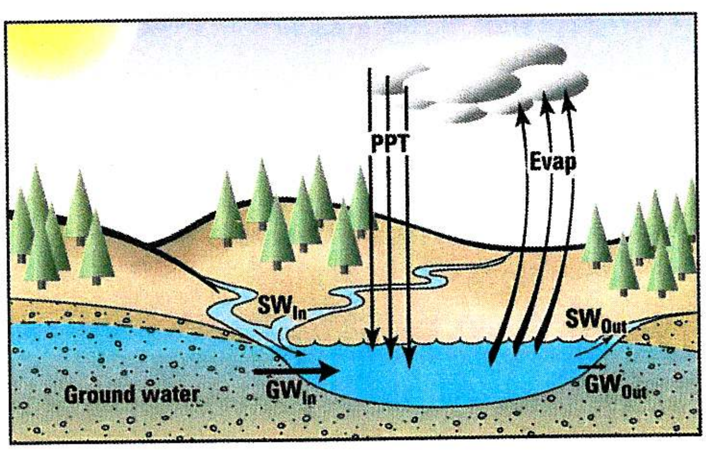


Figure 3. Schematic of the hydrologic budget of Little St. Germain Lake, Wis. Abbreviations are defined in the text.

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.

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.

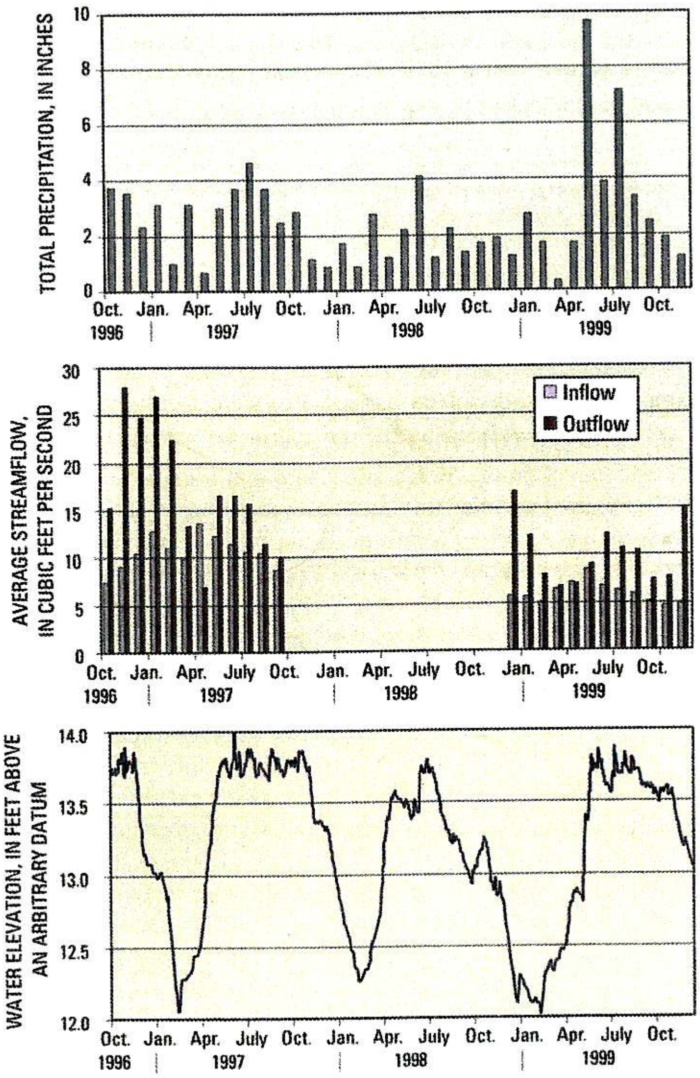


Figure 4. Monthly precipitation, inflow, outflow, and water elevation, Little St. Germain Lake, Wis.

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

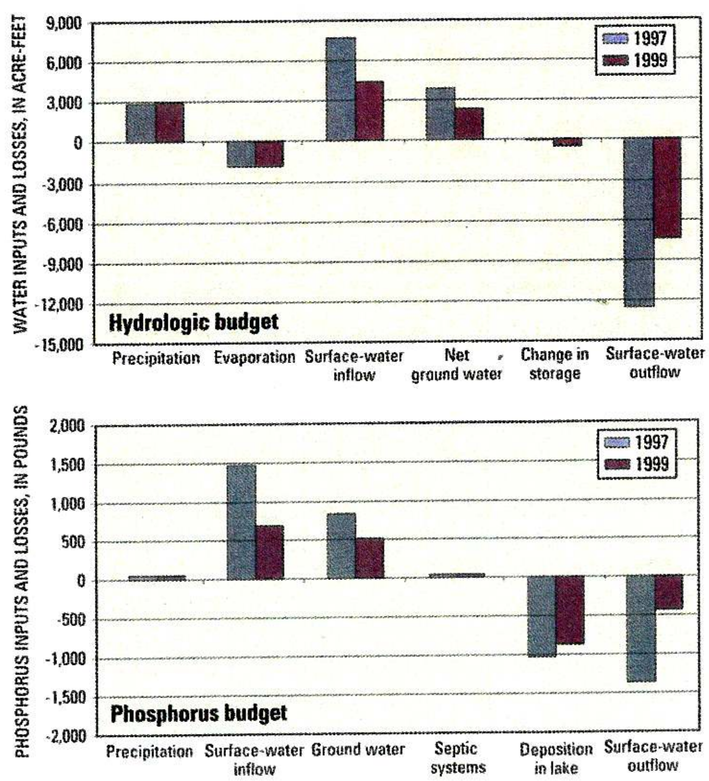


Figure 5. Hydrologic and phosphorus budgets of Little St. Germain Lake, Wis.

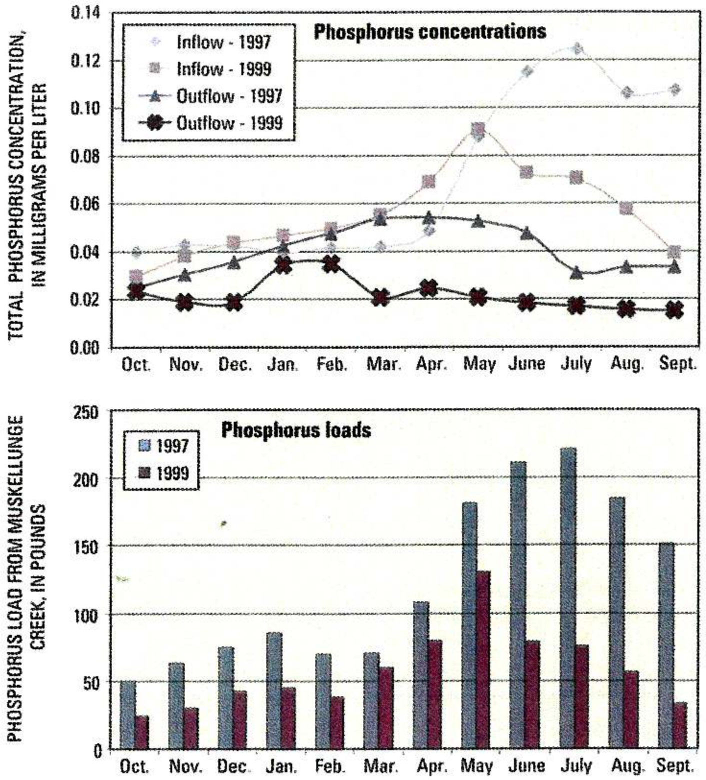


Figure 6. Phosphorus concentrations and loads in the inflow and outflow from Little St. Germain Lake, Wis., and phosphorus loads to the lake from Muskellunge Creek.

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.

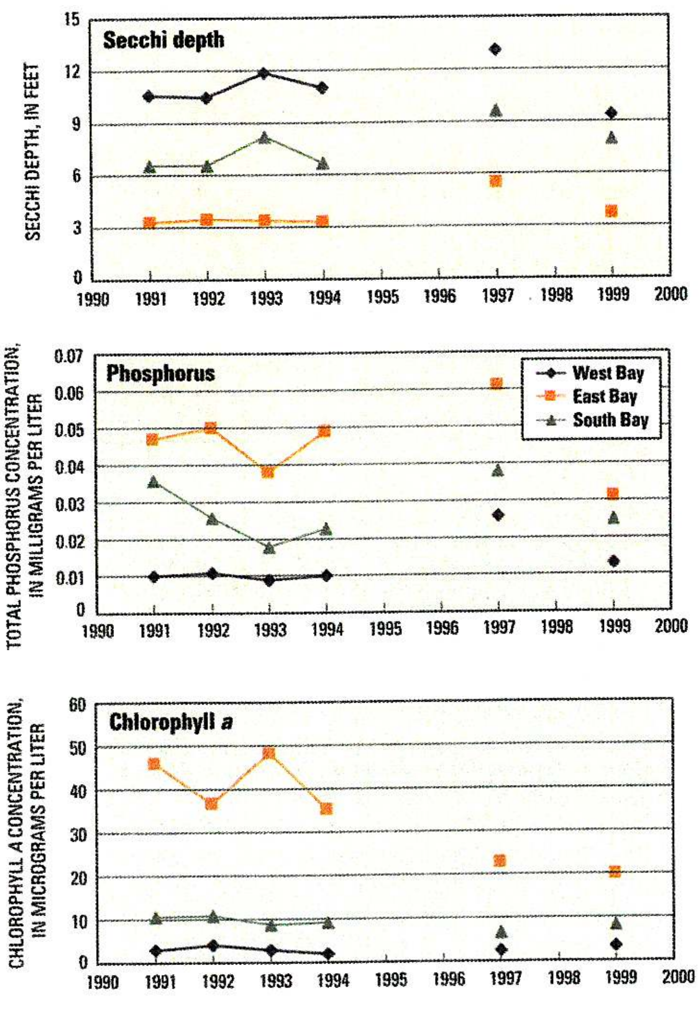


Figure 7. Average summer Secchi depth, and surface concentrations of phosphorus and chlorophyll *a* in the three main basins of Little St. Germain Lake, Wis., by year.

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.

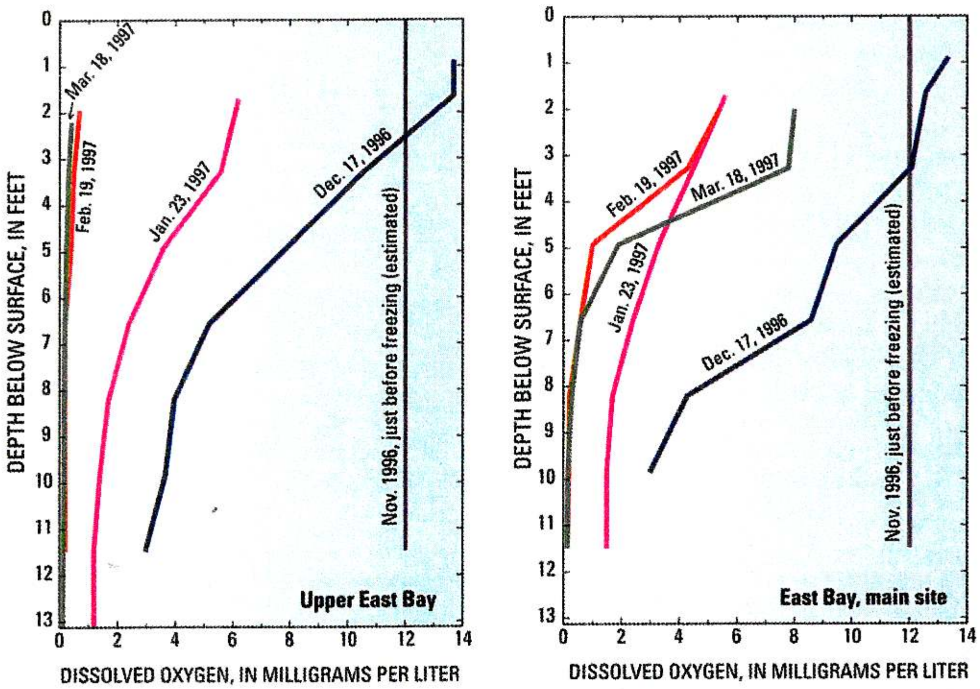


Figure 8. Oxygen distributions in the Upper East and East Bays of Little St. Germain Lake, Wis., during winter 1996–97.

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

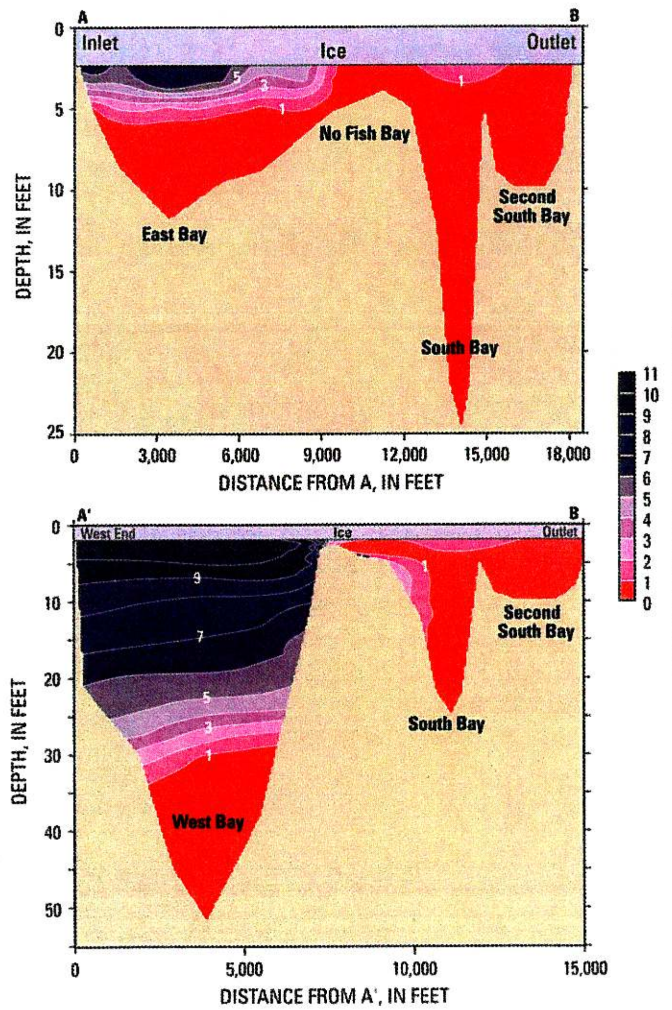


Figure 9. Distributions of dissolved oxygen in Little St. Germain Lake, Wis., March 18, 1997. (Trace of sections are shown in figure 2.)

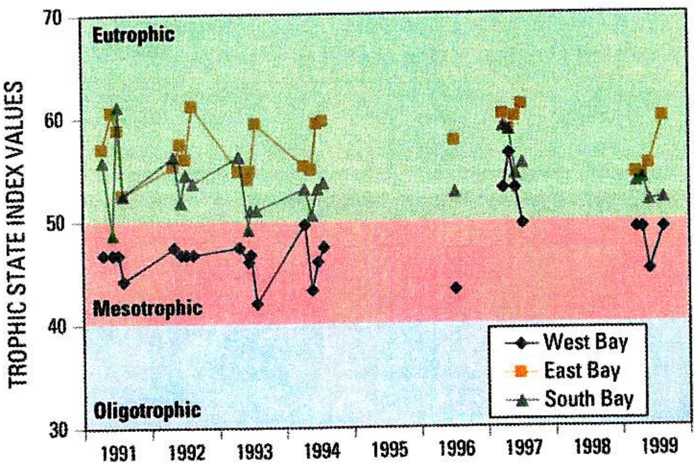


Figure 10. Trophic state indices based on surface total phosphorus concentrations in the West, East, and South Bays of Little St. Germain Lake, Wis., by year.

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 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

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Appendix B

Phosphorus Removal Evaluation

Little St. Germain Lake

Phosphorus Removal Evaluation

Samples were collected from Muskellunge Cr. on 9-3-99
Various concentrations of alum were added to the water samples
The results are shown below

Sample #	Alum conc. mg/l	Phosphorus mg/l
1	0	0.047
2	20	0
3	40	0
4	60	0
5	80	0

All concentrations of Alum reduced the dissolved phosphorus to a concentration of less than 0.002 mg/l which is the level of detection.

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Environmental Science Section — (608) 224-6277 — DNR LAB ID 113133790
Inorganic chemistry

Id: Point/Well/..: Field #: SAMPLE 1 Route: LM40
Collection Date: 09/03/99 Time: 16:30 County: 64 (Vilas)
From: MUSKELLUNGE CREEK
To: PHIL KORTH/FOTH AND VAN DYKE
P.O. BOX 19012
GREEN BAY, WI 54307-9012
Source: Surface Water
Account number: LM006
Collected by: KORTH

Date Received: 09/09/99 Labslip #: IK007142 Reported: 10/13/99

TOTAL PHOSPHORUS (AS P) (EPA 365.1)	0.047	MG/L
DISS REACTIVE PHOSPHORUS AS P (ORTHO-P)(SM 4500PE)	**	MG/L #1
TEMPERATURE ON RECEIPT	ICED	C

--- Footnotes ---
Remark #1: NO BOTTLE RECEIVED, NO TEST DONE

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Inorganic chemistry

Id: Point/Well/..: Field #: SAMPLE 2 Route: LM40
Collection Date: 09/03/99 Time: 16:30 County: 64 (Vilas)
From: MUSKELLUNGE CREEK
To: PHIL KORTH/FOTH AND VAN DYKE
P.O. BOX 19012
GREEN BAY, WI 54307-9012
Source: Surface Water
Account number: LM006 Collected by: KORTH

Date Received: 09/09/99 Labslip #: IK007143 Reported: 09/23/99

TOTAL PHOSPHORUS (AS P) (EPA 365.1)	**	MG/L	#1
DISS REACTIVE PHOSPHORUS AS P (ORTHO-P)(SM 4500PE)	*ND LOD=0.002	MG/L	#2
TEMPERATURE ON RECEIPT	ICED	C	

--- Footnotes ---
Remark #1: NO BOTTLE RECEIVED, NO TEST DONE
Remark #2: HOLDING TIME EXCEEDED BY 4 DAYS

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Environmental Science Section (608) 224-6277 DNR LAB ID 113133790
Inorganic chemistry

Id: Point/Well/..: Field #: SAMPLE 3 Route: LM40
Collection Date: 09/03/99 Time: 16:30 County: 64 (Vilas)
From: MUSKELLUNGE CREEK
To: PHIL KORTH/FOTH AND VAN DYKE
P.O. BOX 19012
GREEN BAY, WI 54307-9012
Source: Surface Water
Account number: LM006
Collected by: KORTH

Date Received: 09/09/99 Labslip #: IK007144 Reported: 09/23/99

TOTAL PHOSPHORUS (AS P) (EPA 365.1)	**	MG/L #1
DISS REACTIVE PHOSPHORUS AS P (ORTHO-P)(SM 4500PE)	*ND LOD=0.002	MG/L #2
TEMPERATURE ON RECEIPT	ICED	C

--- Footnotes ---
Remark #1: NO BOTTLE RECEIVED, NO TEST DONE
Remark #2: HOLDING TIME EXCEEDED BY 4 DAYS

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Environmental Science Section (608) 224-6277 DNR LAB ID 113133790
Inorganic chemistry

Id: Point/Well/..: Field #: SAMPLE 4 Route: LM40
Collection Date: 09/03/99 Time: 16:30 County: 64 (Vilas)
From: MUSKELLUNGE CREEK
To: PHIL KORTH/FOTH AND VAN DYKE
P.O. BOX 19012
GREEN BAY, WI 54307-9012
Source: Surface Water
Account number: LM006
Collected by: KORTH

Date Received: 09/09/99 Labslip #: IK007145 Reported: 09/23/99

TOTAL PHOSPHORUS (AS P) (EPA 365.1)	**	MG/L #1
DISS REACTIVE PHOSPHORUS AS P (ORTHO-P) (SM 4500PE)	*ND LOD=0.002	MG/L #2
TEMPERATURE ON RECEIPT	ICED	C

--- Footnotes ---
Remark #1: NO BOTTLE RECEIVED, NO TEST DONE
Remark #2: HOLDING TIME EXCEEDED BY 4 DAYS

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Environmental Science Section   (608) 224-6277   DNR LAB ID 113133790
Inorganic chemistry

Id: Point/Well/..:   Field #: SAMPLE 5   Route: LM40
Collection Date: 09/03/99 Time: 16:30 County: 64 (Vilas)
From: MUSKELLUNGE CREEK
To: PHIL KORTH/FOTH AND VAN DYKE
P.O. BOX 19012   Source: Surface Water
GREEN BAY, WI 54307-9012
Account number: LM006   Collected by: KORTH

Date Received: 09/09/99   Labslip #: IK007146   Reported: 09/23/99

TOTAL PHOSPHORUS (AS P) (EPA 365.1)	**	MG/L #1
DISS REACTIVE PHOSPHORUS AS P (ORTHO-P)(SM 4500PE)	*ND LOD=0.002	MG/L #2
TEMPERATURE ON RECEIPT	ICED	C

--- Footnotes ---
Remark #1: NO BOTTLE RECEIVED, NO TEST DONE
Remark #2: HOLDING TIME EXCEEDED BY 4 DAYS

Appendix C

Phosphorus Removal Cost Analysis

Little St Germain Lake
Phosphorus Removal System
Alum Addition - Direct Addition to Muskellunge Cr.

Capital Costs

Description		**Capital Cost**		
Chemical Feed Pump (1)		$6,000	20	$0
Chemical Storage Tank (1)		$11,000	20	$0
Equipment Building:				
Building Structure		$32,000	40	$16,000
HVAC		$6,000	20	$0
Electric & Controls		$10,000	20	$0
Piping & Valves		$5,000	20	$0
Pipeline to Stream		$5,000	40	$2,500
Stream Influent Structure		$3,000	40	$1,500
Land		$10,000	40	$5,000
Site Work		$5,000	20	$0
Access roads		$8,000	20	$0
Electric Power to Site		$15,000	20	$0
Subtotal		$116,000		$25,000
Overhead/Profit	16.0%	$18,600		
Allowances	4.0%	$4,600		
Subtotal		$139,200		
Engr/Admin/Contingency		$48,720		
Project Total		$187,920		

O&M Costs

Description	**Annual Cost**
Power (30hp - 12 mo.)	$12,000
Chemical (93gpd, 12 mo., $0.40/gal)	$13,600
Labor (8 hr/wk; 12 mo; $20/hr)	$8,300
Sludge Dredging and Disposal	$131,000
Lab Analysis	$2.000
Total	$166,900

Present Worth Analysis

	Cost	Present Worth Factor	Present Worth
Capital Cost	$187,920	1	$187,920
Annual O&M Cost	$166,900	10.7	$1,785,830
Salvage Value	$25,000	0.265	($6.613)
Total Present Worth			$1,967,000

Little St Germain Lake
Phosphorus Removal System
Alum Addition - Settling Lagoon (Unlined)

Capital Costs

Description		Capital Cost	Service Life	Salvage Value
Stream Diversion Structure & Pipeline		$20,000	20	$0
Submersible Water Pump (1)		$35,400	20	$0
Chemical Feed Pump (1)		$6,000	20	$0
Chemical Storage Tank (1)		$8,400	20	$0
Equipment Building:				
Building Structure		$28,800	40	$14,400
Wet Well		$24,000	40	$12,000
HVAC		$5,700	20	$0
Electric & Controls		$16,200	20	$0
Piping & Valves		$13,000	20	$0
Pipeline to Lagoon		$20,000	40	$10,000
Lagoon construction:				
Clear & Grub		$13,000	40	$6,500
Cut & Fill		$72,000	40	$36,000
Rip Rap		$35,000	20	$0
Turf		$6,000	20	$0
Fence		$21,000	20	$0
Pond Effluent Structure		$7,700	20	$0
Pipeline to Stream		$63,600	40	$31,800
Stream Influent Structure		$8,600	40	$4,300
Land		$50,000	40	$25,000
Access roads		$15,000	40	$7,500
Electric Power to Site		$35,000	40	$17,500
Subtotal		$504,400		$165,000
Overhead/Profit	16.0%	$80,700	20	$0
Allowances	4.0%	$20,200	20	$0
Subtotal		$605,300		$165,000
Engr/Admin/Contingency		$211,855		
Project Total		$817,155		

O&M Costs

Description	Annual Cost
Power (30-hp - 12 mo.)	$12,000
Chemical (93 gpd, 12 mo., $0.40/gal)	$13,400
Labor (8 hr/wk; 12 mo; $20/hr)	$8,300
Sludge Disposal	$44,000
Lab Analysis	$2.000
Total	$79,700

Present Worth Analysis

	Cost	Present Worth Factor	Present Worth
Capital Cost	$817,155	1	$817,155
Annual O&M Cost	$79,700	10.7	$852,790
Salvage Value	$165,000	0.265	($43,643)
Total Present Worth			$1,626,000