LITTLE GREEN LAKE MANAGEMENT PLAN

PREPARED FOR:
LITTLE GREEN LAKE PROTECTION & REHABILITATION DISTRICT

PREPARED BY:
RAMAKER & ASSOCIATES, INC.

December, 1997

LPL-445?

RAMAKER
& ASSOCIATES, INC.
Consulting Engineers

February 9, 1998

Mr. Carroll Schaal, Lake Management Planner
WDNR, Bureau of Water Resources Management
101 S. Webster Street
P.O. Box 7921
Madison, WI 53707-7921

SUBJECT: LITTLE GREEN LAKE MANAGEMENT PLAN

Dear Mr. Schaal:

Please find enclosed a copy of the lake management plan that was recently completed by Ramaker & Associates, Inc. on behalf of the Little Green Lake Protection and Rehabilitation District. You may recall that I promised to give you a copy of the report as soon as it was finalized.

If you have any questions or comments regarding the document, please feel free to call me.

Sincerely,

RAMAKER & ASSOCIATES, INC.

Paul D. Dearlove

Paul D. Dearlove
Water Resources Specialist

Enclosure

Document2

LAKE MANAGEMENT PLAN

LAKE: Little Green Lake

LOCATION: Township of Green Lake
Green Lake County, Wisconsin

PREPARED FOR: Little Green Lake Protection and Rehabilitation District
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Markesan, Wisconsin 53946

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RAMAKER JOB NUMBER: 2928

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Paul D. Dearlove Date
Water Resources Specialist

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Stephen J. Field Date
Project Advisor

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Terry J. Ramaker, P.E. Date
President

I, Terry J. Ramaker, hereby certify that I am a registered professional engineer in the State of Wisconsin, registered in accordance with the requirements of ch. A-E, Wis. Adm. Code; that this document has been prepared in accordance with the Rules of Professional Conduct in ch. A-E 8, Wis. Adm. Code; and that, to the best of my knowledge, all information contained in this document is correct.

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EXECUTIVE SUMMARY

Little Green Lake is a small, relatively shallow water body located just north of the City of Markesan in the Township of Green Lake, Green Lake County, Wisconsin. The lake is a regional asset that supports a variety of recreational activities, such as fishing, boating, swimming and wildlife viewing. Little Green Lake is classified as eutrophic, indicating a high level of fertility and primary productivity caused by nutrient-enrichment. Water chemistry data indicate phosphorus is the nutrient responsible for nuisance algae blooms and the generally poor water quality conditions.

Surface water runoff transports phosphorus-containing material such as eroded soil, organic debris and agricultural/lawn fertilizers to the lake from the surrounding watershed (the land area that drains to the lake) – a process referred to as external nutrient loading. Phosphorus is also delivered to the lake through internal nutrient loading mechanisms that result in an in-lake recycling of nutrients. For instance, phosphorus is commonly released during aquatic plant senescence and decomposition, as well as from the bottom sediments when the overlying water layer, called the hypolimnion, becomes devoid of oxygen.

Sediment data collected by the U.S. Geological Survey in the summer of 1997 revealed that sediment phosphorus concentrations and lake-depth are positively correlated. In other words, the data show that as lake-depth increases, phosphorus concentrations also increase. This suggests that the bottom sediment in the deep water, hypolimnetic areas is of higher phosphorus content than the sediment in the shallower areas. Finally, the data reveal that the sediment phosphorus content within the bays is relatively consistent.

As with all lake ecosystems, Little Green Lake is governed by complex and highly interrelated physical, chemical and biological processes. Thus, it is not uncommon for an isolated problem area(s) within the lake or its surrounding drainage basin to translate into whole-lake impacts. The Little Green Lake Protection and Rehabilitation District (Lake District) is commended on its role of working in an expeditious, but cautious manner to accurately identify and address these problem areas. The efforts that are already taking place within the surrounding watershed to control external nutrient loading (i.e., sediment detention basins and barnyard runoff control measures) represent an important step in the comprehensive management and improvement of Little Green Lake.

According to the Lake District, present lake conditions—namely excessive plant and algae growth—are interfering with desired lake uses and jeopardizing the long-term health of the lake. Concerns raised by many of the lake residents regarding these conditions prompted the Lake District to develop a comprehensive lake management plan. The purpose of the lake management plan was to (1) compile and analyze existing lake and watershed data, (2) identify and prioritize desired lake uses and problems, and (3) determine the appropriate management options that are best designed to address the key issues.

Input from Little Green Lake residents was solicited through a survey and town meeting. This input, in conjunction with data characterizing the lake and its contributing watershed, was used to rank desired lake uses and identify the main factors that inhibit these uses. Upon completion of the citizen participation phase, it was revealed that water quality/clarity was viewed as the most important aspect contributing to a preferred lake environment. Fishing and aesthetic enjoyment of the lake setting (e.g., scenic views and tranquility) were identified as the two most desirable and valued lake uses. There was overwhelming agreement that nuisance algae and aquatic weed growth represented the greatest lake-use impairments.

Various management options were then researched to determine their applicability in rectifying the particular problems. Management techniques were evaluated based on certain criteria, and recommendations were made unless information gaps prevented sufficient analysis. Critical information gaps discovered during the planning process include a phosphorus budget for the lake and determination of annual mean discharge. When these data are obtained, the Lake District will be in a more advantageous position to expand appropriate management strategies.

The Lake District is advised to take the following actions:

1. Rectify the identified information gaps. The U.S. Geological Survey is currently obtaining discharge measurements at the outlet. Annual mean discharge is a critical input variable used in a number of lake-modeling applications. This information is also needed to develop a phosphorus budget for Little Green Lake, which is another identified information gap. Therefore, the Lake District is now encouraged to develop a "limited" phosphorus budget that will show whether the majority of the nutrient loading to the lake is occurring from external (watershed) sources or internal (in-lake) sources. This information is needed to help focus management efforts appropriately. If it is confirmed that internal, rather than external nutrient loading is the problem, the Lake District will have to decide whether to pursue the funds to precisely identify and remedy the internal nutrient recycling problem.

2. Re-evaluate management options that were recommended on a tentative basis as a result of information gaps that previously prevented sufficient analysis. For instance, if the limited phosphorus budget suggests that the level of external nutrient loading is unacceptable, management options should be implemented that are designed to address the external loading problem (i.e., landowner activities and watershed planning/runoff control). This scenario should also warrant further analysis to determine actual phosphorus contributions from individual septic systems, and the feasibility of sewering the lake as a cost-effective management alternative. Conversely, if the limited phosphorus budget suggests that the in-lake recycling of nutrients is the main problem, management options should be implemented that are designed to address the internal nutrient loading problem (i.e., phosphorus precipitation/inactivation and hypolimnetic withdrawal).

3. Select and implement viable management options that satisfy the Lake District's budgetary constraints, address the identified problem areas, support desired lake-use activities, etc. The Lake District should pay close attention to the potential benefits, potential negative impacts, estimated costs, and longevity of effectiveness associated with each management technique. Viable management options based on current information include the following:

   Control of external nutrient loading

   - Individual landowner activities and watershed planning/runoff control measures (currently being addressed)

   Control of internal nutrient loading

   - Phosphorus precipitation/inactivation (also known as an alum treatment) and hypolimnetic withdrawal; note that mechanical harvesting and removal of aquatic plant biomass has also been shown to remove nutrients from lakes

   Control of biological consequences of nutrient loading

   - Mechanical plant harvesting (also shown to remove nutrients) and sediment covers to specifically control nuisance aquatic plant growth
   - Biomanipulation (e.g., through fish stocking programs) to specifically control nuisance algae growth

   <u>Notes</u>:
   A majority of the desired lake uses and values will be supported if a reduction in algae growth is achieved in conjunction with a thriving, but controlled plant community. Therefore, mechanical plant harvesting is recommended as a management technique to be used along with nutrient loading reduction strategies. If mechanical harvesting is selected as a management technique, the preparation of an Aquatic Plant Harvesting Plan is recommended to meet eligibility requirements for financial assistance programs administered by the Wisconsin Department of Natural Resources. These programs offer grants that can be used to purchase mechanical harvesters.

In addition, the Lake District is encouraged to continue participating in the planning process regarding the proposed Highway 44 dam improvement project. If a lake level drawdown is ultimately considered as a potential management technique to control nuisance plant growth, the new dam will need to be designed accordingly.

Modification of lake-use behavior

- Lake resident participation/education to increase awareness and support of management activities (i.e., through a regular newsletter mailing to Lake District members)

4. Finally, continue the water quality monitoring program. Continuous, long-term water quality data are needed to assess the effectiveness of management actions. This information is also used to accurately identify and characterize water quality trends and problems.

ACKNOWLEDGMENTS

Ramaker & Associates, Inc. thank the following people who contributed to the development of this lake management plan: Ms. Jill Geisthardt and Mr. Gregory Cygnar, primary liaisons for the Lake Planning Subcommittee of the Little Green Lake Protection & Rehabilitation District; Mr. William Rose, Hydrologist with the U.S. Geological Survey; Mr. Mark Sesing, Water Resources Manager for the Wisconsin Department of Natural Resources; Mr. James Hebbe, County Conservationist for the Green Lake County Conservation Department; Mr. Dale Robertson, Limnologist for the U.S. Geological Survey; Mr. William James, Aquatic Biologist for the U.S. Army Engineer Waterways Experiment Station (Eau Galle Aquatic Ecology Laboratory); and all the Little Green Lake residents who participated by completing surveys, attending the Town Meeting and offering valuable information.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

Little Green Lake is located in Township 15 North, Range 13 East, Sections 29-32, Green Lake County, Wisconsin. A map depicting the location of Little Green Lake is included in Figure 1. The lake is characterized as a seepage lake with two intermittent inlets and one intermittent outlet. It is a small, shallow system that is highly productive as a result of nutrient-enrichment. The shoreline is moderately developed with approximately 167 residences bordering the lake. Little Green Lake is used primarily for recreational purposes such as fishing, boating, swimming, wildlife viewing and relaxation.

A lake management plan was developed in response to concerns raised by many of the more than 240 lake residents regarding the deterioration of Little Green Lake's water quality. According to the Little Green Lake Protection and Rehabilitation District (Lake District), present lake conditions (namely excessive aquatic plant and algae growth) were interfering with desired lake uses and jeopardizing the long-term health of the lake.

On June 21, 1997, the Lake District convened its annual meeting and was granted approval to prepare a comprehensive lake management plan by contracting with the engineering consulting firm of Ramaker & Associates, Inc. A $10,000 matching grant, awarded through Wisconsin's Lake Planning Grant Program, was used in conjunction with local revenues to fund the project.

1.2 PROJECT GOALS & STRATEGY

As outlined in the Lake District's Request for Proposals, the development of a comprehensive lake management plan was intended to help attain the following goals:

1. To prevent further deterioration of the water quality; and
2. To implement those programs that will greatly improve the lake's entire ecosystem

A strategy consisting of four phases was employed to satisfy the planning component of the lake protection and rehabilitation process. The four phases of the lake management planning strategy are detailed below.

<u>Phase 1: Analysis of Existing Lake & Watershed Data</u>
This phase involved the collection and analysis of existing data that characterizes Little Green Lake and its surrounding drainage basin.

<u>Phase 2: Identification of Desired Lake Uses & Problems</u>
This phase included the solicitation of opinions and views of the lake residents regarding the present condition and future management of the lake environment. A comprehensive survey and town hall meeting were used to identify the lake uses that are most important to lake residents, as well as the conditions that interfere with these uses.

<u>Phase 3: Prioritization of Desired Lake Uses & Problems</u>
This phase involved the prioritization of desired lake uses and perceived problems identified during Phase 2. The prioritization of these issues was supported by a consensus, to the extent possible, of the lake residents. The purpose of this phase was to resolve conflicting lake-use goals, determine if the identified goals were obtainable, and distinguish between real and perceived problems. This phase identified those problems that pose the most consistent and serious threat to the lake's water quality.

Phase 4: Presentation of Potential Solutions

This phase involved the presentation of potential solutions to the problems identified in Phase 2 & 3. The recommended management strategy's goal is the improvement of the lake's overall ecosystem. This phase also included the identification of information gaps that will need to be addressed prior to the implementation of particular management options.

Successful lake protection and improvement projects generally follow a three-step process. The process includes:

1. The collection of baseline information characterizing the physical, chemical and biological aspects of the lake and its drainage basin;
2. The preparation of a lake management plan utilizing the baseline information to determine the appropriate protection and rehabilitation strategy; and
3. The implementation of the strategy that is outlined in the lake management plan.

Adhering to the above methodology encourages sound decision making while increasing the probability that the most cost-effective lake improvement strategy is ultimately implemented. As a result, "quick fixes" that are often short-lived and cost-prohibitive over the long-term are avoided. Instead, a management strategy will be employed that addresses the underlying causes or source of a particular problem rather than the symptoms.

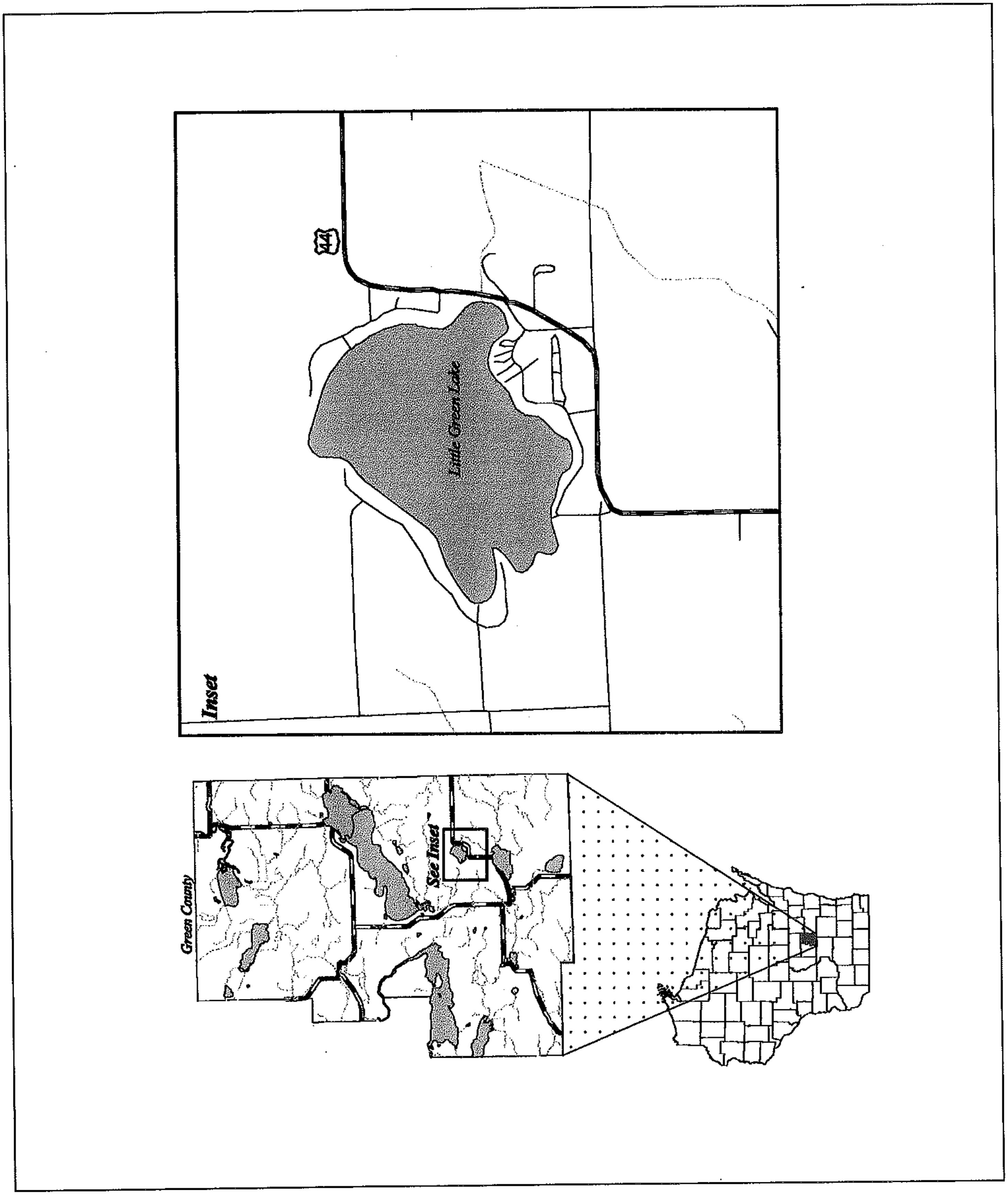


Figure 1
Location Map

SECTION 2
ANALYSIS OF EXISTING LAKE & WATERSHED DATA

A list of some past lake and watershed studies conducted on Little Green Lake is included in Appendix A. The results of these studies provided the necessary baseline information that was critical to the development of the lake management plan. A brief summary of the key information that was collected from these studies and other available and ascertainable sources is presented below.

2.1 DRAINAGE BASIN

The land area that drains into a given body of water is defined as a drainage basin or watershed. Topographic high points (e.g., ridge tops) delineate the boundaries of a particular watershed and separate it from other adjoining watersheds. Water from snowmelt, precipitation and groundwater-derived discharge is collected within the watershed and eventually drains into the receiving water body as surface water runoff. This runoff transports pollutants and sediment from the watershed to the lake. The actual amount of material delivered depends on watershed land-use practices and runoff flow characteristics.

Little Green Lake is part of a 3.33-square mile watershed [United States Geological Survey (USGS) Data Summary, 1996]. The watershed area is delineated from the lake's outlet and includes the surface area of the lake. Given that Little Green Lake has a 0.728 square mile surface area, the watershed-to-lake surface area ratio is 3.57:1. Lakes with ratios exceeding 10:1 generally exhibit water quality problems. A 7.5-Minute Topographic Quadrangle Map with the Little Green Lake Watershed delineated on the map is included in Figure 2.

The watershed consists predominantly of the Plano-Mendota-St. Charles soils association. A soil association is a landscape that has a distinctive pattern of soils in defined proportions. It typically consists of one or more major soils and at least one minor soil, and is named for the major soils. The Plano-Mendota-St. Charles soils association is described as well drained to moderately well drained, with nearly level to sloping soils that have a subsoil mainly of silt loam and silty clay loam underlain by calcareous, gravelly or very gravelly, sandy loam glacial till[United States Department of Agriculture (USDA), 1977].

Watershed topography is gently rolling, with the most dramatic elevation changes (i.e., 110-foot change in relief within a one-quarter mile distance) located just north of Little Green Lake. The lake is situated at an average elevation of 922 feet above mean sea level. The direction of surface water flow at the outlet is toward the east (USGS Quadrangle Map, 1980).

Land use within the watershed of Little Green Lake is 77% agricultural, 15% wooded, 5% residential and 3% roads. Most of the cropland is farmed intensively with row crops such as sweet corn, field corn, peas, soybeans and wheat (Green Lake County Conservation Department, 1994). This type of land use is known to contribute significant quantities of sediment-laden runoff and nutrient loads to receiving water bodies, especially if runoff control measures (known as Best Management Practices, or BMPs) are not implemented. Results from a recent watershed inventory study that estimated the amount of sediment and nutrient loading to Little Green Lake are included in Appendix B.

2.2 LAKE TYPE

Little Green Lake is characterized as a groundwater seepage lake [United States Geological Survey (USGS) Data Summary, 1996; Wisconsin Department of Natural Resources (WDNR), 1995]. Groundwater seepage lakes are defined as systems that lack a significant inlet or outlet (Little Green Lake has two intermittent inlets and one intermittent outlet). They are further defined as landlocked water bodies where the principal source of water is precipitation and/or runoff, supplemented by groundwater from the immediate drainage area.

Water levels in these systems tend to fluctuate on a seasonal basis. Little Green Lake is also described as a shallow water body. Shallow lakes tend to be more productive than deep lakes due to a number of factors. These factors include the large area of bottom sediments relative to the volume of water, more complete wind mixing of the water column, and the large, shallow areas along the lake perimeter that can be colonized by rooted and floating aquatic plants (also known as the littoral zone).

2.3 LAKE MORPHOLOGY

Little Green Lake has a surface area of 0.728 square miles (466 acres), with 4.2 miles of shoreline. The lake is 26.5 feet at its deepest point near the center, has a mean depth of 10 feet, and contains an average of 4,817 acre-feet of water. Approximately 12% of the lake area is under 3 feet deep, while about 4% of the lake area is greater than 20 feet deep (WDNR Lake Survey Map, 1965). A bathymetric, or lake contour map showing the morphology of Little Green Lake is presented in Figure 3.

Water volume in Little Green Lake is regulated by an outlet structure located at Highway 44, on the east side of the lake. The existing dam consists of an embankment and a 3-foot by 4-foot drop inlet box with a screen and fixed weir for lake level control. The outlet structure is a 15-inch diameter corrugated metal pipe and a 32-inch diameter overflow iron culvert pipe. This outlet structure will be modified during a Highway 44 improvement project that is currently scheduled for the spring of 1998 (O'Meara, personal communication).

2.4 MACROPHYTE COMPOSITION

Little Green Lake has a relatively extensive littoral zone in relation to its surface area. The littoral zone is the portion of the lake that is able to support rooted aquatic plant, or macrophyte, growth. The depth at which sunlight is able to penetrate the water column in quantities necessary to promote photosythesis determines the extent of the littoral zone. The littoral zone in Little Green Lake ranges from 0-14 feet in depth. Submergent vegetation is most common in depths of less than 10 feet, while floating and emergent vegetation is most common at depths of less than 5 feet.

During the summer of 1993, an aquatic macrophyte survey was performed on Little Green Lake. Results indicate that Little Green Lake is an ecosystem with low to moderate species diversity and a high amount of biomass, or species abundance. *Ceratophyllum demersum*, or coontail, was the single most abundant species sampled (relative frequency of 24%), followed by *Potamogeton crispus*, or curlyleaf pondweed (relative frequency of 21%), *Myriophyllum spicatum*, or Eurasian milfoil (relative frequency of 19%) and filamentous algae (relative frequency of 17%). No endangered or threatened plant species were identified during the survey. It is important to recognize that species composition and density are known to vary considerably throughout the growing season and from year to year.

The plant community in Little Green Lake is considered a fair food source for wildlife and waterfowl. Aquatic macrophyte growth in the lake is beneficial to the fishery by providing food, cover and spawning habitat. However, excessive growth often inhibits desired lake uses such as swimming and boating, and may result in stunted fish populations by reducing predator success. For example, *Potamogeton crispus* and *Myriophyllum spicatum* are non-native invasive species that, if left unchecked, have the potential to rapidly proliferate and out-compete native species (Northern Environmental Technologies, Inc., 1994).

2.5 FISHERY

Carp and white bass were the two most common species found in Little Green Lake prior to 1955. However, an intense algae bloom that occurred in the summer of 1955 resulted in a massive fish kill as dissolved oxygen levels were depleted from subsequent decomposition of decaying plant matter. The remaining carp and white bass were later completely eliminated from the lake when they were exposed to a fish toxicant known as toxaphene. Walleye, largemouth bass and bluegill were then introduced in an effort to establish a more desirable fishery.

A 1966 seine hall confirmed that carp and white bass had been completely eliminated from the lake. To help control a stunted bluegill population, muskellunge were introduced in 1956, followed by hybrid muskellunge in 1970. Mr. James Congdon, Area Fish Manager for the WDNR, conducted a partial fish survey in 1990 which showed that panfish overabundance was still a problem, especially white crappie populations. The panfish population explosions have resulted in the stunting of fish growth due to increased competition for limited resources, such as food and space. Mr. Congdon reported that panfish have a history of overabundance and slow growth in the lake due to limited predator abundance and dense macrophyte beds that provide refuge from existing predators (Miller Severn, 1974).

According to a survey of lake residents conducted as part of this Lake Management Plan, the most valued fish species found in Little Green Lake today include walleye, panfish, muskellunge, largemouth bass and smallmouth bass, respectively (Appendix B). The survey indicated that the average size (in inches) of each fish species caught on the lake is as follows: walleye (14.7), panfish (6.4), muskellunge (32.4), largemouth bass (12.6), and smallmouth bass (10.4). This size distribution falls within the average range for lakes exhibiting characteristics similar to Little Green Lake.

2.6 THERMAL STRATIFICATION

Little Green Lake is considered a shallow system that exhibits weak thermal stratification during the summer months (USGS Data Summary, 1996). Thermal stratification of a lake's water column is caused by differential heating, temperature-dependent variations in density and wind-driven mixing. As air temperatures rise, a density "barrier" begins to form between the warmer surface water that is heated by solar energy and the underlying denser, colder water. This barrier is marked by a sharp temperature gradient known as the thermocline. The zone where the thermocline occurs is known as the metalimnion. It separates the warmer, less dense, upper zone of water called the epilimnion, from the cooler, more dense, lower zone called the hypolimnion. Complete mixing of the water column, known as destratification, occurs during spring and fall turnover, while intermittent mixing of hypolimnetic and epilimnetic waters occurs during Little Green Lake's weakly stratified summer period.

2.7 TROPHIC STATUS

Trophic status is a measure of nutrient enrichment and primary productivity, and is determined by correlating three water quality parameters--phosphorus concentration, chlorophyll *a* concentration and Secchi depth. Phosphorus is generally the nutrient that limits the amount of primary productivity in temperate, freshwater lakes. Chlorophyll *a* is the green photosynthetic pigment found in plant cells and is an indicator of phytoplankton (algae) biomass. Finally, Secchi depth measures water clarity.

Lakes are frequently characterized according to their trophic state, which may range from nutrient-poor and relatively unproductive, to nutrient-rich and highly productive. In order from least to most productive, lakes are characterized as either oligotrophic, mesotrophic, eutrophic or hypereutrophic, respectively. These trophic state categories represent degrees of eutrophication.

Eutrophication, natural or human-induced, is the response of a lake to over-enrichment of nutrients, particularly phosphorus and nitrogen. The resultant increase in fertility in an affected water body may cause algal blooms and excessive aquatic plant growth, which may ultimately lead to the depletion of dissolved oxygen and unpleasant odors as decomposition rates increase. Several factors determine the rate of eutrophication, including watershed size, nutrient and sediment inputs, lake morphology, soil type, climate and human activities. Human-induced eutrophication is caused by such inputs as municipal wastewater, fertilizers and agricultural runoff.

The trophic status of Little Green Lake over the six-year monitoring period was predominantly eutrophic, especially in terms of total phosphorus. However, chlorophyll *a* and Secchi depth indices revealed that the lake shifted to a mesotrophic state in 1993, 1995 and 1996 (USGS Data, 1991-96). A plot of total phosphorus and chlorophyll *a* concentrations, and Secchi depths for Little Green Lake is shown in Figure 4.

This data was used to graph trophic state indices for Little Green Lake over the six-year sampling period, and is illustrated in Figure 5.

2.8 WATER-QUALITY INDEX

Lillie and Mason (1983) classified all Wisconsin lakes using a random data set collected in the months of July and August. The water-quality index that was developed is based on surface total-phosphorus and chlorophyll *a* concentrations and Secchi depths. Applying the water-quality index to Little Green Lake revealed that the measured surface total-phosphorus and chlorophyll *a* concentrations were indicative of "very poor" water quality, while Secchi depths were indicative of "poor" water quality.

Lillie and Mason (1983) also provide a means of comparing the condition of Little Green Lake with other lakes in southeastern Wisconsin. Table 1 shows the percentage distribution of southeastern Wisconsin lakes that fall within a certain range of values for each condition group (i.e., total phosphorus, chlorophyll *a* and Secchi depth), and the relative position of Little Green Lake (USGS Data Summary, 1996).

2.9 ACIDITY/BUFFERING CAPACITY

The pH is a measure of the hydrogen-ion concentration, which affects the solubility of many chemical constituents and is influenced by biological activity. A pH of 0 is highly acidic, a pH of 14 is highly basic, and a pH of 7 is considered neutral. The amount of dissolved carbon dioxide in a lake, which is influenced by photosynthesis and respiration processes, generally influences pH. For instance, as carbon dioxide levels increase, pH usually decreases, and vice versa. Water chemistry data indicate that the pH of Little Green Lake ranges from 7.2 to 8.8. These values are common for southeastern Wisconsin lakes, and indicate that the system is well buffered from acidification (USGS Data, 1991-96).

2.10 LIMITING NUTRIENT

A limiting nutrient is an element that is critical to the growth of primary producers, but is found in short supply relative to other required elements found in a particular water body. Because the essential nutrient is in short supply, it effectively limits the amount of productivity.

The limiting nutrient for algae growth in Little Green Lake is predominantly phosphorus, but occasionally nitrogen becomes limiting. Nitrogen to phosphorus (N:P) ratios ranged from 13:1 to 22:1 during the six-year sampling period. A N:P ratio greater than 20 suggests that phosphorus is the limiting nutrient, whereas nitrogen may be the limiting factor when the ratio is less than 13. Lakes with intermediate ratios could be limited from time to time by either element, but by reducing phosphorus availability, phosphorus could be made the limiting factor.

Phosphorus is generally the focus of lake-management programs because it is usually the limiting nutrient that controls algae growth. Furthermore, phosphorus is an element with no gaseous component in its biogeochemical cycle and is therefore easier to manipulate.

As illustrated in Figure 4, there is no clear year-to-year trend toward increasing or decreasing total phosphorus concentration in Little Green Lake during the six-year sampling period (USGS Data Summary, 1996).

2.11 PHYTOPLANKTON ABUNDANCE

Chlorophyll *a* is the primary photosynthetic pigment found in all photosynthesizing organisms (e.g., algae). It is commonly used as an indicator of total algae biomass. Chlorophyll *a* values for Little Green Lake during the summer months generally indicated a eutrophic, or highly productive ecosystem, but occasionally were representative of a mesotrophic system. As illustrated in Figure 4, there appears to be a slight trend toward decreasing chlorophyll *a* concentration during the six-year sampling period (USGS Data Summary, 1996).

2,500 mg/Kg at the deepest point (26-foot lake depth). The data also show that the sediment phosphorus content within the bays is relatively consistent (USGS sediment data, 1997).

To evaluate the sediment phosphorus data in Little Green Lake's shallow areas, comparisons of sediment phosphorus data at 0-3-foot water depths are shown in the following table for Big Muskego Lake (Muskego, Wisconsin) and the Delavan Lake inlet (Delavan, Wisconsin). These data were obtained through the U.S. Army Engineer Waterways Experiment Station (Eau Galle Aquatic Ecology Laboratory). Because there is a great deal of physical, chemical and biological variability among lake ecosystems, the reader should be very cautious in attempting to derive conclusions regarding Little Green Lake based on these limited data comparisons.

LAKE NAME	MEAN TOTAL PHOSPHORUS (mg/Kg) (sediment data for 0-3-foot water depths)
Little Green Lake	645
Big Muskego Lake	932
Delavan Lake (inlet)	1,392

In reference to the above table, Big Muskego Lake and the Delavan Lake inlet are both shallow water bodies with depths less than or equal to three feet. Big Muskego Lake was shown to have little phosphorus release from the sediment during elevated pH or anoxic conditions. On the other hand, the Delavan Lake inlet was shown to have large amounts of pbosphorus release from the sediment during elevated pH or anoxic conditions (William James, personal communication).

Only a detailed study of the internal recycling mechanism for Little Green Lake will quantify phosphorus releases from sediment in the near shore areas. However, it is evident that the nutrient-rich sediment is generally confined within the deeper, hypolimnion of the lake, suggesting the potential for large phosphorus releases from this area during periods of anoxia. A map depicting the various sample locations and a summary of the data are included in Appendix C.

There are at least two explanations that might account for the observed relationship between sediment phosphorus content and lake-depth. First, fertile sediment that may have once been deposited in the near shore areas could become buried under less nutrient-rich material over time. This process may be occurring within Little Green Lake, especially as barnyard manure/agricultural runoff into the lake is mitigated through the implementation of watershed Best Management Practices such as conservation farming and sediment detention basins. Second, a process known as sediment focusing may be transporting phosphorus-rich sediment into the deeper areas as a result of physical lake mixing.

2.12 WATER CLARITY

Secchi-disc measurements, known as Secchi depths, provide a measurement of water clarity. A Secchi disc is an eight-inch-diameter, black-and-white patterned disc that is lowered to a depth at which it is no longer visible from the water surface. The recorded depth is used to evaluate the transparency of the water column. Transparency may be affected by factors such as turbidity (caused by suspended particulate matter), water color (influenced by dissolved organic and inorganic material), and/or algae.

Secchi depth values for Little Green Lake during the summer months were generally indicative of a eutrophic, or highly productive ecosystem. However, values were occasionally representative of a more mesotrophic system. As illustrated in Figure 4, there appears to be a slight trend toward increasing Secchi depths or an increase in water clarity during the six-year sampling period (USGS Data Summary, 1996).

2.13 DISSOLVED OXYGEN/WATER TEMPERATURE PROFILES

Dissolved oxygen is one of the most critical factors affecting a lake ecosystem, and is essential to all aquatic organisms that require aerobic conditions. In addition, the amount of oxygen at the sediment-water interface within the hypolimnion plays an important role in the mobilization of nutrients such as phosphorus from the bottom sediments to the water column, where these nutrients become available for algae growth.

Nutrient releases often occur when oxygen is depleted to the point where anoxic conditions develop. For instance, as thermal stratification isolates the hypolimnion from the atmosphere, the surface supply of oxygen from the atmosphere is sealed off. The remaining dissolved oxygen is often rapidly consumed when respiration rates increase due to excessive decomposition of organic material that settles to the bottom. As anoxia develops, phosphorus contained in the sediments chemically converts into a more soluble state, migrating from the sediments to the surrounding water. This nutrient-enriched water may then be mixed throughout the entire water column as a result of thermal destratification.

Higher phosphorus concentrations measured near the bottom of Little Green Lake suggest that anoxic conditions are causing nutrient releases from the sediments. For instance, during the summer of 1991, the total phosphorus concentration at the bottom of the lake was 1.29 mg/L, compared to 0.17 mg/L near the lake's surface. The anoxic zone in Little Green Lake varies from year to year, but has beeu shown to extend from 15 to 27 feet below the water surface (USGS data, 1991-96). The absence of oxygen in the deeper, colder portions of the lake may result in fish-kills. Fish-kills are common during conditions of increasing water temperature and decreasing dissolved oxygen concentrations in cool water habitat zones. It has not been determined whether anoxic conditions develop in the shallow, littoral areas during non-daylight hours when respiration is likely to exceed photosynthesis.

Water quality data and depth profiles for Little Green Lake for the 1991-97 water years are presented in Figures 6-12, respectively. These data are also available in the U.S. Geological Survey publications titled "Water-Quality and Lake-Stage Data for Wisconsin Lakes."

2.14 SEDIMENT CHARACTERISTICS

Phosphorus is commonly released from nutrient-rich lake sediments as a result of sediment disturbance, elevated pH, and/or anoxic conditions at the sediment-water interface of thermally stratified lakes. This phosphorus may cause noxious algae blooms, especially when it is mixed throughout the water column.

Knowledge of the phosphorus content of sediment in various locations along the lakebed is useful in identifying potential "hot spots" that are most likely to contribute the largest amounts of nutrients to the lake. In Little Green Lake, the phosphorus content of the sediment is positively correlated with lake-depth (Figure 13). In other words, phosphorus levels increase with increasing lake-depth. Total phosphorus concentrations in the shallow sediments (0- to 3-foot lake depths) averaged 645 mg/Kg, compared with a concentration of

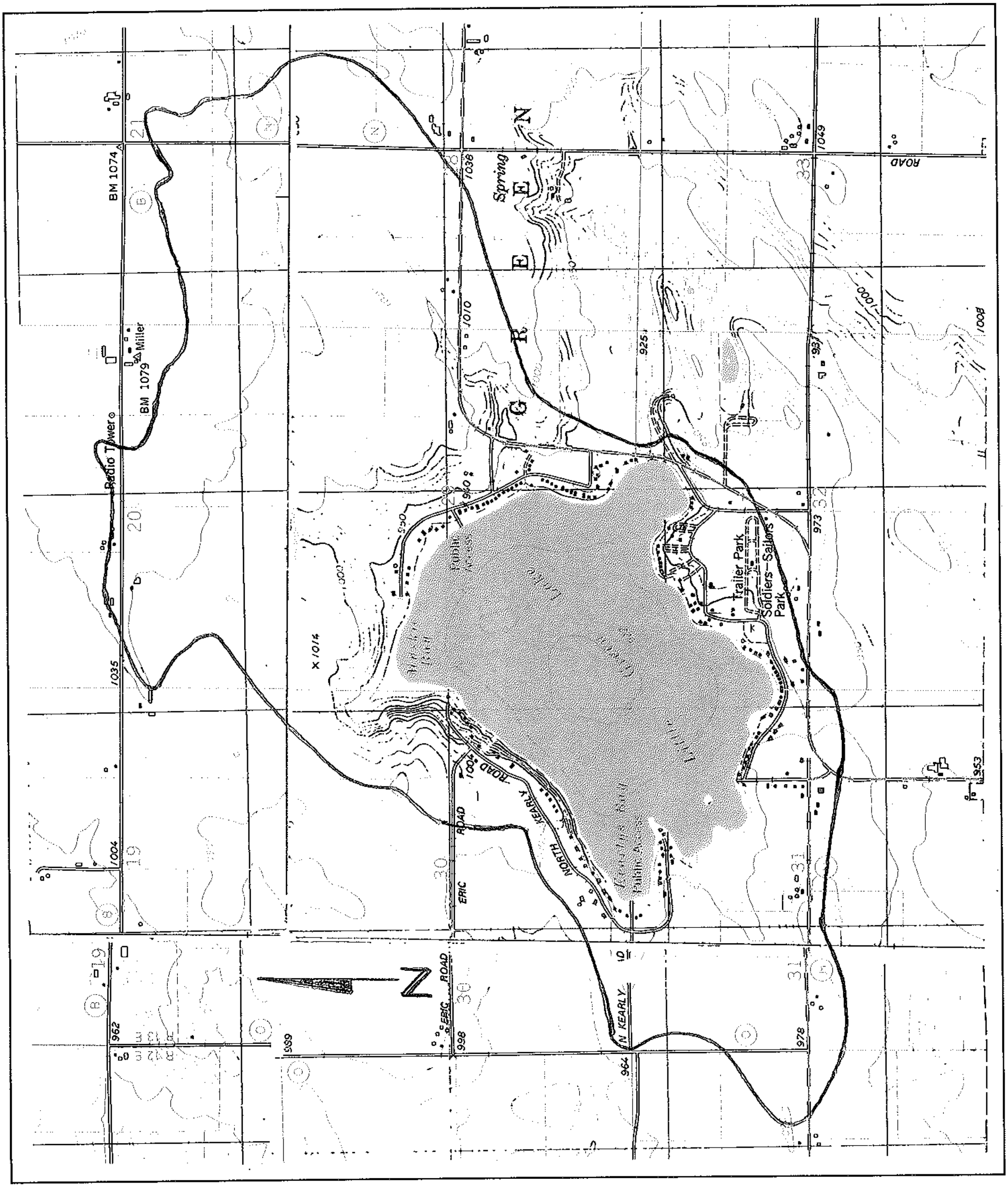


Figure 2
Topographic Map with Delineated Watershed (Scale: 1 = 24,000)

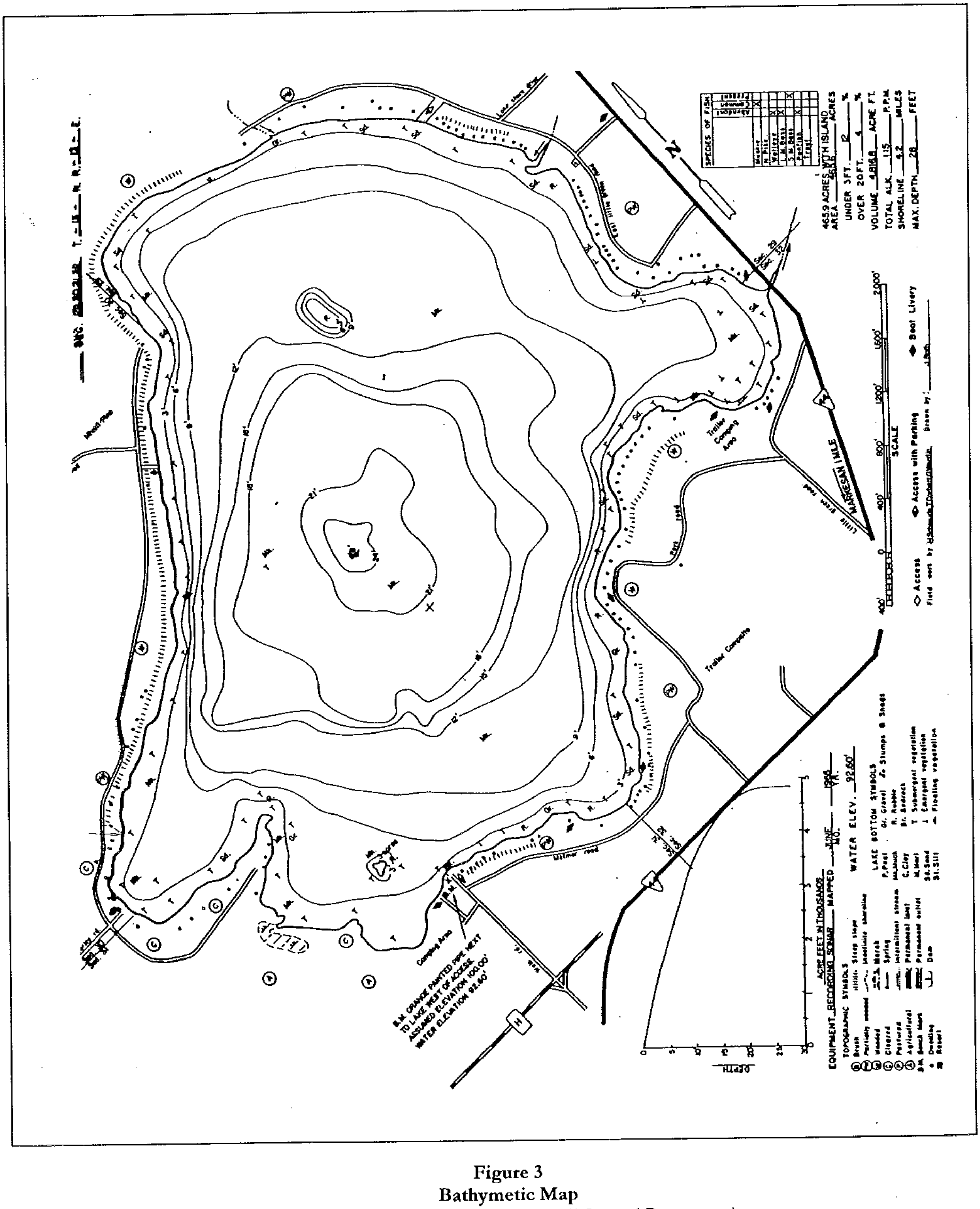


Figure 3
Bathymetic Map
(source: Wisconsin Department of Natural Resources)

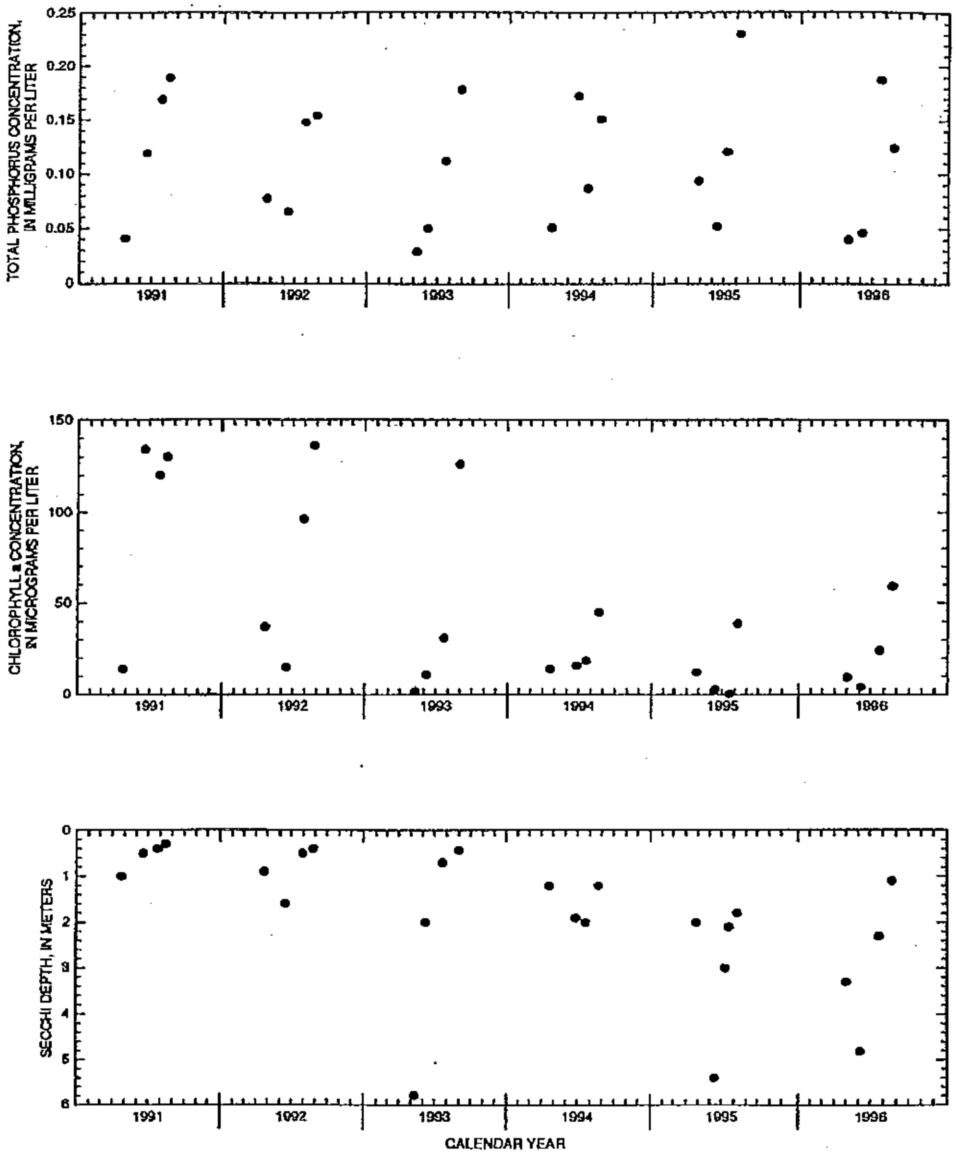


Figure 4
Total Phosphorus, Chlorophyll *a* Concentrations, and Secchi Depths Versus Time
(source: U.S. Geological Survey)

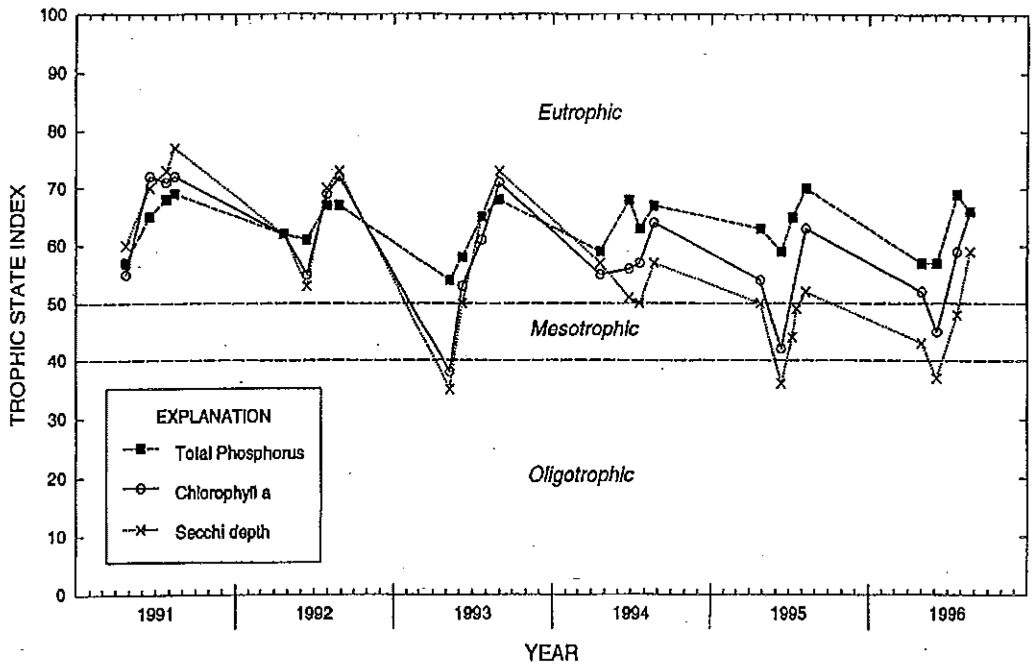


Figure 5
Trophic State Indices Versus Time
(source: U.S. Geological Survey)

	Parameter	Percentage distribution of lakes in southeast Wisconsin within parameter ranges	
	Total-phosphorus (mg/L)		
	<0.010	best condition	7
	0.010-0.020	↓	21
	0.020-0.030	↓	15
	0.030-0.050	↓	21
	0.050-0.100	↓	21
	0.100-0.150	↓	3
Little Green Lake Values	>0.150	worst condition	12
	Chlorophyll a (µg/L)		
	0-5	best condition	22
	5-10	↓	31
	10-15	↓	14
	15-30	↓	12
Little Green Lake Values	>30	worst condition	22
	Secchi depth (feet)		
	>19.7	best condition	1
	9.8-19.7	↓	9
	6.6-9.8	↓	26
Little Green Lake Values	3.3-6.6	↓	31
	<3.3	worst condition	33

Table 1
Regional Lake Comparison of Total Phosphorus, Chlorophyll *a* and Secchi Depths
(source: U.S. Geological Survey)

434412088590700 LITTLE GREEN LAKE, AT CENTER, NEAR MARKESAN, WI

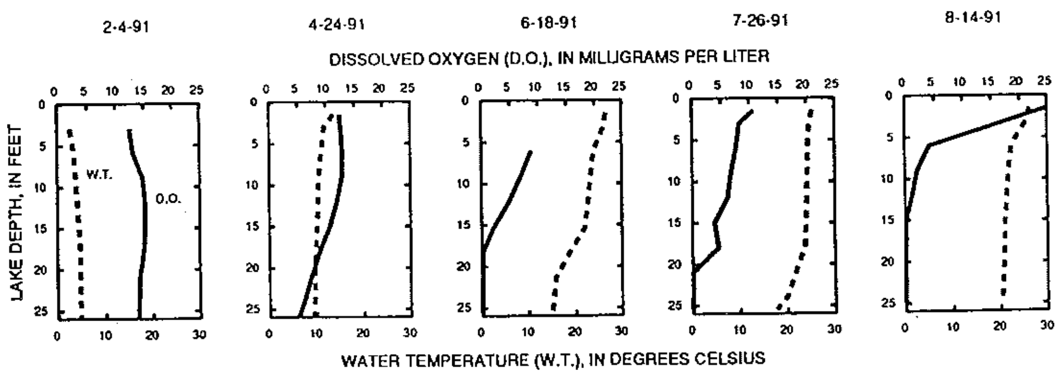
LOCATION--Lat 43°44'12", long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

PERIOD OF RECORD.--February to September 1991.

REMARKS.--Lake sampled near center at a lake depth of about 28 ft. Lake ice-covered during Feburary sampling. Water-quality analyses by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, FEBRUARY 05 TO AUGUST 20, 1991
(Milligrams per liter unless otherwise indicated)

	Feb. 04		Apr. 24		June 18		July 26		Aug. 14	
Depth of sample (ft)	3.0	26.0	1.5	25.0	1.5	26.0	1.5	25.5	1.5	25.0
Lake stage (ft)	---		5.51		6.07		6.06		7.96	
Specific conductance (µS/cm)	405	418	340	356	203	374	255	528	262	304
pH (units)	7.1	7.1	8.5	7.9	9.4	7.6	9.5	6.8	10.1	8.1
Water temperature (°C)	2.6	4.7	13.8	9.5	26.3	15.1	25.3	17.7	26.2	20.1
Color (Pt-Co, scale)	---	---	10	10	---	---	---	---	---	---
Turbidity (NTU)	---	---	2.1	4.5	---	---	---	---	---	---
Secchi-depth (meters)	---		1.00		0.50		6.06		65	
Dissolved oxygen	12.6	14.1	12.5	5.1	---	0.1	10.9	0.0	25.1	0.1
Hardness, as CaCO3	---	---	170	170	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	33	33	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	21	21	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	6.0	6.0	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4.44	4.62	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	162	165	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	<5.0	<5.0	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	0.1	0.1	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	14	14	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	<0.2	0.4	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	216	216	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	<0.015	<0.015	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	<0.013	0.020	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.8	1.2	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.041	0.096	0.119	0.480	0.169	1.290	0.189	0.410
Phosphorus, ortho, dissolved (as P)	---	---	0.004	0.005	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<50	<50	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<40	<40	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L)	---	---	14	---	134	---	120	---	130	---



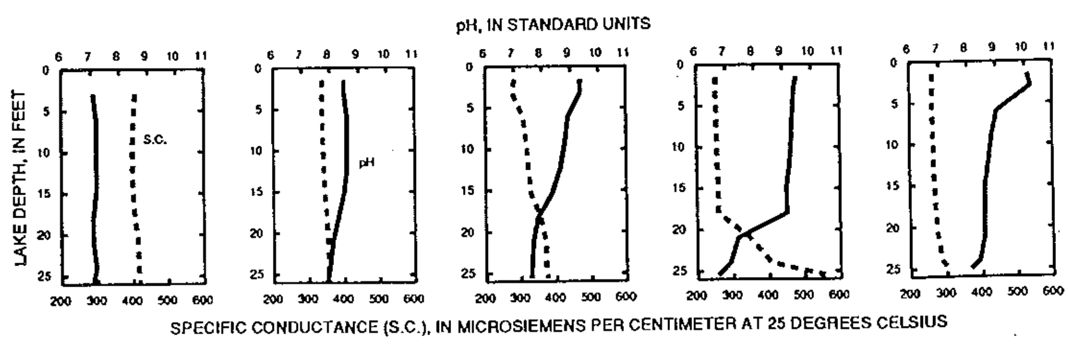


Figure 6
1991 USGS Water Quality Data

434412088590700 LITTLE GREEN LAKE, AT CENTER, NEAR MARKESAN, WI

LOCATION.--Lat 43°44'12", long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

PERIOD OF RECORD.--February 1991 to current year.

REMARKS.--Lake sampled near center at a lake depth of about 28 ft. Lake ice-covered during Feburary sampling. Water-quality analyses by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, FEBRUARY 07 TO AUGUST 27, 1992
(Milligrams per liter unless otherwise indicated)

	Feb. 07		Apr. 22		June 15		July 30		Aug. 27	
Depth of sample (ft)	1.5	24	1.5	24	1.5	23	1.5	22	1.5	23
Lake stage (ft)	---		---		5.80		5.57		5.32	
Specific conductance (µS/cm)	327	361	328	328	278	325	315	354	287	345
pH (units)	8.8	7.6	8.0	8.5	9.1	7.7	8.7	7.5	8.6	7.5
Water temperature (°C)	4.5	4.5	9.0	9.0	21.5	15.5	22.5	19.5	21.5	20.0
Color (Pt-Co. scale)	---	---	10	15	---	---	---	---	---	---
Turbidity (NTU)	---	---	5.0	5.6	---	---	---	---	---	---
Secchi-depth (meters)	---		0.9		1.6		0.5		0.4	
Dissolved oxygen	17.5	1.0	13.0	12.9	7.5	1.0	9.2	0.1	6.5	0.8
Hardness, as CaCO3	---	---	150	150	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	28	28	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	20	20	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	6.6	6.6	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	4	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	140	140	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	5.0	5.0	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	14	14	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	0.1	0.1	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	<0.2	<0.2	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	186	186	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	0.09	0.10	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	0.03	0.04	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.90	0.50	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.077	0.070	0.065	0.330	0.148	0.400	0.154	0.440
Phosphorus, ortho, dissolved (as P)	---	---	0.006	0.006	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<50	<50	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<40	<40	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L)	---	---	37	---	15	---	96	---	140	---

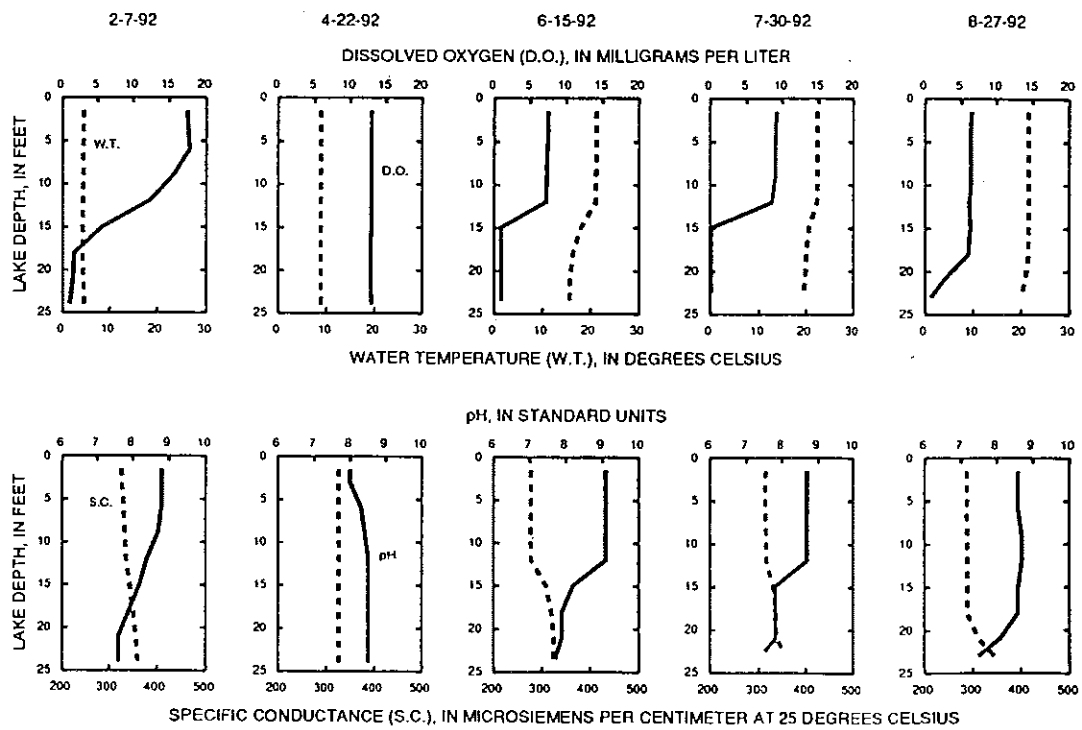


Figure 7
1992 USGS Water Quality Data

LOCATION--Lat 43°44'12", Long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

PERIOD OF RECORD.--February 1991 to current year.

REMARKS.--Lake sampled near center at a lake depth of about 27 ft. Lake ice-covered during Feburary sampling. Water-quality analyses by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, FEBRUARY 10 TO AUGUST 31, 1993
(Milligrams per liter unless otherwise indicated)

	Feb. 10		May 10		June 08		July 22		Aug. 31	
Depth of sample (ft)	1.5	25	1.5	25	1.5	24	1.5	25	1.5	23
Lake stage (ft)	6.40		6.64		6.53		6.98		6.27	
Specific conductance (µS/cm)	363	395	333	371	312	323	312	384	310	380
pH (units)	7.4	7.3	8.3	7.5	8.4	8.4	8.8	7.7	8.5	7.5
Water temperature (°C)	2.5	5.5	17.5	12.0	16.5	16.5	23.5	21.5	23.5	22.0
Color (Pt-Co. scale)	---	---	5	10	---	---	---	---	---	---
Turbidity (NTU)	---	---	0.80	2.6	---	---	---	---	---	---
Secchi-depth (meters)	---		5.8		2.0		0.7		0.4	
Dissolved oxygen	8.1	3.4	9.4	0.2	8.4	8.0	10.0	0.4	7.3	0.4
Hardness, as CaCO3	---	---	160	170	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	30	35	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	20	20	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	6.1	6.2	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	4	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	140	160	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	10	10	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	14	13	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	0.1	0.1	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	0.8	3.8	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	188	204	---	---	---	---	---	---
Nitrogen, nitrate, total (as N)	---	---	0.14	0.06	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	0.14	0.06	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	0.10	0.47	---	---	---	---	---	---
Nitrogen, organic, total (as N)	---	---	0.60	0.63	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.70	1.1	---	---	---	---	---	---
Nitrogen, total (as N)	---	---	0.84	1.2	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.029	0.174	0.050	0.080	0.112	1.4	0.178	0.820
Phosphorus, ortho, dissolved (as P)	---	---	0.006	0.101	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<50	<50	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<40	500	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L)	---	---	1.5	---	11	---	31	---	130	---

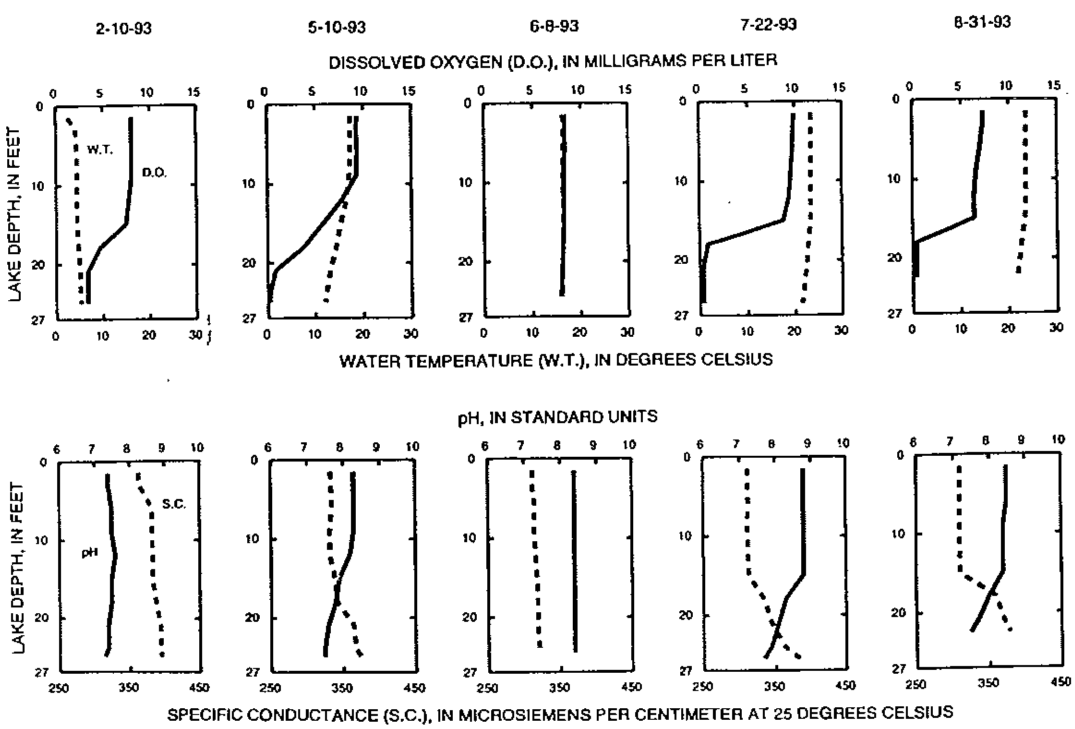


Figure 8
1993 USGS Water Quality Data

434412088590700 LITTLE GREEN LAKE, AT CENTER, NEAR MARKESAN, WI

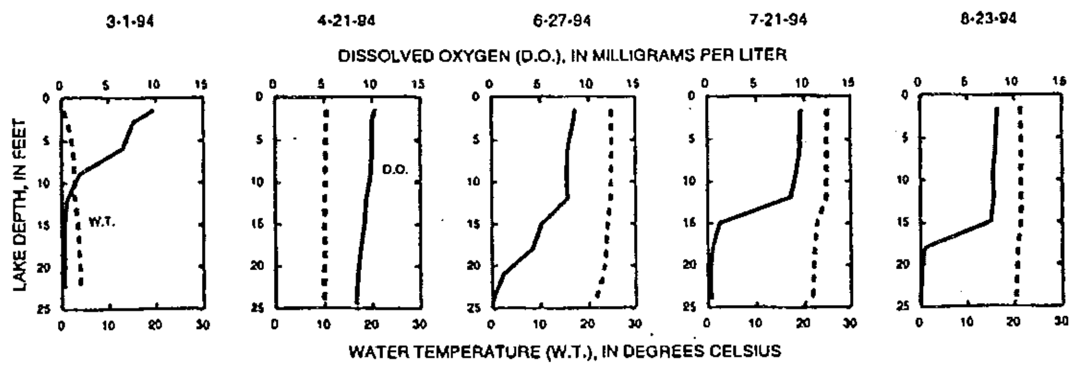
LOCATION--Lat 43°44'12", long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

PERIOD OF RECORD.--February 1991 to current year.

REMARKS.--Lake sampled near center at a lake depth of about 27 ft. Lake ice-covered during March sampling. Water-quality analyses by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, MARCH 01 TO AUGUST 23, 1994
(Milligrams per liter unless otherwise indicated)

	Mar. 01		Apr. 21		June 27		July 21		Aug. 23	
Depth of sample (ft)	1.5	23	1.5	24	1.5	24	1.5	24	1.5	24
Lake stage (ft)	6.41		6.45		6.02		6.23		6.09	
Specific conductance (µS/cm)	350	463	370	370	357	393	345	368	332	376
pH (units)	7.7	7.6	8.2	7.9	7.8	7.4	8.5	7.4	8.7	7.7
Water temperature (°C)	0.5	4.0	10.5	10.0	25.0	21.0	25.0	22.0	21.5	20.5
Color (Pt-Co. scale)	---	---	15	15	---	---	---	---	---	---
Turbidity (NTU)	---	---	1.4	1.8	---	---	---	---	---	---
Secchi-depth (meters)	2.2		1.2		1.9		2.0		1.2	
Dissolved oxygen	9.8	0.3	10.3	8.3	8.7	0.1	9.7	0.4	8.3	0.0
Hardness, as CaCO3	---	---	180	180	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	36	37	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	21	22	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	6.7	6.7	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	4	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	160	160	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	12	13	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	15	15	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	0.1	0.1	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	2.2	2.3	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	222	224	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	0.04	0.08	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	0.01	0.02	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.70	0.70	---	---	---	---	---	---
Nitrogen, total (as N)	---	---	0.74	0.78	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.051	0.052	0.172	0.640	0.087	0.234	0.151	0.716
Phosphorus, ortho, dissolved (as P)	---	---	<0.002	0.002	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<50	<50	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<40	<40	---	---	---	---	---	---
Chlorophyll a, phytoplankton(µg/L)	---	---	14	---	16	---	18	---	45	---



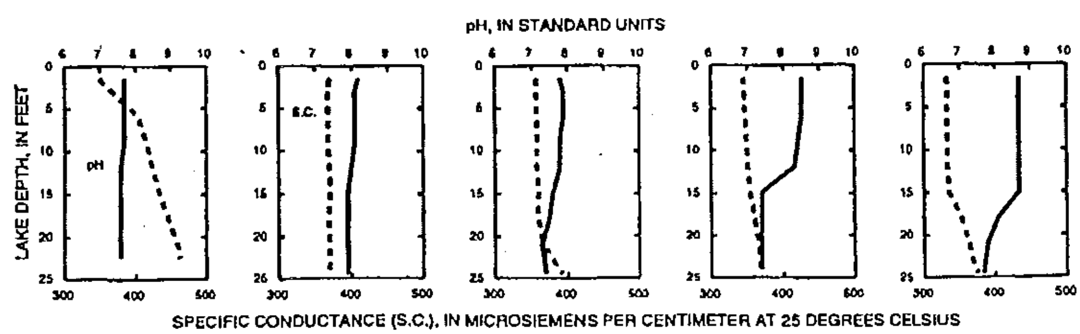


Figure 9
1994 USGS Water Quality Data

LOCATION--Lat 43°44'12", long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

PERIOD OF RECORD.--February 1991 to current year.

REMARKS.--Lake sampled near center at the deep hole. Lake ice-covered during February measurements. Water-quality analyses done by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, FEBRUARY 23 TO AUGUST 10, 1995
(Milligrams per liter unless otherwise indicated)

	Feb. 23		Apr. 27		June 14		July 10		July 20	Aug. 10	
Depth of sample (ft)	1.5	24	1.5	24	1.5	25	1.5	24	1.5	1.5	24
Lake stage (ft)	6.12		6.37		6.28		5.94		---	6.06	
Specific conductance (µS/cm)	392	430	342	343	312	340	340	375	339	335	440
pH (units)	8.1	7.8	8.1	8.1	8.3	7.5	8.2	7.6	8.5	8.4	7.3
Water temperature (°C)	3.0	4.5	9.0	9.0	20.5	17.0	23.5	19.0	25.0	25.0	20.5
Color (Pt-Co. scale)	---	---	10	10	---	---	---	---	---	---	---
Turbidity (NTU)	---	---	1.5	1.3	---	---	---	---	---	---	---
Secchi-depth (meters)	---		2.0		5.4		3.0		2.1	1.8	
Dissolved oxygen	10.2	4.2	10.4	9.9	8.6	0.1	9.5	0.1	7.6	6.2	0.3
Hardness, as CaCO3	---	---	170	170	---	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	33	33	---	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	22	22	---	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	6.8	6.7	---	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	4	---	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	150	150	---	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	12	12	---	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	15	15	---	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	<0.1	<0.1	---	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	<0.1	0.1	---	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	188	190	---	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	<0.01	<0.01	---	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	<0.03	<0.03	---	---	---	---	---	---	---
Nitrogen, organic, total (as N)	---	---	0.80	0.80	---	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.80	0.80	---	---	---	---	---	---	---
Nitrogen, total (as N)	---	---	0.80	0.80	---	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.094	0.038	0.052	0.192	0.121	0.365	---	0.230	1.4
Phosphorus, ortho, dissolved (as P)	---	---	<0.002	<0.002	---	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<10	<10	---	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<0.4	0.4	---	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L	---	---	12	---	2.5	---	---	---	0.1	39	---

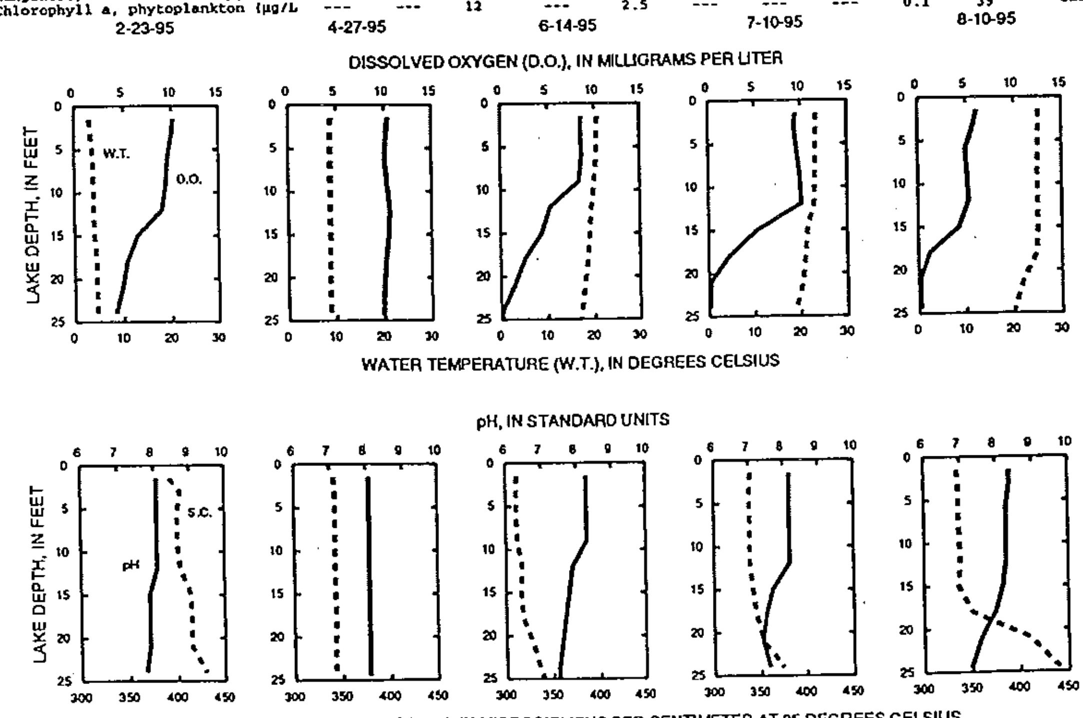


Figure 2. Water-quality data and depth profiles for Little Green Lake near Markesan, Wisconsin, 1995 water year

Figure 10
1995 USGS Water Quality Data

LOCATION--Lat 43°44'12", long 88°59'07", in SW 1/4 SW 1/4 sec.29, T.15 N., R.13 E., Green Lake County, Hydrologic Unit 04030201, 2 mi north of Markesan.

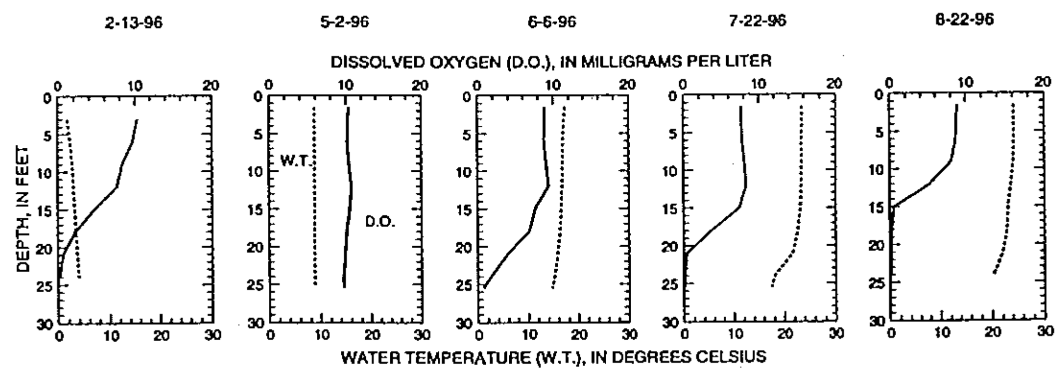
PERIOD OF RECORD.--February 1991 to current year.

REMARKS.--Lake sampled near center at the deep hole. Lake ice-covered during February measurements. Water-quality analyses done by Wisconsin State Laboratory of Hygiene.

WATER-QUALITY DATA, FEBRUARY 13 TO AUGUST 22, 1996

(Milligrams per liter unless otherwise indicated)

	Feb. 13		May 02		June 06		July 22		Aug. 22	
Depth of sample (ft)	3.0	24	1.5	26	1.5	26	1.5	26	1.5	24
Lake stage (ft)	---		6.47		6.39		6.51		6.24	
Specific conductance (µS/cm)	406	433	344	343	311	337	337	410	315	422
pH (units)	7.6	7.5	8.2	8.2	8.4	7.5	8.6	7.8	8.8	7.2
Water temperature (°C)	2.0	4.0	9.0	9.0	17.0	14.5	23.5	17.5	24.5	20.5
Color (Pt-Co. scale)	---	---	10	15	---	---	---	---	---	---
Turbidity (NTU)	---	---	1.00	1.4	---	---	---	---	---	---
Secchi-depth (meters)	---		3.3		4.8		2.3		1.1	
Dissolved oxygen	10.3	0.2	10.4	9.7	8.9	0.7	7.7	0.1	8.9	0.1
Hardness, as CaCO3	---	---	160	160	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	31	31	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	21	21	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	7.0	6.6	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	4	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	160	160	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	9.0	9.0	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	15	15	---	---	---	---	---	---
Fluoride, dissolved (F)	---	---	0.1	0.1	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	1.0	1.0	---	---	---	---	---	---
Solids, dissolved, at 180°C	---	---	196	196	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	0.06	0.06	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	<0.03	<0.03	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.70	0.70	---	---	---	---	---	---
Nitrogen, total (as N)	---	---	0.76	0.76	---	---	---	---	---	---
Phosphorus, total (as P)	---	---	0.040	0.040	0.046	0.116	0.187	0.522	0.124	1.1
Phosphorus, ortho, dissolved (as P)	---	---	0.004	0.005	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<10	<10	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	1	1	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L)	---	---	9.4	---	3.9	---	24	---	59	---



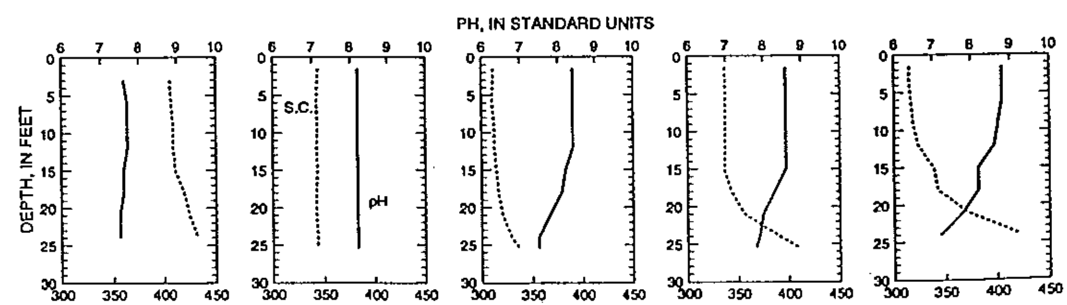


Figure 11
1996 USGS Water Quality Data

Little Green Lake near Markesan, Wisconsin, Lake Data 1997

	Feb. 14		Apr. 2		June 12		July 23		Aug. 27				
Depth of sample (m)	0.5	7.5	0.5	7.5	0.5	7.5	0.5	7.5	0.5	2	4	6.5	7.5
Specific conductance (µS/cm)	411	439	350	350	331	359	311	388	298	297	301	317	319
pH (units)	7.8	7.8	8.5	8.4	8.4	7.4	8.7	7.2	9	8.9	8.7	8.2	8.1
Water temperature (°C)	2	5	8	7.5	21	17.5	24.5	20.5	21.5	21	20.5	20	20
Color (Pt-Co. scale)	---	---	15	---	---	---	---	---	---	---	---	---	---
Turbidity (NTU)	---	---	1.7	---	---	---	---	---	---	---	---	---	---
Secchi-depth (meters)	---		1.7		5.4		1.3		0.8				
Dissolved oxygen	4.9	0.7	12.9	11.2	10.4	1.1	9.4	0	14.5	12.4	8.7	2.7	0.6
Hardness, as CaCO3	---	---	160	---	---	---	---	---	---	---	---	---	---
Calcium, dissolved (Ca)	---	---	31	---	---	---	---	---	---	---	---	---	---
Magnesium, dissolved (Mg)	---	---	21	---	---	---	---	---	---	---	---	---	---
Sodium, dissolved (Na)	---	---	7.1	---	---	---	---	---	---	---	---	---	---
Potassium, dissolved (K)	---	---	4	---	---	---	---	---	---	---	---	---	---
Alkalinity, as CaCO3	---	---	160	---	---	---	---	---	---	---	---	---	---
Sulfate, dissolved (SO4)	---	---	6	---	---	---	---	---	---	---	---	---	---
Chloride, dissolved (Cl)	---	---	15	---	---	---	---	---	---	---	---	---	---
Silica, dissolved (SiO2)	---	---	0	---	---	---	---	---	---	---	---	---	---
Solids, dissolved, at 160°C	---	---	190	---	---	---	---	---	---	---	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	<0.01	---	---	---	---	---	---	---	---	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	<0.01	---	---	---	---	---	---	---	---	---	---
Nitrogen, organic, total (as N)	---	---	0.8	---	---	---	---	---	---	---	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	0.8	---	---	---	---	---	---	---	---	---	---
Nitrogen, total (as N)	---	---	0.8	---	---	---	---	---	---	---	---	---	---
Phosphorus, total (as P)	0.055	0.149	0.036	---	0.022	0.101	0.119	0.682	0.175	0.17	0.176	0.248	0.253
Phosphorus, ortho, dissolved (as P)	---	---	<0.002	---	---	---	---	---	---	---	---	---	---
Iron, dissolved (Fe) µg/L	---	---	<10	---	---	---	---	---	---	---	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	<0.4	---	---	---	---	---	---	---	---	---	---
Chlorophyll a, phytoplankton (µg/L)	---	---	24	---	4.4	---	78	---	78.7	---	---	---	---

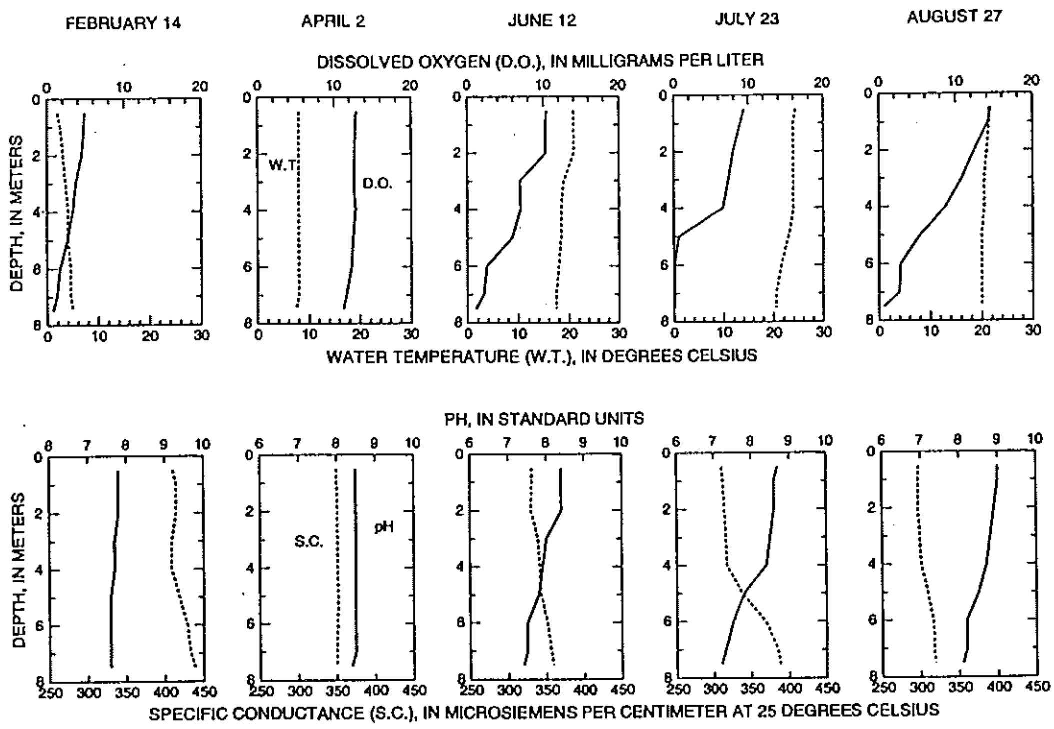


Figure 12
1997 USGS Water Quality Data

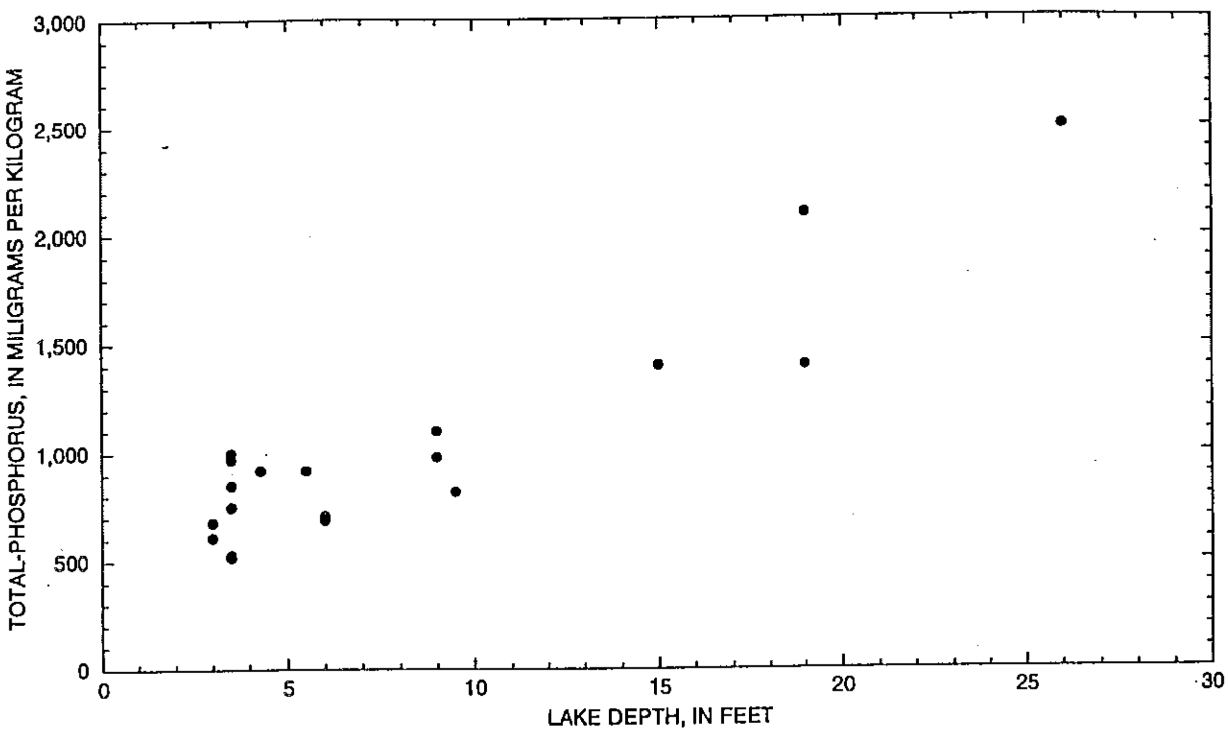


Figure 13
Sediment Phosphorus Content versus Lake-Depth
(source: U.S. Geological Survey)

SECTION 3
IDENTIFICATION OF DESIRED LAKE USES & PROBLEMS

Actively involving the public is important in facilitating the identification and prioritization of desired lake uses and problems, especially considering that lake users have direct, day-to-day experience with the lake environment. In addition, public involvement helps to educate the users about the lake ecosystem, their role in contributing to some lake problems, and the actions they can take to reduce or eliminate the severity of these problems. Greater understanding and awareness of problems will generally lead to increased cooperation in their solution and thus a greater likelihood of program success.

3.1 METHODOLOGY

In July of 1997, a survey was developed and distributed to the approximately 240 seasonal and year-round residents on Little Green Lake. A copy of the survey is included in Appendix D. Surveys were hand-delivered by Lake District volunteers to each lakefront residence. Additional surveys were mailed to individuals who did not respond after a certain time period or permanently resided at an out-of-town address. The purpose of the effort was to engage public participation in the lake planning process by soliciting the opinions and concerns of lake residents regarding the present condition and future management of the resource. Responses were used to determine and help prioritize desired lake uses, as well as to identify the problems that are currently inhibiting these lake uses.

Ultimately, 125 of the surveys were completed and returned for analysis, representing a 54% response rate. The high response rate exceeded expectations, and may be indicative of a prevalent interest to protect and enhance this valued resource. A meeting of lake residents was subsequently held at the Green Lake Town Hall on August 9, 1997. The Town Meeting was advertised in the local newspapers two weeks in advance. The purpose of the meeting was to present the survey results, solicit additional comments, and discuss the status of the lake management planning process. The Town Meeting was organized to provide a forum for further public participation, and to address any lingering questions and concerns. Thirty-six people were in attendance at the Town Meeting.

3.2 LAKE RESIDENT SURVEY RESULTS

Survey results are briefly summarized below. A more complete and detailed summary of the survey responses is presented in Appendix D.

Demographic Information:

- Most of the respondents were seasonal/part-time residents (62%) who spent most of their time on the lake on weekends during the summer months. Year-round residents comprised 38% of the total lake resident population.
- The largest percentage of residents (36%) have owned lakefront property on Little Green Lake for over 20 years, followed by only 0-5 years of lakefront property ownership (29%).

Lake Use Preferences:

- People generally chose to purchase property on Little Green Lake based on its distance from a permanent home, enjoyment of common lake activities, and cost of the property.
- The most valued lake uses are fishing, scenic view/tranquility, motor boating, and observing wildlife, respectively.
- A vast majority (81%) felt that the water quality of Little Green Lake is the most important factor contributing to a desirable lake environment, followed by fishing success/habitat (59%) and overall ecosystem health (24%). Tourism was the least important.

- The most positive aspects of the lake that were identified include solitude, scenic views, fishing, small size, organized lake-management efforts and nice homes/neighbors.
- Anglers identified walleye as the most valued fish in Little Green Lake, followed by panfish, muskellunge and largemouth bass, respectively.

Perceived Problems:

- Most people felt that algae and aquatic plant growth were the biggest problems (77% and 69%, respectively), with the bays and shallow areas generating the most concern.
- Most people believed runoff of agricultural fertilizers/pesticides/soil, faulty septic systems and in-lake recycling of nutrients were the biggest contributors to the lake degradation.
- Most people rated water quality during the summer months as poor (53%), and fishing success as fair (57%).
- Respondents generally indicated that the most negative aspects of the lake include nuisance aquatic plants, algae, muck, smell of the water and power crafts.
- Most people felt either slightly crowded (39%) or moderately crowded (34%) on summer weekends spent on the lake. On summer weekdays, most people did not feel crowded (86%).
- The following long-term observations were made by the largest percentage of the respondents (note that these statements are not necessarily supported by long-term data):
    - nuisance aquatic plant growth has gotten worse (72%)
    - nuisance algae growth has gotten worse (71%)
    - water quality/clarity has declined (49%)
    - fishing success for panfish has remained the same (50%), while fishing success for large gamefish has declined (52%)
    - the smell of the water has gotten worse (55%)
    - motor boating and non-motor boating traffic has remained the same (56% and 83%, respectively)
    - conflicts between anglers and boaters has remained the same (65%)
    - noise and congestion has remained the same (52%)
    - muckiness of lake bottom has gotten worse (60%)
    - scenic views from land and water have remained the same (81% and 72%, respectively).

Lake Management & Decision Making:

- Most people felt that there is currently adequate public access to Little Green Lake.
- Almost half of the respondents (46%) did not feel adequately informed of lake-management decisions. Requests were made for a semiannual newsletter, better advertising of meeting dates/times, information flyers sent to permanent addresses and posted meeting minutes.
- Almost half of the respondents (54%) felt that they did not have a voice in decision-making matters regarding lake management. Reasons include part-time residency, not enough Lake District meetings, bad meeting dates and times, Lake District Board having own agenda, too much State agency control, and never being asked for an opinion.
- Most people either agreed or strongly agreed that more cooperation was needed among lake residents when dealing with lake management issues.
- The top three entities believed to be responsible for managing the lake include the Lake Association, Lake District and local government.
- The top three entities that most residents believed should be responsible for funding lake projects include State government, the general public through user fees and local government.
- Most people felt that a reasonable time period to see a visible improvement in the lake once a project has been undertaken is 3-5 years (50%), followed by 1-2 years (44%).

SECTION 4
PRIORITIZATION OF DESIRED LAKE USES & PROBLEMS

4.1 PRIORITY LAKE USES

It is important to recognize that a lake cannot be all things to all people, and desirable uses, even obtainable ones, often conflict. Because this was the case with Little Green Lake, desired lake uses and values were prioritized based on considerations such as level of lake resident support and feasibility of attainment given the nature of the lake ecosystem. Prioritizing was used a means of resolving mutually exclusive management goals.

According to the lake resident survey results, most of the respondents chose to purchase property on Little Green Lake because of its reasonable distance from a permanent home, affordable cost of the property, and the lake's ability to support a variety of activities and values. The most valued lake use was fishing, followed by scenic views/tranquility, motor boating and observing wildlife, respectively. Finally, a vast majority of the respondents felt that water quality/clarity was the most important aspect contributing to a desirable lake environment, followed by fishing success/habitat.

It is evident that water quality/clarity is of overwhelming importance to the residents of Little Green Lake. Improving the lake's water quality was also identified as a primary Lake District goal as outlined in the Request for Proposals. Thus, an improvement in the lake's water quality is given top priority in the development of appropriate management strategies. Management alternatives were also evaluated based on their potential impacts to the Little Green Lake fishery, a valuable resource that supports the most popular lake activity.

Although recommended management strategies will attempt to simultaneously enhance both water quality/clarity and fishing, this may not always be possible. For instance, fishing is an activity that may be negatively impacted in some ways by an improvement in water clarity. Walleye, the most valued fish species in the lake, prefer slightly turbid, cooler water. The preferred walleye habitat may therefore be jeopardized by an improvement in water clarity. On the other hand, warmer water, sight-feeding gamefish species such as largemouth bass are likely to fair well under these new conditions. Aquatic plant growth may also be enhanced as a result of increased sunlight penetration. These tradeoffs are explained in greater detail in the following sections.

4.2 PRIORITY LAKE PROBLEMS

While lake users may be able to identify the symptoms of a problem or limitations on lake uses, technical data and expertise are often needed to confirm and better define the problem. It is also important to determine whether the issues identified are real problems that can be alleviated through lake-management efforts.

Survey results indicate that nuisance algae and plant growth, respectively, were the biggest perceived problems associated with Little Green Lake. Furthermore, the largest percentage of respondents believed nuisance algae and aquatic plant growth has gotten worse over time. These survey results bring up two important points. First, nuisance algae and aquatic plant growth are actually symptoms of a larger problem—nutrient enrichment. Little Green Lake is a shallow water body located in a naturally fertile watershed. The watershed is also farmed intensively with row crops, which is a form of land use that generally contributes high nutrient loads to the lake through runoff of agricultural fertilizers and sediment. These factors generally create a physical setting that is conducive to eutrophic surface water systems that have high plant and/or algae production, as is the case with Little Green Lake. Fortunately, the relatively small watershed-to-lake area ratio of Little Green Lake suggests the opposite--namely that water quality should not be a problem due to limited sediment and nutrient loading from the contributing watershed.

Secondly, algae and aquatic plant abundance represent two ecological variables that are inextricably linked. This relationship makes it difficult if not impossible to manipulate one variable without dramatically affecting the other variable. For example, reducing or eliminating algae growth will result in improved water clarity, enhancing sunlight penetration through the water column and, thus, plant growth. Conversely, eliminating plant growth will reduce structural refuges used by algae-consuming zooplankton, ultimately establishing an environment favorable for increased algae growth. Also, attempting to dramatically reduce or eliminate both algae and aquatic vegetation could potentially upset the entire ecological balance of the lake. For instance, an increase in turbidity (suspended sediment) may result as vegetation is eliminated that once stabilized bottom sediments. A new water quality problem driven by a re-suspension of sediment will then take the place of the problem caused by algae growth.

Reducing algae and aquatic plant growth are the primary objectives of this Lake Management Plan. However, because there are numerous benefits associated with a healthy plant community, algae reduction is given priority over aquatic plant control as a goal when considering the various management options. Furthermore, the amount of algae growth in the lake is closely tied to overall water quality/clarity. *A majority of the desired lake uses and values will be supported if a reduction in algae growth is achieved in conjunction with a thriving, but controlled plant community.*

4.3 PROBLEM ANALYSIS

Algae

Algae are small, generally microscopic plants found in lakes, and are primary producers that form the base of the aquatic food chain. Algae growth may reach nuisance proportions in fertile or eutrophic lakes, often causing surface scum or slime. High concentrations of wind-blown algae may accumulate on shorelines, where they die and decompose, causing noxious odors, unsightly conditions and oxygen depletion. Summer fish kills have been reported on Little Green Lake and are likely caused by depleted oxygen levels caused by excessive algae growth and subsequent decomposition.

Controlling nuisance algae populations in lakes is a difficult undertaking. Because algae are microscopic plants that are free-floating and even free-swimming in the water column, managing the whole lake rather than just near shore areas is necessary. Since algae populations are caused by high nutrient concentrations, attempting to eliminate algae by attacking it directly is a short-term solution that may become a costly management approach over the long run. The best way to manage excessive algae is to both reduce the flow of nutrients into the lake, and control the availability of nutrients that are already contained within the lake. That is, the source of the problem should be treated rather than the symptoms. Only when it becomes infeasible to address the source of the problem should symptom-oriented strategies (i.e., algacides) be implemented.

Aquatic Vegetation

Aquatic vegetation is an important component of a healthy lake ecosystem. Plants stabilize the bottom sediment, oxygenate the water during photosynthesis, provide shelter and spawning habitats for fish, act as refuges for zooplankton (algae consumers), and serve as food sources for wildlife. An absence of aquatic vegetation usually leads to poor water quality conditions and a less desirable fishery.

There are instances when aquatic plants become overly abundant, causing a reduction in the recreational potential of a lake, stunting fish growth, and reducing dissolved oxygen levels during senescence and decomposition. The decomposition of plant material is also shown to release nutrients that were previously tied up in the living plant tissues. Aquatic plant growth is limited by factors such as available sunlight, the texture of lake sediments, and the nutrient content of the lake sediments.

Excessive plant growth should be controlled through careful and well-planned management. Aquatic plant management techniques should target specific areas and species, and should not disrupt critical fish and wildlife habitat.

4.4 OTHER ISSUES OF CONCERN FOR LAKE RESIDENTS

Phosphorus Inputs from Septic Systems

A number of lake residents have expressed concern that on-site septic systems around Little Green Lake are contributing to the current water quality problems. According to the Lake District Board, many of these on-site systems were upgraded about 10 years ago after a study discovered that a number of the systems were failing.

Research indicates that on-site systems do not add significant amounts of phosphorus to a lake if they conform to state standards and are well maintained, though localized aquatic plant growth is sometimes observed where septic system effluent enters the lake by way of groundwater. Generally, only a few grams of phosphorus reach the lake on a yearly basis from a conforming on-site system. An overly fertilized yard is known to add more phosphorus to a lake than an on-site system. The primary concern for maintaining properly functioning on-site systems should be to prevent public health problems and protect drinking water from harmful bacteria (McComas, 1993).

In detailed studies of 13 developed lakes in Wisconsin where on-site septic systems were examined, phosphorus contributions from these systems were measured and found to have provided a relatively small percentage of a lake's total nutrient load. When compared to the total phosphorus budget for these lakes, the contributions from the disposal systems did not have a significant impact on the overall trophic condition of these lakes united States Environmental Protection Agency (USEPA, 1990).

Further assessment is needed to verify that there is a problem and, if so, to determine the magnitude of the problem. Management options such as sewering the lake is quite expensive, and cannot be recommended with any level of confidence until a detailed study is conducted. Because local point sources, such as septic tank drainage, are more important in lakes with smaller watersheds (e.g., Little Green Lake), further assessment may be warranted. This issue is discussed further in Section 5.3 of this report.

Phosphorus Inputs from Waterfowl

Little Green Lake residents have expressed concern regarding nutrient additions to the lake by resident waterfowl populations. Large numbers of waterfowl have the potential to significantly impact the rate and pathways of nutrient cycling in aquatic ecosystems because they consume and excrete large amounts to maintain a high metabolic rate. Recent studies show that bird droppings may contribute relatively large percentages of the total phosphorus loading to a lake (Gibbons, 1995; Manny, 1994). However, other studies have concluded that waterfowl were not important in nutrient loading of lakes, but that large bird populations were often associated with productive lakes because of the abundant food supply (Murphy, 1984; Hoyer, 1994).

If large populations of resident waterfowl appear to be a continual problem at Little Green Lake, it is recommended that volunteers attempt to count the number and type of bird species that use the lake at various times of the year. This information is necessary to estimate average phosphorus contributions from waterfowl defecation. Unfortunately, there are limited and often ineffective management techniques that are currently available to control nuisance waterfowl populations. This issue is discussed further in Section 5.3 of this report.

SECTION 5
PRESENTATION OF POTENTIAL SOLUTIONS

5.1 LIMITATIONS & INFORMATION REQUIREMENTS

The preparation of this lake management planning strategy is based on existing information characterizing Little Green Lake and its surrounding watershed. Critical information gaps were identified during the planning process that placed significant limitations on the ability to select the most appropriate and feasible management options. *These information gaps include a phosphorus budget for the lake and determination of annual mean discharge.*

PHOSPHORUS BUDGET

The phosphorus budget identifies the quantity and sources of the various phosphorus inputs into the lake. This information is used to determine high nutrient-loading areas, and to select the management techniques that are best designed to address these areas. Given Little Green Lake's relatively small watershed-to-lake surface area ratio, it is highly probable that phosphorus loading from external sources is low when compared to internal phosphorus loading. The internal recycling of nutrients may be the primary cause of the lake's poor water quality, and is a mechanism that has been shown to be the major source of phosphorus in two Wisconsin lakes—Delavan Lake (Field, 1988) and Whitewater Lake (Field, 1994)—both in southeast Wisconsin.

The source of internal phosphorus recycling is most likely from the deep, anoxic zone and/or the shallow, littoral areas of the lake. Identifying the sources of internal phosphorus recycling could cost as much as $75,000 (Robertson, personal communication). This cost could potentially be reduced to $27,500 if the USGS cost shares the project (50% cost share) and the Lake District is able to secure a Wisconsin Lake Planning Grant through the WDNR (up to $10,000).

It is evident from the above cost estimates that the preparation of a total phosphorus budget can be very expensive. Therefore, a "limited" phosphorus budget is recommended. The development of a limited phosphorus budget will address external phosphorus inputs, and suggest whether internal phosphorus recycling is a significant problem. It will estimate the magnitude and relative importance of external versus internal nutrient loading, thereby allowing the Lake District to focus management efforts accordingly. It will also point out the significance of phosphorus inputs from septic systems, an issue of concern identified in the lake resident survey. The phosphorus budget will use and expand upon the Watershed Inventory Study conducted by the Green Lake County Conservation Department in 1994. *If the limited phosphorus budget suggests that external loading of phosphorus is not the problem, the Lake District will have to decide whether to pursue the costs to identify and remedy the internal nutrient recycling problem.* A limited phosphorus budget can be prepared for a total cost of less than $10,000 (Ramaker & Associates estimate).

ANNUAL MEAN DISCHARGE

Annual mean discharge at the outlet is the volume of water that exits the system over a one-year time period. The annual discharge is necessary to calculate the lake's flushing rate (average length of time water resides in the lake), or hydraulic retention time. Retention time is important in determining the impact of nutrient inputs. For instance, long retention times result in greater nutrient retention in most lakes. These values are also used to determine the amount of time it will take for the lake to refill with water following a hypolimnetic withdrawal or a water level drawdown (two management options that are discussed in Sections 5.4 & 5.5, respectively). Finally, annual discharge is used as an input variable in a number of lake-modeling applications. Discharge measurements at the outlet are currently being performed by the USGS using funding from the Lake Planning Grant Program administered by the WDNR. Phosphorus concentrations and estimates of phosphorus loads leaving the lake are also be determined at the same time discharge measurements are taken. The Lake District will spend approximately $2,000 to $3,000 to cost-share this project (Rose, personal communication).

5.2 INTRODUCTION TO MANAGEMENT OPTIONS

Because the above information is not currently available, the appropriateness of some management techniques could not be assessed at the present time with an acceptable degree of confidence. The reader should, therefore, be cautioned that although some of the management options are addressed with significant detail, others received a more cursory overview due to their relative inappropriateness or uncertainty of effectiveness based on the existing data. Should the Lake District choose to do further research, some of the options that currently appear inappropriate may become more viable in light of new information. It is intended that the Lake District pick and choose from these management techniques as additional information becomes available.

Selection Criteria

Management techniques were selected on the basis of potential benefits, potential negative impacts, estimated costs, longevity of effectiveness and overall potential for success. These criteria are individually presented and addressed for certain management techniques. Restoration-oriented techniques that address real problems were favored over symptom-oriented techniques. Although many of the symptom-oriented techniques have lower initial costs, the benefit-to-cost ratio decreases over time. This is because the symptom of the problem is being treated rather than the cause, which leads to continual operation and maintenance costs.

In selecting viable management techniques, it was recognized that Little Green Lake is influenced by a number of complex physical, chemical and biological components. These components are extremely dynamic and affect the lake's responsiveness to management efforts. Because the lake is a highly interactive system, it is impossible to alter one characteristic, such as algae production or the clarity of the water, without affecting some other aspect, such as aquatic plant production. The complexity and interactive nature of the system, as well as the tradeoffs associated with each management option, were carefully considered during the selection process. The selection of management options was based on high priority lake uses and problems discussed in Section 4 of this report.

Organization

Management options are arranged according to the following categories:

1. Alternatives that reduce the supply of nutrients entering the lake from external sources;
2. Techniques that address in-lake (internal) nutrient sources;
3. Techniques that do not specifically address nutrient supplies, but attempt to manage the biological consequences of a nutrient-rich lake; and
4. Management recommendations to control lake-use behavior.

Management options that could be dismissed with an acceptable level of confidence based on existing information are also included under their appropriate management categories. These management options were determined to be cost-prohibitive, ineffective and/or infeasible given the nature of the system that is being managed. They are included in the lake management plan for two reasons. First, it was necessary to investigate every alternative in detail to determine its characteristics and limitations as completely as possible. This allowed for the most objective appraisal of the alternative's applicability to Little Green Lake. Second, since future conditions cannot be predicted with certainty, alternatives that may not appear viable at this time may become so later.

5.3 MANAGEMENT OF EXTERNAL NUTRIENT LOADING

Introduction

External nutrient loading is the influx of soil, organic debris and other material from the surrounding watershed to the receiving water body. This material is delivered to the lake primarily as storm water runoff, and may contain large amounts of phosphorus and other nutrients. The sources of external nutrient loading should be addressed before any in-lake management techniques are implemented. If not, in-lake management efforts will not be as effective over the long run, especially if external nutrient loading is significant. The following table summarizes the various management options that are available. Each management option is discussed in greater detail in the following sections.

Table 2
Management options to control external nutrient loading

Management Option	Recommendation	Justification
Landowner Activities	Encourage lakefront property owners to implement the suggested nutrient control guidelines.	Individual actions can have a significant cumulative affect on external nutrient loading to the lake.
Watershed Planning/Runoff Control	Agricultural runoff control measures and land use planning in the watershed is recommended. (currently being addressed)	Intensively farmed watersheds with poor land use planning generally contribute the majority of external nutrient loads to a lake.
Lake Sewering	Not recommended at the present time.	This alternative is very expensive and is not warranted until phosphorus loading from septic systems is quantified. A phosphorus budget and further study is needed to address this information gap.

Landowner Activities

Little Green Lake is described as having a relatively small watershed-to-lake surface area ratio. Under these conditions, riparian (shoreline) activities are believed to account for a higher proportion of the nutrient loading to the lake when compared to surface water systems with larger watershed-to-lake ratios. Lawn fertilization, tree cutting, shrub clearing and earth moving have the potential to add significant amounts of phosphorus to the lake. Therefore, actions taken by individual lakefront property owners may have a significant impact on overall nutrient-loading dynamics.

Lakefront property owners are encouraged to take the following actions to help reduce external phosphorus loading and thereby protect and improve the lake environment. Free informational materials are available on many of these topics through the WDNR and the University of Wisconsin – Extension.

1. Establish shoreline buffer strips by planting or maintaining a thickly vegetated area between a fertilized lawn and the lake. Through proper landscaping techniques (i.e., planting trees tolerant of wet conditions that do not contribute organic matter to the lake, such as willow, cottonwood or dogwood), riparian property owners can create vegetated shorelines that offer numerous benefits. These natural buffer strips:

    - protect against shoreline erosion;
    - discourage resident geese populations from using the property to feed and defecate;
    - provide natural filters for nonpoint source pollution;
    - provide shade for fish;
    - block sunlight that encourages aquatic plant and algae growth;
    - enhance scenic views and natural shoreline beauty; and
    - reduce noise levels and enhance privacy.

2. Limit or eliminate the use of phosphorus-containing fertilizers on lawns adjacent to the lake. Lake resident survey results indicate that 17% of the respondents use fertilizers or pesticides on their property. It is suggested that lakefront property owners try using lake water or no-phosphate products, and avoid over-fertilizing their lawns. Also, property owners are encouraged to keep their grass between 2-3 inches in height, and prevent leaves and grass clippings from entering the lake.

3. Install riprap or vegetate intermittent inlets and storm water channels that funnel runoff into the lake. This procedure reduces the velocity of channelized surface water flow, reducing its erosive potential and promoting deposition of sediment within the storm channel rather than the lake. Also, stabilize soil in erosion-sensitive areas such as on steep slopes.

4. During future development projects, attempt to *reduce* the amount of impervious areas (e.g., driveways, patios, sidewalks, etc.), and *increase* vegetated areas. Impervious areas do not allow water to infiltrate, and increase surface water runoff volumes and velocities. Also, consider the feasibility of dismantling curbs and gutters to allow road runoff to flow over grassed areas.

5. Discourage waterfowl such as ducks and geese by not feeding them. Waterfowl, in sufficient numbers, can contribute significant phosphorus loads to the lake. Waterfowl favor mowed lawns, but are discouraged by high grass and natural shorelines where predators may lurk.

6. Properly locate and maintain on-site septic systems to protect surface and groundwater from contamination. Lakefront property owners are encouraged to:

   - locate drain fields as far as possible from surface waters;
   - divert surface water away from the drainfield;
   - avoid driving or parking over the drain field to prevent compaction of the soil and
   - premature failure;
   - pump the tank found in an at-grade or mound system at least every three years and
   - increase the frequency of pumping if you have a large family;
   - pump a holding tank when the alarm indicates a full tank;
   - keep roots of trees and shrubs away from drain pipes to avoid obstructed drain lines;
   - avoid using a garbage disposal;
   - use water efficient appliances and flow restrictors to reduce the volume of wastewater the
   - system must filter and absorb;
   - avoid chemicals which may harm the organisms that break down wastes;
   - use toilet paper that decomposes quickly;
   - avoid materials that may clog the drain field; and
   - minimize the use of phosphate containing detergents and water conditioners.

WATERSHED PLANNING/RUNOFF CONTROL

The Lake District should participate in land use planning and zoning decision-making processes that dictate the density, type and location of future development within the watershed. Future regulations should include vegetative cover removal restrictions, performance standards for storm water management, wetland protection provisions, and restrictions on development of steeply sloped or highly erodible areas. Construction activities within the watershed, and especially along the lake's shoreline, should be policed for compliance of regulations concerning construction site erosion control. Large amounts of nutrient-laden sediment can wash off these sites during a storm event, and may eventually be deposited in the lake. Storm water control measures such as silt fences are commonly used to mitigate the effects of land disturbance activities that generate large quantities of runoff. For details on construction site erosion controls, contact the WDNR or the USEPA.

Runoff control measures, known as Best Management Practices (BMPs), should also be implemented on farmland within the watershed. Lake resident survey results revealed that only 3% of the respondents own agricultural land adjacent to Little Green Lake. However, agricultural property comprises a majority of the watershed and is expected to contribute a large proportion of the total external nutrient loading to the lake. Most of the survey respondents believe that runoff of pesticides, fertilizers and soil from agricultural land is the major factor causing current eutrophic lake conditions. Agricultural BMPs are designed to mitigate storm water as it is generated on farm fields. BMPs include conservation tillage, contour stripcropping, vegetative buffer strips and crop rotations, to name a few. The County Land Conservation Department, State Department of Agriculture, Trade and Consumer Protection and Federal Natural Resources Conservation

Service should be contacted since they may offer incentive programs that encourage the implementation of agricultural BMPs. The Lake District has cost-shared the installation of conservation practices in the watershed for the past several years.

Sediment detention basins may be used to mitigate storm water runoff that cannot be controlled through the implementation of BMPs. This technique essentially diverts storm water runoff that is generated within the watershed to holding ponds. These ponds reduce runoff velocities and allow suspended sediment to settle out before the water reaches the lake. The Green Lake County Land Conservation Department has already had great success in dealing with a barnyard runoff problem as well as sediment delivery to Little Green Lake utilizing this strategy. In fact, "substantial phosphorus loading reductions occurred when the Ron Kearly barnyard runoff control system (1987) and Doug Degener water and sediment control basin (1992) were installed" (Green Lake County Department of Land Conservation, 1994). Another sediment detention basin will be installed on the William Krentz farm in the spring of 1998. This sediment detention basin is located within a 450-acre subwatershed on the northeast side of the lake. Three to four other potential sites are currently being considered (Hebbe, personal communication).

As stated in the 1994 Inventory of Little Green Lake Watershed report, "The Little Green Lake Watershed is a success story waiting to happen from the standpoint of non-point source pollution reduction. The Land Conservation Department has a good working relationship with all the watershed landowners and have successfully installed conservation practices already on some of the major pollutant loading sites." However, it is important to understand that addressing the external nutrient loading problem alone may not improve the water quality conditions in Little Green Lake. This may be the case if internal nutrient loading is determined to represent a significant proportion of the total phosphorus contribution to the lake.

LAKE SEWERING

Many lake residents expressed concern that on-site septic systems might be contributing to the deterioration of Little Green Lake's water quality as a result of system failure. Many of these septic systems were upgraded approximately 10 years earlier as a result of previous concerns. As discussed in Section 4 of this report, on-site septic systems generally do not deliver sufficient nutrient loads to a lake to influence a lake's trophic status or cause water quality problems. However, existing information pertaining to Little Green Lake was insufficient to reasonably estimate the amount of phosphorus that is contributed to the lake as a result of on-site septic systems.

A limited phosphorus budget, discussed in Section 5.1 under "Limitations & Information Requirements," is recommended to better assess the possible magnitude of this perceived problem. This and other information are needed before a costly lake-sewering project is considered as a management option to improve water quality. If the sewering of the lake is pursued in the future, the Lake District should be cautioned that sewering may foster an increase in lake-use and development of a rural area. The Lake District is encouraged to consider setting up a septic system inspection program to identify systems that are not in regulatory compliance. Fines could be levied (or holding tanks could be required) in situations of repeated non-compliance.

5.4 MANAGEMENT OF INTERNAL NUTRIENT LOADING

INTRODUCTION

Internal nutrient loading occurs as phosphorus and other nutrients are recycled within the lake itself. This process may account for a significant proportion of the total nutrient loading to the lake, fueling algae blooms, excessive plant growth and other symptoms of eutrophication. Once external nutrient contributions are sufficiently controlled, management techniques that address internal loading/recycling should be implemented. The following table summarizes the various management options that are available. These management options are discussed in greater detail in the following sections.

Table 3
Management options to control internal nutrient loading

Management Option	Recommendation	Justification
Phosphorus Precipitation/Inactivation (Alum Treatment)	Recommended if a phosphorus budget suggests that external nutrient loading is acceptable and internal nutrient recycling is a significant problem. It should also be confirmed whether the majority of phosphorus is released from sediment in the hypolimnion during periods of anoxia.	This technique is an effective strategy to reduce phosphorus releases that occur in the anoxic hypolimnions of stratifed lakes.
Hypolimnetic Withdrawal	Recommended under two conditions. First, a phosphorus budget should suggest that external nutrient loading is acceptable and internal nutrient recycling is a significant problem (it should also be confirmed whether the majority of phosphorus is released from sediment in the hypolimnion during periods of anoxia). Second, discharge measurements should indicate that the lake has sufficient recharge capacity to support a summer withdrawal.	This technique is an effective strategy to remove anoxic, nutrient-rich water as it develops in the hypolimnion during the summer months.
Sediment Removal	Not recommended at the present time as a cost-effective technique to control internal nutrient loading. Sediment removal is recommended only if public access is severely limited due to factors such as shallow lake depths.	May be very cost prohibitive and ecologically disruptive. Furthermore, sediment phosphorus data suggest that the shallower areas in the lake that are most conducive to dredging are not as nutrient-rich as the sediment found in the deeper, anoxic areas.
Dilution & Flushing	Not recommended.	Large supply of nutrient-poor water is not available; outlet structure is not designed to handle large flow volumes.

In-lake processes (such as internal nutrient cycling) are usually more important in lakes with smaller watersheds and longer hydraulic retention times. Lakes with larger watersheds and shorter hydraulic retention times are influenced more by external inputs (USEPA, 1990). The hydraulic retention time, defined as the amount of time required to completely replace the lake's current volume of water with an equal volume of "new" water, has not been calculated for Little Green Lake due to data limitations described earlier (see Section 5.1 under "Limitations & Information Requirements"). However, the lake's relatively small watershed suggests that internal nutrient cycling may likely be the predominant influence governing the lake's overall trophic condition.

There are multiple in-lake mechanisms that can trigger internal phosphorus releases. One, well-documented mechanism is anoxia at the sediment-water interface. In the hypolimnion of productive lakes, the sedimentation of organic matter from the surface waters is extensive. In addition, light penetration through the water column to the hypolimnion becomes limited or absent due to the excessive abundance of algae and other suspended particles, prohibiting photosynthesis. Under these conditions, the consumption of oxygen in the hypolimnion during decomposition of this organic matter exceeds the amount of oxygen that is produced. The result is a depletion or elimination of dissolved oxygen in the hypolimnion of a thermally stratified lake. Under these conditions, phosphorus that is tied up in the sediments is chemically converted to a soluble state and released into the surrounding water. This process is occurring within Little Green Lake.

The large increases in phosphorus concentration near the bottom sediments measured by the USGS in Little Green Lake during anoxic periods is indicative of phosphorus being released from the sediments (USGS Data, 1991-96).

It is important to recognize that the anoxic hypolimnion is not the only area known to cause large-scale, in-lake phosphorus releases. The shallow, littoral zone of many lakes is also shown to contribute to internal phosphorus recycling as a result of anoxia, sediment disturbance and elevated pH. Anoxic conditions may develop in shallower areas during non-daylight hours when respiration exceeds photosynthesis, causing phosphorus to be released from near shore areas. Also, sediment disturbance caused by wind/wave action and motor boating activity may re-suspend bottom sediment that is rich in phosphorus, increasing nutrient availability in the water column. Finally, pH levels may increase as carbon dioxide concentrations decrease during photosynthesis. These high pH conditions are shown to be a mechanism for phosphorus release due to complex biochemical processes.

Thus, the source of internal phosphorus recycling may be from the deep, anoxic zone and/or the shallow, littoral areas. To treat these areas and remedy the situation can be extremely expensive. A limited phosphorus budget is recommended before an expensive management technique is considered which may not target the actual problem area. As mentioned earlier, if the limited phosphorus budget suggests that internal nutrient loading is indeed the problem, the Lake District will need to decide whether to pursue the funds to identify and remedy the internal recycling problem.

Phosphorus Precipitation and Inactivation

This management alternative addresses phosphorus release that occurs from the anoxic hypolimnion of a lake. As Little Green Lake thermally stratifies and becomes anoxic in the hypolimnion, phosphorus is released from the sediments and becomes readily available for algae growth. This internal phosphorus loading can be extensive in many lakes and may persist even after external phosphorus loading from the surrounding watershed is curtailed. Phosphorus precipitation and inactivation are lake-improvement techniques that use aluminum sulfate (alum) to lower the lake's phosphorus content by removing the limiting nutrient from the water column and retarding its release from anoxic lake sediments. Alum is a nontoxic material that is commonly used in lakes to reduce phosphorus levels, thereby controlling the nutrient that encourages algae growth. This management technique does not, however, address phosphorus that is released from the shallow, littoral areas as a result of elevated pH, sediment disturbance and/or anoxia during non-daylight hours.

On contact with water, alum forms an aluminum hydroxide precipitate known as floc. Aluminum hydroxide reacts with phosphorus to form an aluminum phosphate compound that is insoluble in water under most conditions, depriving algae of this critical nutrient. As the floc settles, inorganic phosphorus and phosphorus-containing particulate matter is removed from the water column. The floc, which is harmless to aquatic life, eventually consolidates with the sediments. The floc, when applied in sufficient quantities, forms a chemical barrier that retards phosphorus release at the sediment-water interface as anoxic conditions develop in the hypolimnion.

Little Green Lake may be a good candidate for this procedure if a limited phosphorus budget shows that external nutrient loading is being effectively managed, and high internal phosphorus releases are shown to occur within the anoxic hypolimnion of the lake. Sediment analyses recently performed by the USGS for Little Green Lake revealed that the phosphorus content of the sediment increases with increasing water depth, lending further support for this particular management technique. Note that sediment with a high moisture content may cause the floc to settle below the sediment surface, reducing its effectiveness. However, this problem is more common in southern lakes where sediment is unconsolidated and easily redistributed by water currents (Eberhardt, personal communication). Toxicity problems from lowered pH are unlikely given the relatively high buffering capacity of Little Green Lake.

When implemented correctly, this technique provides an effective, nontoxic and long-term approach to algae control by reducing concentrations of the limiting nutrient that usually drives algae growth. A number of case studies indicate that this approach can significantly lower the phosphorus content of a lake, maintain that low level for many years, and bring about a measurable and lasting improvement in trophic state (Cooke, 1986).

Phosphorus precipitation and inactivation should be implemented during spring turnover when most phosphorus is in an inorganic fraction. Alum may be applied at the surface or injected into the hypolimnion when algae blooms inhibit the application process. Treatments should be applied primarily over the anoxic zone of the lake. The anoxic zone in Little Green Lake occurs at depths of 15 feet and greater, but a natural process known as sediment focusing (caused by physical wind-driven mixing) is likely to transport some of the floc toward the deeper holes. Boat traffic speed should be reduced to "no wake" in areas less than 10 feet deep for up to four weeks after treatment.

Potential Benefits:

- Dramatically reduces in-lake phosphorus concentrations
- Increases water clarity
- Reduces algae populations

Potential Negative Impacts:

- Reduces pH (potential for toxicity problems in Little Green Lake would be minimal due to the high buffering capacity of the system)
- Increases plant growth as a result of increased water clarity

Estimated Costs:

- Relatively inexpensive when compared to other management strategies such as dredging
- High initial cost that is amortized over the long-term
- Costs are highly variable, depending upon local salaries, rentals, and the price of chemicals.
- There is a high benefit-cost ratio associated with this management strategy.
- It is estimated that an alum treatment for Little Green Lake would cost $150,000 to $200,000, which includes $12,000 to deliver and set up the equipment and about $500 per acre to be treated (Eberhardt, personal communication)
- If algae blooms prevent an effective surface application, alum will have to be injected directly into the sediment, increasing costs by approximately 20 percent (Eberhardt, personal com.).
- The Lake District can apply for a Wisconsin Lake Protection Grant to help fund the project (up to $200,000).

Longevity of Effectiveness:

- May be effective for up to 12 years after the initial treatment if external nutrient loading has been controlled
- Average effectiveness timeframe is between 7-10 years (Eberhardt, personal communication)

Hypolimnetic Withdrawal

This management technique addresses phosphorus releases that occur from the deep, anoxic zone by removing nutrient-rich, hypolimnetic water before it mixes with the entire water column. The principal purpose of this technique is to change the depth at which water leaves the lake, from the surface to within the hypolimnion, so that nutrient-rich instead of nutrient-poor water is discharged from the lake. Hypolimnetic withdrawal is accomplished by installing a tube along the lake bottom from the deep area to the outlet. The tube acts as a siphon, removing nutrient-rich water from the hypolimnion and discharging it at the outlet. A discharge permit is usually required.

There are few documented case histories regarding this procedure. The technique is most applicable to stratified lakes and small reservoirs in which anaerobic hypolimnia restrict fish habitat and promote the release of phosphorus from the sediments. It requires a sufficient water exchange rate to replenish the amount of water that needs to be discharged. To be successful the exchange rate should be severalfold per stratified period (Cooke, 1986). Hypolimnetic withdrawal should only be implemented during the summer months when anoxic conditions develop in the hypolimnion. Discharge measurements at Little Green Lake's outlet are necessary to evaluate the feasibility of this management approach. The proposed dam improvements at the lake's outlet should be evaluated for its water storage capabilities to determine if it is sufficient to compensate for the required discharge volumes.

Potential Benefits:
- Reduces likelihood of developing anoxic conditions in the hypolimnion
- Reduces internal loading of phosphorus

Potential Negative Impacts:
- May produce thermal instability and destratification that could introduce nutrient-rich, anoxic water to the epilimnion
- Poor quality water will be released downstream and may need treatment.
- The effect of hypolimnetic withdrawal on internal loading of phosphorus is not well understood.
- There are very few case studies available that can be used to analyze the effectiveness of this technique.

Estimated Costs:
- Very low operational costs given the continual dependability of the siphon which operates by gravity
- Costs would involve a capital outlay for a pump (if required), pipe, and an aeration device for discharge water (if needed).

Longevity of Effectiveness:
- Indefinite as long as siphon is operational, and external nutrient loading is controlled

Sediment Removal

This management alternative may be used to address phosphorus releases that occur in the shallow, littoral areas of a lake (although it is more frequently employed to deepen a lake or remove aquatic plants). If sediments are the source of internal nutrient loading, and the bulk of nutrients are located in the top 1-1.5 feet of a sediment core, then removal of that layer by dredging may provide the most reliable and permanent solution. However, it will also be the most costly and involved management procedure. If sediments are rich in nutrients below that depth, then dredging would result in only exposing more sediment with the same high nutrient content providing little or no expected decrease in internal loading.

The release of algae-stimulating nutrients from lake sediments can be controlled by removing the most highly enriched layer of materials, assuming that external nutrient loading is brought under control. Dredging may be very effective if targeted areas have sediment that is high in phosphorus, but all the nutrient-rich layers will need to be removed. Lakes most suitable for dredging have shallow depths, low sedimentation rates, organically rich sediments, long hydraulic retention times, and the potential for extensive use following dredging. Little Green Lake sediment data indicate that sediment phosphorus content increases with lake-depth. This suggests that sediment removal would have to target the lake's deepest areas, and may not prove be the most cost-effective approach to control internal nutrient loading.

Investigation of the sediment to be dredged must be conducted to determine how difficult it will be to dredge the material and its appropriateness for land disposal. Selective dredging is less expensive and is not as detrimental to aquatic plant and animal habitat, biodiversity, various recreational uses, and aesthetics. One major technique is to draw down the lake and expose near shore sediment that can then be removed by earth-moving equipment. This may be the simplest and most cost-effective method, even though mechanical and hydraulic dredging are much more common approaches to sediment removal. Those performing sediment removal projects will need to identify the source of sediment; characterize the sediment for engineering and legal reasons (thickness, distribution, grain size, organic content, contaminant analysis, nutrient analysis);

determine the volume of sediment to be removed; consider environmental issues; and obtain the appropriate local, state and federal permits.

Potential Benefits:
- Deepens the lake and improves navigation
- Removes plant material
- Removes nutrient-rich sediment

Potential Negative Impacts:
- This technique may cause increased turbidity due to re-suspension of sediment (usually temporary).
- Sediment removal disrupts spawning habitat.
- This technique destroys benthic (bottom-dwelling) organisms that represent an important component of the food chain.
- If present, heavy metals and other contaminants within the sediment may be released into the water column.
- Anaerobic gases such as ammonia and hydrogen sulfide may be released, causing adverse conditions for aquatic life.
- A large, suitable land area near the lake will need to be sacrificed for sediment disposal purposes.

Estimated Costs:
- Sediment removal is one of the more expensive management strategies.
- Costs are highly variable, depending upon site conditions, access, nature of the sludge, disposal method, monitoring and other factors.
- In 1988 dollars, costs have been shown to range from $0.40 to $23.35 per cubic yard of material removed (Peterson, 1981).
- In 1988 dollars, costs for hydraulic dredging were generally between $2 and $3 per cubic yard of material removed (USEPA, 1990 and Peterson, 1981). Assuming a cost of $2.50 per cubic yard of material removed, and estimating that Kearly Bay has a surface area slightly greater than 71,000 square yards, it would cost nearly $60,000 to remove only one foot of sediment from Kearly Bay at water depths not exceeding six feet. This dollar figure jumps to over $550,000 (using $23.35 per cubic yard of material removed) if a more expensive dredging technique is employed. It is not uncommon for lake-dredging efforts to end up being multi-million dollar projects.
- High costs of dredging dictate that the feasibility of this treatment be examined closely in comparison to the intended use of the lake and alternative treatment methods.
- Potential funding opportunities through a Waterways Commission grant should be considered if dredging is necessary for navigational and public access purposes.

Longevity of Effectiveness:
- Long-term effectiveness is likely if external sediment/nutrient loading is addressed and all nutrient-rich sediment is removed.

Dilution & Flushing

Dilution and flushing is a management technique that uses large quantities of nutrient-poor water from an upstream source to dilute nutrient concentrations in the lake and flush out algae cells. Lakes with low initial flushing rates, or hydraulic retention times, are poor candidates because in-lake phosphorus concentrations could increase unless the dilution water is essentially devoid of phosphorus. Flushing rates of 10-15% of the lake volume per day are believed to be sufficient. Internal phosphorus release could further complicate the effect (USEPA, 1990).

Little Green Lake is not a likely candidate for this management approach for two reasons. First, a large, upstream source of nutrient-poor water has not been identified. Second, it does not appear that the lake has a sufficient flushing rate or an outlet structure that will be able to handle the required discharge (discharge measurements at the outlet are needed to verify this statement).

5.5 MANAGEMENT OF BIOLOGICAL CONSEQUENCES OF NUTRIENT LOADING

INTRODUCTION

Symptoms of nutrient loading, including nuisance algae and aquatic plant growth, may continue even after the implementation of nutrient reduction techniques. The various management options that are available to treat the biological consequences of a nutrient-rich system are summarized in the table below. These management options are discussed in greater detail in the following sections.

Table 4
Management options that control biological consequences of nutrient enrichment

Management Option	Recommendation	Justification
Mechanical Plant Harvesting	Recommended to control nuisance aquatic plant growth following the preparation of an Aquatic Plant Management Plan.	This technique is an effective strategy to selectively harvest nuisance plant communities (nutrients are also removed through the removal of plant biomass). The Aquatic Plant Management Plan is required to obtain State funding for the purchase of a harvester.
Sediment Covers	Recommended to control aquatic vegetation in small, isolated areas where mechanical harvesters cannot reach. Not recommended, however, as a lake-wide management strategy.	This technique is effective in small beach areas and around piers if plant control is required in these areas.
Biomanipulation	Recommended in conjunction with nutrient-reduction strategies to control algae growth.	This technique is not always reliable or long lasting. It should be used to supplement other management techniques.
Lake Level Drawdown	Not recommended at the present time. Discharge measurements at the outlet are needed to help determine the lake's recharge potential following a drawdown. The proposed dam at the outlet will need to be evaluated for drawdown capability.	This technique requires considerable control and manipulation of lake levels. Recreational use of the lake will be severely impacted for a significant time period.
Herbicides	Not recommended at the present time. Implement in small areas only if mechanical harvesters and other recommended strategies are unable to adequately control specific stands of exotic, invasive plant species.	This technique may be necessary to control isolated patches of nuisance, exotic plants that cannot be controlled by other means. Herbicides may cause adverse side effects.
Algacides	Not recommended at the present time. However, this management option could be used if nutrient loading to the lake cannot be controlled.	This technique is a strategy for immediate but temporary relief of nuisance algae. It does not address the actual problem and may become costly over the long-term. Algacides may cause adverse side effects.
Artificial Circulation	Not recommended.	This technique has not produced enough positive results to be considered an established and effective long-term procedure.

Hypolimnetic Aeration	Not recommended.	This technique is not as effective in shallow lakes with smaller hypolimnions.

Mechanical Plant harvesting

It is important to recognize that aquatic plants form the foundation of a healthy lake ecosystem by protecting water quality and producing oxygen. Aquatic plants are important in filtering pollutants, absorbing nutrients, stabilizing sediment, as well as providing food, spawning habitat and structural refuge for aquatic life.

When plant growth becomes a problem, aquatic plant harvesting is a procedure to cut and remove nuisance rooted plants and associated filamentous algae. Unlike herbicide applications where plants are left in the lake to die, decompose and release nutrients and organic matter, harvesters are designed to physically remove plants and the associated organic matter and nutrients. Harvesters can clear an area of vegetation without the post-treatment waiting period associated with herbicides and without significant danger to non-target species.

The typical harvester is a highly maneuverable, low-draft barge designed with one horizontal and two vertical cutting bars, a conveyor to remove cut plants to a storage unit on the machine, and another conveyor to rapidly unload plants. Harvesters vary in size and storage capacity from about 200 cubic feet (6 cubic meters) of cut vegetation to 800 cubic feet (23 cubic meters). Cutting rates range from about 0.2 to 0.6 acres per hour, depending on machine size. The barge itself can be very useful with other lake improvement procedures, including alum applications. *An Aquatic Plant Management Plan is usually required before a plant harvester can be purchased using money from a Wisconsin Lake Protection Grant.*

Aquatic plants that are cut are required by law to be removed from the water for a number of reasons. Fragments of certain plants that are not removed from the water can re-root and form new plant beds. Also, plant material that is left in the water to decompose will deplete oxygen levels and may release nutrients that fertilize other plants. Finally, floating plants can obstruct navigation. However, when harvesting is performed in a proper fashion, the problems associated with plant fragmentation can be avoided.

Plant disposal is usually not a problem, in part because lakeshore residents and farmers often will use the plant material as mulch and fertilizer. Also, since aquatic plants are more than 90% water, their dry bulk is comparatively small. Most harvesting operations are successful in producing at least temporary relief from nuisance plants by removing organic matter and nutrients without the addition of potentially deleterious substances. Plant re-growth can be very rapid (days or weeks), but several case histories illustrate the effectiveness of harvesting in northern waters (USEPA, 1990).

Harvesting works best in open, unobstructed areas of the lake where the water is two to six feet deep. A selective harvesting approach, rather than clear cutting, is recommended to avoid causing serious habitat disturbance. Harvesting is most effective when used to create boat lanes and open spaces in particular locations. Generally, one to two harvests in the same area during the summer are recommended for most aquatic plant species. The first cutting should be done about mid-June (avoid fish spawning areas) with the second cutting in mid-July.

Potential Benefits:

- Proper collection removes plant biomass and associated nutrients from the lake.
- Temporary and immediate relief from nuisance aquatic plants
- Structural refuge for small panfish is often reduced, increasing predator success and overall fish sizes (favorable in terms of biomanipulation).
- Harmful chemicals are avoided.
- Harvested plants may be used as a nutrient-rich soil conditioner or fertilizer.
- Can target specific areas.
- Harvesting is fully controlled by the machine operator.
- Multiple use of the water body may continue with minor interference during harvesting.

- Harvesting activities pose little hazard to non-target organisms other than those inadvertently removed with the cut vegetation.

Potential Negative Aspects:

- Only relatively small areas can be treated per unit of time.
- Harvesting can be over-used, destroying critical habitat.
- Harvesting may encourage vegetative fragmentation of target and non-target plants and may encourage shifts in species composition by encouragement of opportunistic species such as Eurasian Milfoil.
- Plants may fragment and spread.
- Small fish may be inadvertently removed and killed.
- Operating depths may be limited.
- Harvesting may have to be repeated during each growing season for effective control.
- Excessive plant growth may continue in extremely shallow areas where larger harvesters cannot gain access.

Estimated Costs:

- Usually less expensive that herbicide treatments.
- A high capital outlay for equipment is required, and may be energy- and labor-intensive and thus expensive.
- Expenditures for a particular project will vary depending on machine cost and reliability, labor, fuel, insurance, disposal charges, and the amount of down time.
- Harvesting costs in the Midwest have ranged from $140 to $310 per acre (1984 dollars), making the technique somewhat less expensive than herbicide treatments (USEPA, 1990).
- Harvesters generally cost $20,000-$80,000 (WDNR, 1988); both a harvester and transport were recently purchased by the Lake Beulah Management District for a total cost of $150,000.
- Operating costs can be quite variable, but generally average around several thousand dollars per year with labor comprising from 20-65% of the total operating costs.

Longevity of Effectiveness:

- Harvesting is most effective when it is repeated multiple times during each growing season.
- Research indicates that there is often a carry-over effect from season to season (evidence of less growth in subsequent years following multiple harvests).

SEDIMENT COVERS

Plastic sheets of polyethylene, polypropylene, fiberglass or nylon can be used as sediment covering materials in lakes to prevent aquatic plant growth. Since rooted plants require light and cannot grow through physical barriers, sediment covers are an effective means of controlling plant growth, especially in small areas such as around piers and swimming beaches. Gravel, sand, silt and clay are also used as sediment covers, although these materials are less effective plant barriers.

The most effective covers are opaque, durable, negatively buoyant, vented and gas-permeable. Proper application requires that the screens be placed flush with the sediment surface and securely anchored. Because this is difficult to accomplish over heavy plant growth, a spring or winter lake level drawdown provides ideal application conditions. Depending upon sedimentation rates, sediment covers will have to occasionally be removed and cleaned so plants cannot become re-established. Sediment covers are usually not employed over large areas due to the high costs of the materials and their application. Effectiveness is highly correlated with application techniques and type of materials used.

Potential benefits:

- There is little negative impact to the lake.
- Use is confined to a specific area.
- Sediment covers can be installed in areas that will not be disrupted by boat traffic or harvesters.

- No toxic chemicals are used.
- Sediment covers are easy to install over small areas.

Potential negative impacts:
- The cause of the problem is not addressed.
- Materials are expensive.
- It is difficult to apply over large areas or over obstructions.
- Sediment covers may be difficult to secure to the bottom sediments, especially if there are steep grades or if gases are trapped beneath the covers.
- They can be difficult to remove or relocate.
- They may tear during application.
- Some materials are degraded by sunlight.
- A permit may be required.
- Benthic invertebrates may be eliminated in treatment areas.

Estimated costs:
- The more effective synthetic materials are expensive.
- Polypropyl (Typar): $3,240/acre.
- Fiberglass PVC (Aquascreen): $8,700/acre.

Longevity of Effectiveness:
- Sediment covers will have to routinely be reinstalled due to the build-up of sediment.

BIOMANIPULATION

Biomanipulation involves the manipulation of the food web (usually fish) to facilitate changes in the lake environment that will mainly reduce algae biomass and improve water quality. It is a top-down management strategy that may be used to compliment bottom-up management strategies that manipulate nutrient inputs. Biomanipulation is based on a theory known as the Trophic Cascade Hypothesis. Simply stated, top predators such as fish can control the abundance and productivity of lower trophic levels, such as algae, which in turn can affect water clarity and nutrient recycling. The Trophic Cascade Hypothesis is described below.

1. A large biomass of piscivorous (fish-eating) fish will consume large numbers of smaller, planktivorous (plankton-eating) fish, resulting in a decline in the abundance of planktivores;
2. Lower numbers of planktivores will consume fewer zooplankton (algae consumers), allowing for the development of a large zooplankton biomass, including large-sized zooplankton taxa;
3. Large numbers of zooplankton will consume large numbers of algae, reducing algae abundance; and
4. Lower algae abundance will result in an increase in water transparency and overall improvement in water quality.

Piscivorous fish such as bass and walleye may be increased through stocking programs; development of fishing regulations to restrict angler harvests; and habitat improvements to enhance piscivore survival and reproduction. Planktivorous fish such as small panfish may be reduced through fish poisoning; extreme water level drawdown; selective catches and fish removal; disruption of spawning behavior and reproduction; and fish barriers. Zooplankton grazing on algae may be encouraged by reducing the number of planktivores that feed on zooplankton. This is often accomplished by increasing the number of piscivores, or the effectiveness of existing piscivores (i.e., by reducing structural refuges used by prey fish through the mechanical harvesting of aquatic plants) that feed on the smaller panfish. Reducing panfish populations frees up food resources for small piscivores that are often out-competed in the early life stages. Zooplankton grazing may also be encouraged by oxygenating the hypoliminion, allowing vertical migration and avoidance of planktivores. Aquatic plant beds also provide a refuge for zooplankton.

Biomanipulation is a strategy that should only be used in conjunction with other strategies if a significant, long-term improvement is going to occur. Full implementation of a biomanipulation project, which prohibits the harvesting of gamefish, is not recommended since fishing is identified as a top priority lake use. Biomanipulation was recently implemented at Lake Delavan, located in Walworth County, Wisconsin, through a walleye-stocking program. Although phosphorus concentrations increased following the walleye stocking, water clarity actually improved. A dramatic, temporary improvement in water clarity also occurred on Lake Mendota, located in Dane County, Wisconsin, following a summer kill of the cisco population (a planktivorous fish) several years ago.

Lake Level Drawdown

Lake level drawdowns expose sediments to prolonged freezing and drying. Some rooted plant species are permanently damaged by these conditions and the entire plant is killed if exposed to freezing for two to four weeks. Other species, however, are either unaffected or enhanced. A drawdown may allow for limited dredging in the near shore areas. To be most effective, complete freezing and desiccation are required, and freezing operations should be alternated every two years with no drawdown so that resistant species do not become firmly established.

This management technique is best suited for reservoirs or water bodies that have a well-maintained outlet structure and a steady water flow that will refill the lake or reservoir by the summer. On smaller water bodies, the lake is more susceptible to fish kills in summer or winter. Lower water levels may also damage banks and shorelines, and fish spawning grounds may be adversely affected. A winter drawdown should be conducted to control vegetation through freezing and scouring, as opposed to a summer drawdown that will usually encourage plant growth. A winter lake level drawdown was implemented two years ago on Big Muskego Lake, located in Waukesha County, Wisconsin. The lake is several thousand acres in size with a maximum depth of only three feet. Water clarity was improved and macrophyte growth increased following the drawdown (Rose, personal communication).

The following is a list of some common aquatic plants and their general response to a lake level drawdown (USEPA, 1990; Cooke, 1986). The list should only be used for illustrative purposes since many of these plant species respond differently depending the lake and on whether a whole-year, summer or winter drawdown is implemented.

Decrease:
1. Coontail (Ceratophyllum demersum) – annual, winter, summer (increases and no change are occasionally reported)
2. Brazilian elodea (Elodea = Egeria densa) – winter, summer
3. Milfoil (Myriophyllum spp.) – winter, summer (increases and no change are occasionally reported)
4. Southern naiad (Najas guadalupensis) – annual, winter
5. Yellow Water Lily (Nuphar lutea) – winter, summer (increases and no change are occasionally reported)
6. Robbin's Pondweed (Potamogeton robbinsii) - winter
7. Water Shield (*Brasenia schreberi*) – winter, summer
8. Fanwort (*Cabomba caroliniana*) – winter, summer

Increase:
1. Alligator Weed (Alternanthera philoxeroides) – annual, winter, summer
2. Hydrilla (Hydrilla verticillata) – winter
3. Cutgrass (*Leersia oryzoides*) – winter, summer
4. Bushy Pondweed (Najas flexilis) – annual, winter, summer
5. Smartwood (*Polygonum coccineum*) – winter, summer
6. Leafy Pondweed (*Potamogeton epihydrous*) – winter, summer

Variable:
1. Water Hyacinth (Eichhornia crassipes)
2. Common Elodea (Elodea canadensis)

3. Cattail (Typha latifolia)

Potential Benefits:

- Dries and consolidates near shore sediments that may increase water depths when prior lake levels are restored.
- Kills certain plant species, which can then be removed before prior lake levels are restored.

Potential Negative Impacts:

- Algae blooms may occur due to nutrient releases from the oxidized organic matter, or to an absence of competition from aquatic plants.
- Certain plant species may not be impacted or could actually proliferate.
- Recreational use of the lake will be severely restricted usually for a minimum of three weeks.
- Drying and freezing of the bottom sediment can sharply reduce the abundance of benthic invertebrates essential to fish diets.
- Oxygen depletion may occur in the remaining water pool.
- Mud flats will be created along the near shore areas as water levels recede, causing unsightly conditions and noxious odors.
- The water exchange rate of the lake may not be sufficient to raise water levels within a reasonable time period following a drawdown.

Estimated Costs:

- Expenditures will be minimal if the lake is controlled by a dam with several feet of drawdown capability (*make sure Little Green Lake's dam has these capabilities before it is installed*).
- One of the least expensive management options.
- Additional costs are associated with losing the use of the lake for recreational purposes.

Longevity of Effectiveness:

- This procedure may need to be repeated every few years to effectively control plant growth.

HERBICIDES

Herbicide treatments are management techniques that use chemicals to control the growth of aquatic vegetation. This technique does not address the source or underlying cause of the problem. It may, however, be the only option available for short-term relief if nutrient sources cannot feasibly be addressed.

It is recommended that this management technique be implemented <u>only</u> if other strategies are determined to be infeasible due to costs or other considerations. If necessary, herbicides should only be applied to small areas to control specific stands of exotic, invasive plant species. Reasons for caution include the following:

- Herbicides provide only temporary relief of nuisance aquatic plant growth, so treatments will have to be reapplied on a regular basis.
- Nutrients and organic matter are not removed from the lake.
- This plant control method causes decreases in dissolved oxygen levels due to decomposition of plant matter.
- Some nuisance species may be unaffected by the herbicides, and may replace the target species.
- Algae blooms may occur as a result of increased nutrient availability.
- This method does not address the actual cause of the problem.
- There are equally cost-effective alternatives available that have smaller environmental impacts.
- Toxicity concerns are poorly understood.
- Undesirable water quality changes have been noted in many lakes with characteristics similar to Little Green Lake following an herbicide application.

- Herbicides produce no restorative benefit, show no carryover of effectiveness to the following season, and may require several applications per year.
- The short-term benefit-cost ratio can be desirably high, but the long-term benefit-cost ratio is likely to be very low.

Algacides

Algacides are commonly used as a tool to chemically control algae growth. This technique does not address the source or underlying cause of the problem. It may, however, be the only option available for short-term relief if nutrient sources cannot feasibly be addressed.

This management technique is recommended only if nutrient loading to the lake cannot be controlled. Algacides are generally applied in small ponds, and should only be used if other strategies are infeasible due to costs or other considerations. Reasons for caution include the following:

- Chemical applications may be toxic to non-target aquatic life.
- Oxygen depletion may occur from the rapid die-off and subsequent decomposition of algae.
- Blue-green algae are known to become increasingly tolerant to the algacides.
- Chemicals may accumulate in the sediment.
- This method is short-term and symptom-oriented.

Artificial circulation

The purpose of this management technique is to thermally destratify a lake by injecting compressed air near the bottom of the lake. If sufficiently powered, rising air bubbles will induce lake-wide mixing, eliminating thermal gradients within the water column while mixing algae cells into deeper, light-limited areas. Artificial circulation is not recommended for Little Green Lake for the following reasons:

- Varied results from case studies (dissolved oxygen concentrations usually increase as expected, however Secchi transparency often decreases and total phosphorus often increases or remains the same).
- This technique has not produced enough positive results to be considered an established and effective long-term procedure (USEPA, 1990).
- Eliminates thermal stratification, which may harm the cool water walleye fishery by raising water temperatures.
- May mix nutrient-rich water throughout the water column.
- May cause turbidity through re-suspension of sediments.

Hypolimnetic aeration

This management technique uses an airlift device to bring nutrient-rich and oxygen-poor water from the hypolimnion to the surface where it can be aerated without thermally destratifying the lake. Hypolimnetic aeration is not recommended for Little Green Lake for the following reasons:

- Aerators need a large hypolimnion to work properly.
- They are not as effective in shallow systems.
- It is easy to become locked into this strategy for the long term.
- Aerators may keep organic matter and sediment in suspension for longer periods of time.
- Destratification is possible if hypolimnetic aeration is done improperly.
- This management option is an experimental rather than a proven technique.
- If the system is turned off, you may end up with oxygen depletion and phosphorus release from the sediments.
- An improperly designed system will circulate nutrient-rich water that increases the growth of undesirable algae.

5.5 OTHER MANAGEMENT RECOMMENDATIONS

Introduction

Management recommendations that involve modifying lake-use behavior through increased awareness and/or regulation are summarized in the table below. A more detailed discussion of each management option is presented in the following sections. These management options attempt to enhance the public's understanding of the ecosystem and its management. They are also designed to increase cooperation among lake users.

Table 5
Management recommendations to control lake use behavior

Management Option	Recommendation	Justification
Time & Use Zoning	Recommended as an effective means of coordinating conflicting lake use activities and increasing cooperation among lake users.	This management technique is an effective strategy to resolve conflicting lake uses.
Lake Resident Participation/Education	Recommended as an effective means of increasing awareness and understanding of individual impacts on the lake ecosystem.	This management technique is an effective strategy to increase understanding and support of lake management activities.

Time & Use Zoning

For small, shallow, nutrient-rich systems like Little Green Lake, an important source of phosphorus in the water is the lake bed itself. Recent studies suggest that sediment re-suspension can act as either a source or sink for phosphorus (Hansen, 1997). When sediment is disturbed, phosphorus mixes into the water column and becomes available for algae growth. Underwater currents produced by a prop from an outboard motor are frequently strong enough to disturb bottom sediments. Since eliminating boats or banning certain horsepower engines may not be feasible, consider restricting boats from near shore, shallow areas by instituting no-wake zones within a certain distance from shore. Instituting no-wake zones is also an effective strategy to protect fish spawning habitats, reduce conflicts with anglers and improve the safety of swimming areas.

Using boat props to essentially mow aquatic plants should be discouraged. These actions usually exacerbates the problem by (1) re-suspending phosphorus-rich sediment, (2) encouraging the spread of certain plant species through fragmentation, and (3) increasing the amount of decaying plant material that depletes dissolved oxygen levels in the lake.

Lake resident survey results indicate that congestion and lake user conflicts do not currently represent a significant problem on Little Green Lake. However, this situation may change in the future as a result of increased use of the lake. To avoid user conflicts in the future, especially between anglers and motor boaters, consider restricting motor boating to "no wake" except during the hours of 10 a.m. to 6 p.m.

Lake Resident Participation/Education

According to the lake resident survey, nearly half of the respondents felt they were not adequately informed of lake-management decisions or that they had a voice in decision-making matters regarding the management of Little Green Lake. Increasing lake resident participation in management decision-making processes offers an excellent opportunity to educate residents about the lake ecosystem and their role in its protection and improvement. Usually, greater cooperation and support of lake management activities can be achieved by employing this strategy.

The Lake District is encouraged to take the following actions to improve public participation and education:

- Develop a lake protection guidebook that illustrates how individual lakefront property owners can protect and enhance the lake environment. Educational materials should explain how a lake ecosystem functions, and the limitations of lake manipulation.
- Produce a regular newsletter or fact sheet that provides information concerning upcoming meetings, fundraisers, lake management projects, fishing derbies and other important events.
- Send mailings to lake residences as well as to the permanent addresses of part-time and seasonal lakefront property owners.
- Publicize Lake District meetings well in advance of the meeting date by sending press releases to the local newspapers and including the information in newsletters/fact sheets.
- Regularly vary the meeting times and dates to encourage participation by all lake residents.

EVALUATION CRITERIA/FUTURE MONITORING

It is important to recognize the complexity inherent in natural systems and the difficulty this presents in trying to characterize the response of the lake to various protection and rehabilitation efforts. Each lake is different, and the results obtained using a given approach at one lake are not necessarily transferable to another lake. Furthermore, many of the restoration techniques are relatively new, and experience with their application is limited. Finally, no matter how well studied a given lake or problem is, there is always a need for more detailed data. Given the above factors, there is no guarantee that a particular management approach will always produce the anticipated improvements. Stated differently, there is always some uncertainty in any management decision involving the manipulation of a lake ecosystem.

The criteria recommended to evaluate in-lake treatment effectiveness should include observed changes in total phosphorus concentration, chlorophyll *a* concentration and water clarity as measured by Secchi depths. Long-term monitoring data sets are necessary to appropriately monitor and evaluate the effectiveness of management practices, especially since natural lake variability may mask management results.

It is recommend that the Lake District continue implementing its current water quality monitoring program.

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APPENDICES

APPENDIX A

REVIEW OF LAKE & WATERSHED STUDIES

SUMMARY OF PRIOR LAKE/WATERSHED STUDIES FOR LITTLE GREEN LAKE

Biology Research Paper, D. Miller Severn, University of Oshkosh, 1974

The earliest Little Green Lake study that was obtained was a University of Oshkosh research paper completed by Ms. Doris Miller Severn in the spring of 1974. Historical documentation describing the evolution of Little Green Lake's fishery was obtained primarily from this study. The report also contained valuable information concerning the physical characteristics of the lake, and some of the problems that were observed more than 20 years ago. Information on geology, soils, water chemistry, fish populations, sediment characteristics, nutrient levels and algae is presented in the report. Results of this earlier study indicated that Little Green Lake was considerably eutrophic, or nutrient-rich and highly productive. The report also indicated that Mr. Vern Hacker of the Wisconsin Department of Natural Resources (WDNR) sent a letter dated November 11, 1965 to property owners on Little Green Lake strongly suggesting that a Sanitary District be formed to help control pollution.

Water Quality Monitoring Program, U.S. Geological Survey, 1991-present

Beginning in the spring of 1991, the Lake District retained the services of the U.S. Geological Survey (USGS) to initiate a water quality monitoring program for Little Green Lake. Water quality data such as temperature, dissolved oxygen, nutrient concentrations, pH, specific conductance, chlorophyll a, Secchi depth and lake stage were collected several times each year over a six-year period. The purpose of the water quality monitoring program was to collect baseline information on a range of physical, chemical and biological parameters. This information is essential to accurately assess the lake's current condition and identify long-term water quality trends.

Macrophyte Inventory, Northern Environmental Technologies, Inc., 1994

During the Summer of 1993, Northern Environmental Technologies, Inc. conducted a macrophyte inventory of Little Green Lake. A final report was issued in November of 1994 that documented the location and frequency of the various plant species found in the lake. The report also summarized the results of the USGS water quality sampling program and a watershed inventory that was performed by the County Land Conservation Department.

Watershed Inventory, Green Lake County Land Conservation Department, 1994

A Little Green Lake Watershed Inventory was completed by the Green Lake County Land Conservation Department in the fall of 1994. This assessment involved delineating the watershed boundary, identifying general land use practices within the watershed, and estimating sediment/phosphorus loading to Little Green Lake. The installation of Water and Sediment Control Basins (WASCOBs) were recommended as a result of the study. This conservation technique stores runoff water in an earthen basin and then stores or slowly releases the water. As runoff velocities decrease, transported sediment from upland sources is allowed to settle out before reaching the lake.

Lake Management and Land Use Survey, MSA Professional Services, Inc., 1996

A lake management and land use survey was conducted for Green Lake County in the fall of 1996. The survey was performed through MSA Professional Services, Inc., with assistance from the Green Lake County Land Conservation Committee and Development Guide Citizen's Advisory Committee. Approximately 500 surveys were distributed to property owners and visitors of Big Green Lake, Little Green Lake and Lake Puckaway in an attempt to measure attitudes and perceptions regarding lake use and management. The County's goal was to "use the results of the survey to make recommendations for changes in local regulations and ordinances aimed at enhancing natural resource protection in the County's valuable watershed areas." A Wisconsin Lake Management Planning Grant was used, in part, to cover the costs of the survey. The following survey results for Little Green Lake were taken from the final report, titled Lake Management and Land Use Survey Results, that was issued in April of 1997. (Note: There were 15 surveys distributed to Little Green Lake residents, of which nine surveys were completed and returned for analysis.)

Type of User - Lake Property Owners

- The most important reason the respondents use or own property on Little Green Lake is to enjoy the view, peace and tranquility, followed by observing wildlife and fishing/ice fishing. They chose to purchase property on the lake because it supports the above activities and is located within a manageable distance from home.
- Most of the respondents use their property for year-round residence. Part-time and seasonal residents occupy their property during the summer and weekends throughout the year.

Opinions on Lake Quality

- Most respondents feel water clarity is unsatisfactory and water quality is poor. These conditions have remained the same or improved since they have been using the lake.
- The lake was viewed as supporting moderate usage with little conflict between users.
- Moderate levels of disturbance affect the peace and tranquility of the lake.
- Respondents felt the shoreline of the lake varies but tends to be more moderately developed than natural looking.
- Although no significant problems exist due to public boating access to the lake, there is substantial concern that litter and noise have increased, local government costs are rising, and water quality has declined.
- According to a majority of the respondents, access to the lake is more than adequate. Respondents were evenly split in how they feel about having no additional lake access versus a public boat landing. A beach/park was preferred secondarily.
- In the user's mind, water quality problems exist mostly because of the use of agricultural fertilizers and faulty septic systems. Other contributing factors include manure runoff, soil erosion from fields, shoreline erosion and siltation. To deal with these issues, most respondents felt that a long-term management plan needs to be developed and aquatic plants/algae need to be managed.

Land Use and Management

- Most respondents felt that stricter enforcement of lake related regulations were needed, especially regulations dealing with local shoreland zoning/building codes, boating regulations and local sanitary ordinances.
- Responses were evenly split on who should manage the lake--local or State government. However, most people felt that the State should finance lake management projects.
- Development within the shorelands of Little Green Lake was generally considered satisfactory. Most people agreed that provisions should be made to provide for adequate green space surrounding the lake.

Sediment Data, U.S. Geological Survey, 1997

At the time of this report, sediment cores taken from Little Green Lake were in the process of being analyzed by the Wisconsin State Laboratory of Hygiene. The U.S. Geological Survey extracted the sediment cores along transects extending from the lake's shallow to deep areas. The purpose of the sediment cores is to in part determine the content and distribution of phosphorus within Little Green Lake's bottom sediments. This information is useful in assessing the practicability of certain management options (e.g. dredging) by identifying the location and extent of nutrient-rich sediment.

APPENDIX B

WATERSHED INVENTORY

INTRODUCTION

Little Green Lake Watershed

The Little Green Lake Watershed consists of approximately 1,645 acres according to the inventory that the Green Lake County Land Conservation Department (LCD) conducted. This is contrary to previously published estimates of approximately 2,000 acres. The LCD found about 300 acres in the upper Northeast area that was considered to be an area that drained to Little Green Lake which in fact does not drain to the lake. Of the 1,645 acres in the watershed 77% is cropland, 15% is woodland, 5% is residential area, and 3% is roads.

Most of the cropland in the watershed is farmed intensively which has the potential to allow large amounts of soil erosion which ultimately leads to large sediment loading to Little Green Lake.

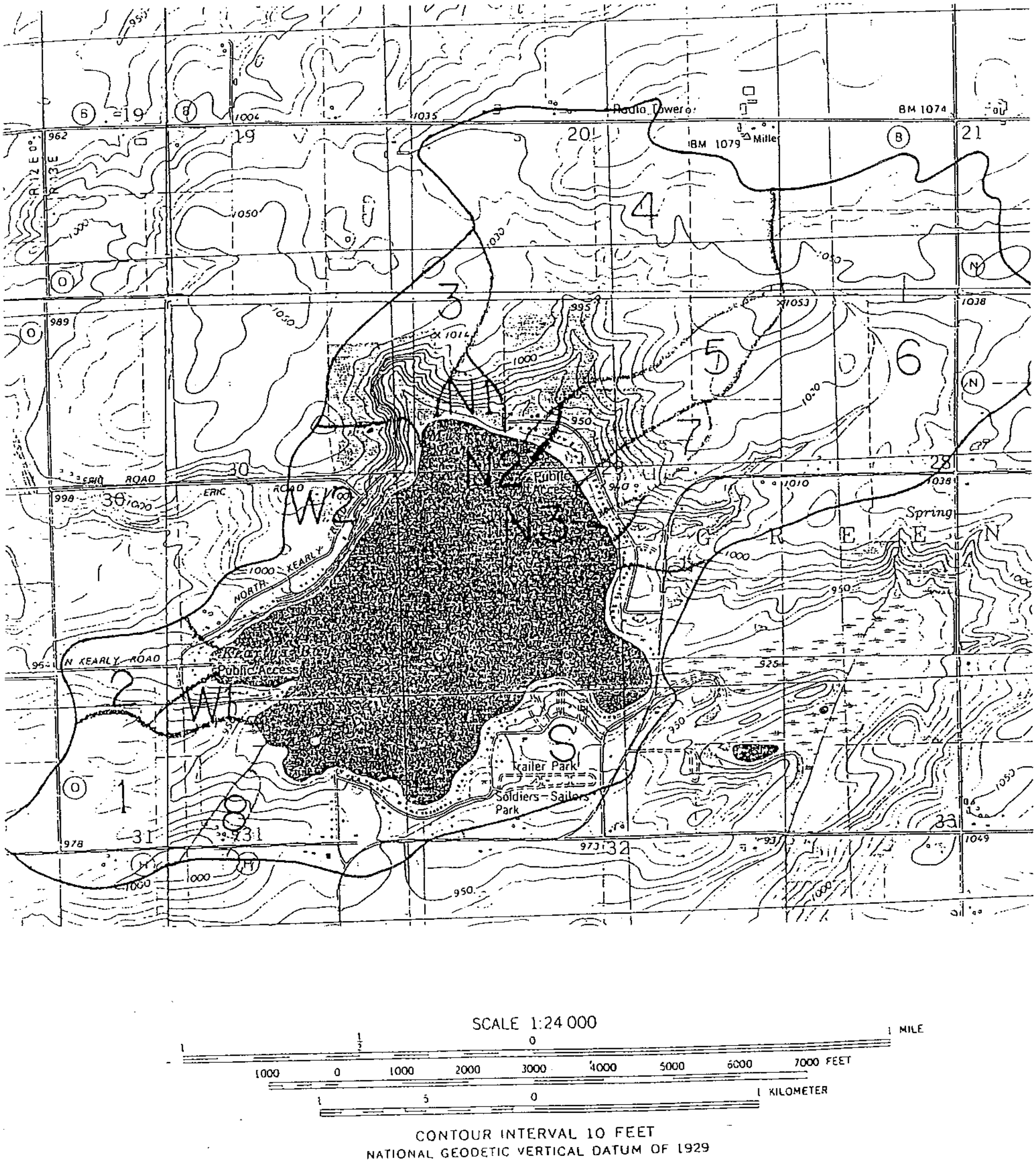
The LCD, through its computerized soil erosion information data which has been established and compiled for the past several years, was able to determine sediment and phosphorus load to Little Green Lake by putting the information into a DNR developed model called WINHUSLE.

WINHUSLE estimates the sediment yield from each inventoried field to the outlet of the hydrologic area that it's in, the sediment and total phosphorus yield out of each area, and the in-stream sediment deposition rate within each area. The model can be run in either an average annual mode or single event mode. It can also be run under either "inventoried", "controlled" or "analytic" (what if) conditions. DNR used WINHUSLE in its Nonpoint Source Program to estimate watershed loads, evaluate alternative management strategies, and track pollutant load reductions as management practices are installed.

WINHUSLE is calibrated by statistically regressing monitored sediment and phosphorus loads on monitored runoff volumes, peak flow rates, and the average soil loss rate from the monitored watershed. The model uses standard Soil Conservation Service (SCS) procedures to estimate runoff volumes and peak flows out of each area, and uses these estimates in the calibration regression to estimate loads.

The LCD divided the watershed into 9 major areas with the 9th area being the combination of all the direct subwatersheds to Little Green Lake. Areas 1 through 8 are subwatersheds with a large percentage of land in cropland use. The results are listed in both an inventoried (conditions as of 1991) and planned inventory (conditions as of 1994).

LITTLE GREEN LAKE WATERSHED



WINHUSLE RESULTS
DIRECT AREA BREAKDOWN
(Planned)

Area	Acres	Sediment Delivered From Fields to Channels (tons)	Sediment Deposited (tons)	Sediment Outflow (tons)	Phosphorus Outflow (lbs)
South	18	21	2	19	5
	4	10	0	10	2
	9	24	2	22	6
	8	2	0	2	1
	3	4	0	4	1
	8	11	0	11	2
	3	6	0	6	1
	3	4	0	4	1
	3	5	0	5	1
	4	6	0	6	1
	8	12	1	11	3
	6	7	0	7	2
	37	53	8	45	15
	13	15	0	15	4
	24	36	3	33	10
	6	7	0	7	2
	20	40	5	35	10
	9	17	0	17	5
	16	31	0	31	8
	---	---	---	---	---
Sub-Total	202	311	21	290	80
North 1	8	0	0	0	0
	8	0	0	0	0
	6	0	0	0	0
	6	1	1	0	0
North 2	3	4	0	4	1
North 3	5	5	0	5	1
	---	---	---	---	---
Sub-Total	36	10	1	9	2
West 1	5	4	0	4	1
	4	6	0	6	1
	13	15	0	15	4
West 2	7	19	0	19	4
	16	39	7	32	8
	5	27	0	27	5
	9	27	0	27	6
	3	4	0	4	1
	3	5	0	5	1
	38	35	8	27	12
	4	3	0	3	1
	3	5	0	5	1
	25	9	2	7	4
	17	1	0	1	1
	---	---	---	---	---
Sub-Total	152	199	17	182	50
Grand Total	390	520	39	481	132

WINHUSLE RESULTS
DIRECT AREA BREAKDOWN
(Inventoried)

Area	Acres	Sediment Delivered From Fields to Channels (tons)	Sediment Deposited (tons)	Sediment Outflow (tons)	Phosphorus Outflow (lbs)
South	18	21	2	19	5
	4	10	0	10	2
	9	24	2	22	6
	8	2	0	2	1
	3	4	0	4	1
	8	11	0	11	2
	3	6	0	6	1
	3	4	0	4	1
	3	5	0	5	1
	4	6	0	6	1
	8	12	1	11	3
	6	7	0	7	2
	37	53	8	45	15
	13	15	0	15	4
	24	36	3	33	10
	6	7	0	7	2
	20	40	5	35	10
	9	17	0	17	5
	16	31	0	31	8
	---	---	---	---	---
Sub-Total	202	311	21	290	80
North 1	8	0	0	0	0
	8	0	0	0	0
	6	0	0	0	0
	6	1	1	0	0
North 2	3	4	0	4	1
North 3	5	5	0	5	1
	---	---	---	---	---
Sub-Total	36	10	1	9	2
West 1	5	4	0	4	1
	4	6	0	6	1
	13	15	0	15	4
West 2	7	19	0	19	4
	16	39	7	32	8
	5	27	0	27	5
	9	27	0	27	6
	3	4	0	4	1
	3	5	0	5	1
	38	35	8	27	12
	4	3	0	3	1
	3	5	0	5	1
	25	9	2	7	4
	17	1	0	1	1
	---	---	---	---	---
Sub-Total	152	199	17	182	50
Grand Total	390	520	39	481	132

WINHUSLE RESULTS
PER SUBWATERSHED
(Planned)

	Acres	Sediment Outflow (tons)	Phosphorus Outflow (lbs)	Average Sediment Outflow (tons) per Acre	Average Phosphorus Outflow (lbs) per Acre
Area 1	145	71	35	.49	.24
Area 2	57	49	18	.86	.32
Area 3	85	20	14	.24	.16
Area 4	344	202	130	.59	.38
Area 5	63	37	16	.59	.25
Area 6	516	313	237	.61	.46
Area 7	35	31	12	.89	.34
Area 8	10	16	4	1.60	.40
Area 9(Direct)	390	481	132	1.23	.34
	-----	-----	-----	-----	-----
TOTALS	1,645	1,220	598		
WATERSHED AVERAGES				.74	.36

WINHUSLE RESULTS
PER SUBWATERSHED
(Inventoried)

	Acres	Sediment Outflow (tons)	Phosphorus Outflow (lbs)	Average Sediment Outflow (tons) per Acre	Average Phosphorus Outflow (lbs) per Acre
Area 1	145	137	63	.94	.43
Area 2	57	59	21	1.04	.37
Area 3	85	20	14	.24	.16
Area 4	344	202	130	.59	.38
Area 5	63	37	16	.59	.25
Area 6	516	313	237	.61	.46
Area 7	35	31	12	.89	.34
Area 8	10	16	4	1.60	.40
Area 9(Direct)	390	481	132	1.23	.34
	-----	-----	-----	-----	-----
TOTALS	1,645	1,296	629		
WATERSHED AVERAGES				.79	.38

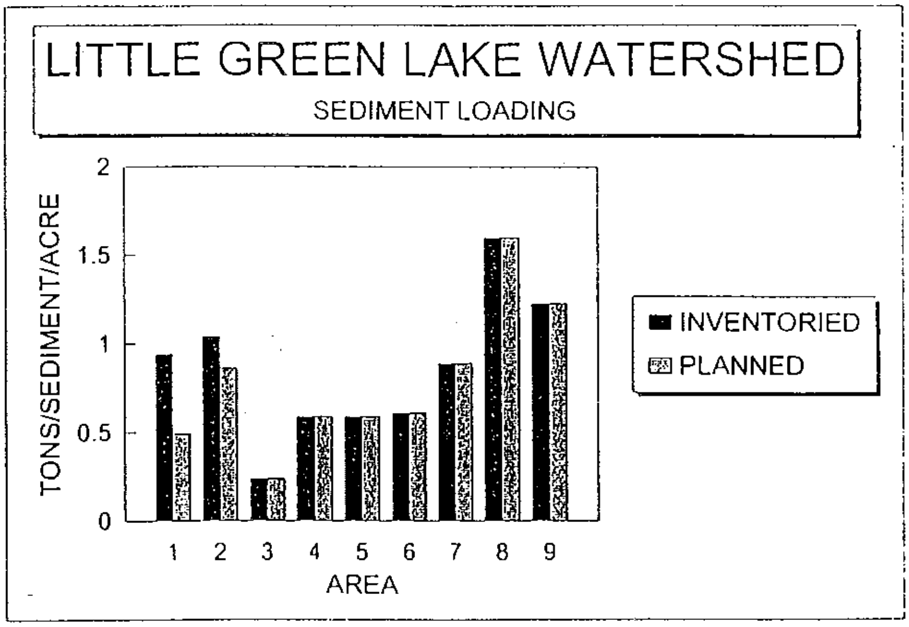
WINHUSLE RESULTS
PER SUBWATERSHED
(Planned)

	Acres	Sediment Delivered From Fields to Channels (tons)	Sediment Deposited (tons)	Sediment Outflow (tons)	Phosphorus Outflow (lbs)
Area 1	145	124	53	71	35
Area 2	57	68	19	49	18
Area 3	85	45	25	20	14
Area 4	344	494	292	202	130
Area 5	63	49	12	37	16
Area 6	516	937	624	313	237
Area 7	35	37	6	31	12
Area 8	10	16	0	16	4
Area 9(Direct)	390	520	39	481	132
	-----	-----	-----	-----	-----
TOTALS	1,645	2,290	1,070	1,220	598

WINHUSLE RESULTS
PER SUBWATERSHED
(Inventoried)

	Acres	Sediment Delivered From Fields to Channels (tons)	Sediment Deposited (tons)	Sediment Outflow (tons)	Phosphorus Outflow (lbs)
Area 1	145	251	114	137	63
Area 2	57	82	23	59	21
Area 3	85	45	25	20	14
Area 4	344	494	292	202	130
Area 5	63	49	12	37	16
Area 6	516	937	624	313	237
Area 7	35	37	6	31	12
Area 8	10	16	0	16	4
Area 9(Direct)	390	520	39	481	132
	-----	-----	-----	-----	-----
TOTALS	1,645	2,431	1,135	1,296	629

WINHUSLE SEDIMENT LOADING AVERAGES

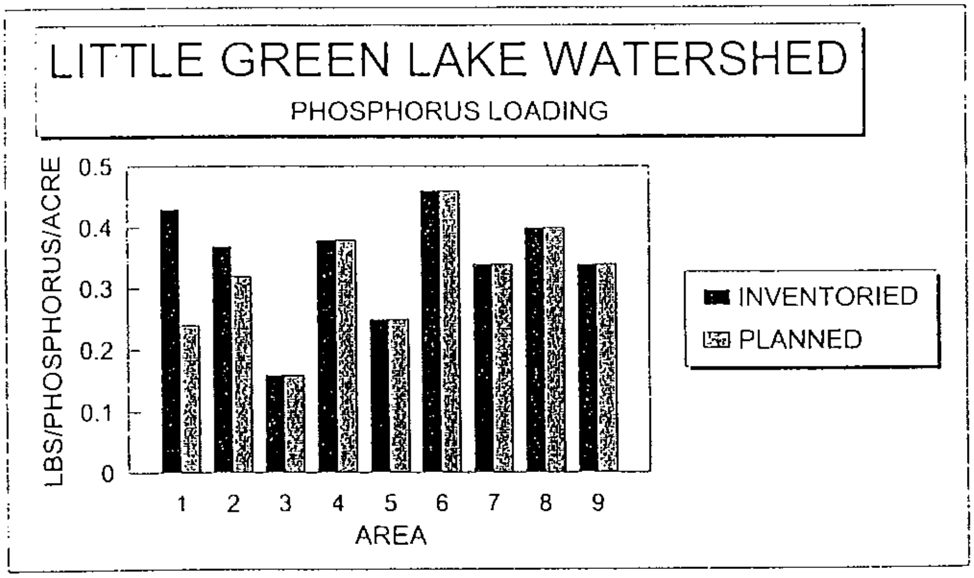


The above chart shows that sediment reduction has occurred in areas 1 and 2. Areas 3,4,5,6,7,8 and 9 have had no reduction for the past 5 years in sediment delivery. The reason for sediment reduction in the two mentioned areas was due to the recent adoption of conservation practices such as contour stripcropping, residue management, grasses and legume seeding.

Anytime sediment is being delivered to a lake the sediment carries phosphorus with it. The phosphorus loading chart (next page) directly shows that when sediment yields are lowered phosphorus yields follow likewise.

A goal of .4 tons/acre/year has been established by the Green Lake County Land Conservation Department and the Little Green Lake Protection and Rehabilitation District. This represents a very ambitious goal but is possible due to the small acreage of the watershed along with the ability to construct total containment pollution control practices.

WINHUSLE PHOSPHORUS LOADING AVERAGES



The above chart shows that phosphorus reduction like sediment reduction has occurred in areas 1 and 2. Areas 3,4,5,6,7,8 and 9 have had no reduction for the past 5 years in phosphorus delivery as the result of sediment delivery.

Substantial phosphorus loading reductions occurred when the Ron Kearley barnyard runoff control system (1987) and Doug Degener water and sediment control basin (1992) were installed. These two systems eliminated virtually all of the phosphorus loading from their livestock facilities.

Only one major livestock facility remains that is discharging a substantial amount of phosphorus to Little Green Lake. The William Krentz farm, which is located on the Northeast corner of Little Green Lake (Area 6), already has a total waste control containment facility designed (by the Land Conservation Department in 1994). It is the department and Mr. Krentz's intentions to install this practice in the Spring of 1995. Upon installation Little Green Lake will have all livestock facilities which have the potential to discharge to the lake controlled. Due to this reason the Land Conservation Department decided that there was no reason to run any barnyard runoff models (BARNY) due to the success already with livestock facility runoff control.

APPENDIX C

SEDIMENT DATA

Figure 1.--Locations of lake-bed sediment sampling sites in Little Green Lake

EXPLANATION

⑪ Sampling site location

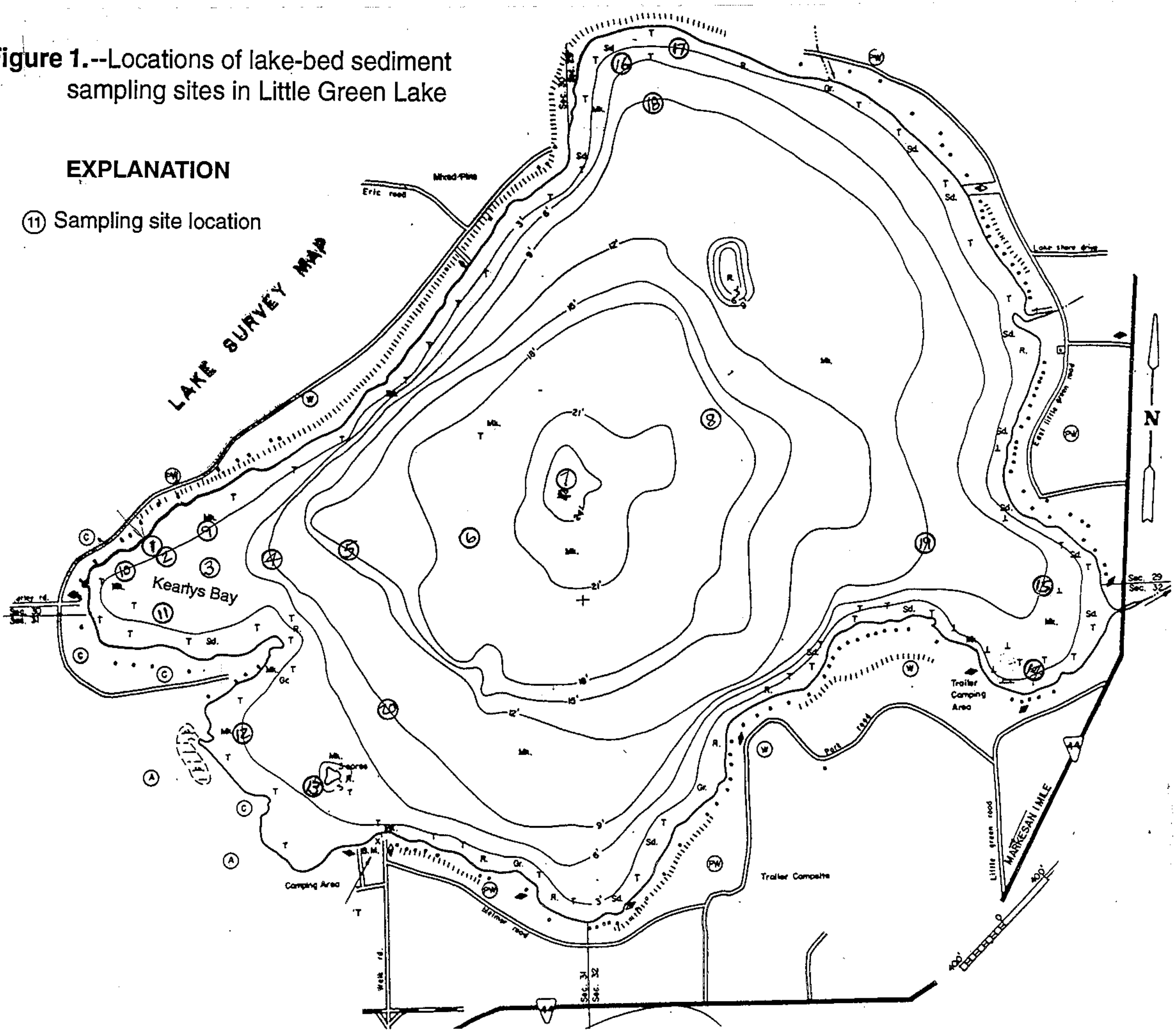


Table 1--Summary of sediment chemistry data for Little Green Lake from samples collected August 21, 1997.

[gm/cc, grams per cubic centimeter; mg/Kg, milligrams per kilogram]

Sample site number	Lake depth at sample site (feet)	Bulk density (gm/cc)	Percent solids	Percent volatile solids	Total Kjeldahl nitrogen (mg/Kg)	Total phosphorus (mg/Kg)	Phosphate (as P) (mg/Kg)	Percent moisture
1	3	0.200	18.6	14.0	7900	610	141	81.6
2	4.3	0.115	11.4	19.3	11000	920	312	88.7
3	5.5	0.122	11.6	19.4	10000	920	471	88.4
4	9	0.116	11.1	22.0	13000	1100	235	88.8
5	15	0.052	5.2	39.3	23000	1400	324	94.8
6	19	0.100	9.7	24.5	18000	2100	326	90.4
7	26	0.085	8.3	24.1	13000	2500	1310	91.8
8	19	0.109	10.5	23.2	14000	1400	229	89.6
9	3.5	0.155	14.5	16.6	10000	850	164	85.8
10	3.5	0.128	12.3	19.7	13000	970	187	87.9
11	3.5	0.287	25.1	8.5	4900	530	102	73.3
12	3.5	0.121	11.6	21.7	13000	1000	224	88.4
13	3.5	0.170	15.9	19.0	8800	750	145	84.2
14	3.5	0.318	27.8	8.5	5600	520	94	71.9
15	6	0.217	20.0	11.6	7100	690	126	80.3
16	6	0.112	11.0	15.8	7900	710	227	89.4
17	3	0.269	23.9	9.2	5500	680	179	76.1
18	9	0.114	11.2	18.2	10000	980	279	89.0
19	9.5	0.134	13.0	16.5	8300	820	210	87.0
20	9	0.102	10.1	21.3	12000	1100	286	90.0

Figure 2. Lake depth at sampling sites and concentrations of total phosphorus, total Kjeldahl nitrogen, and phosphate in lake-bed samples collected August 21, 1997 from Little Green Lake.

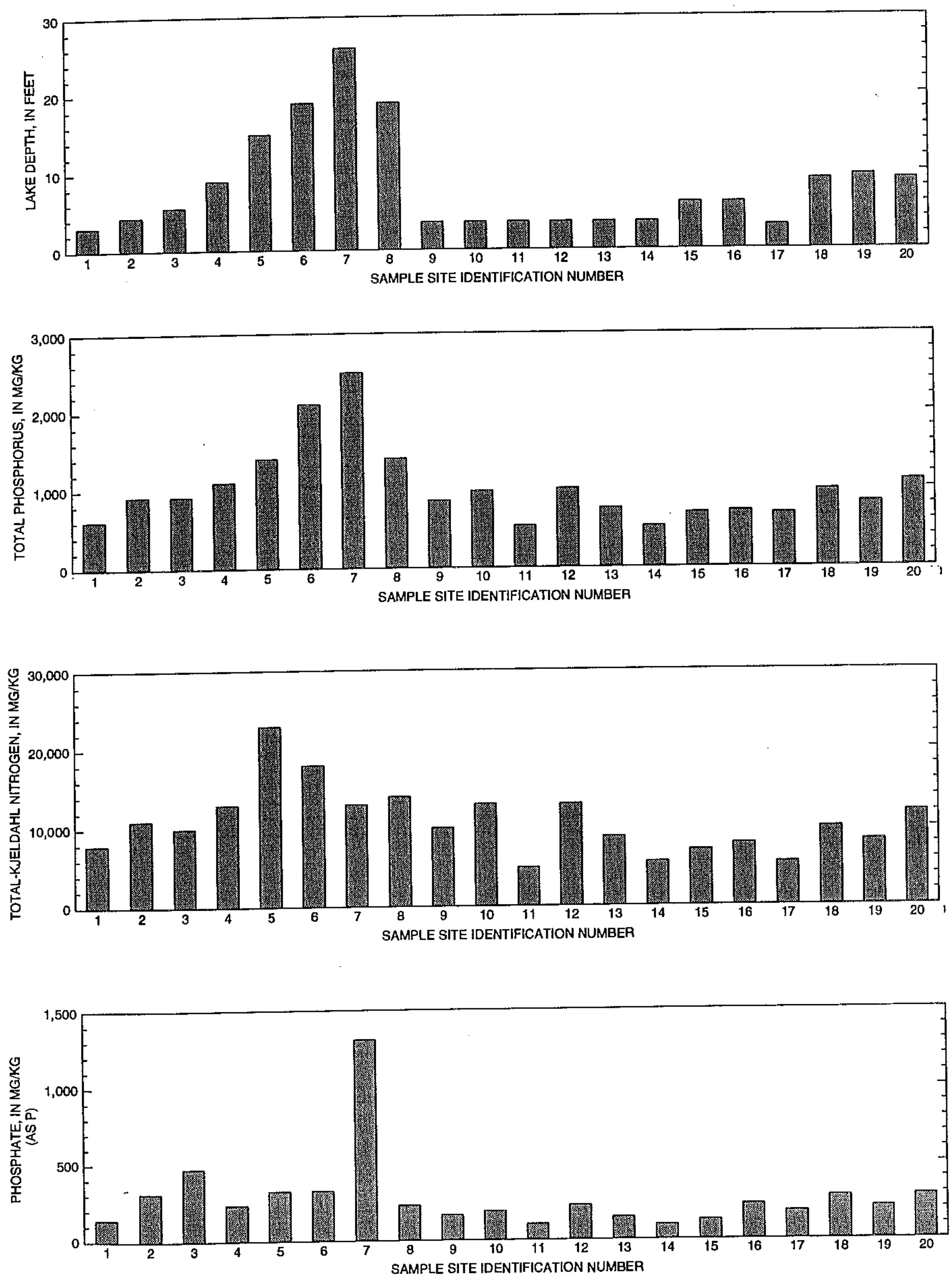


Figure 3. Little Green Lake bed-sediment analyses for bulk density, and percentages of solids, volatile solids, and moisture of samples collected August 21,1997.

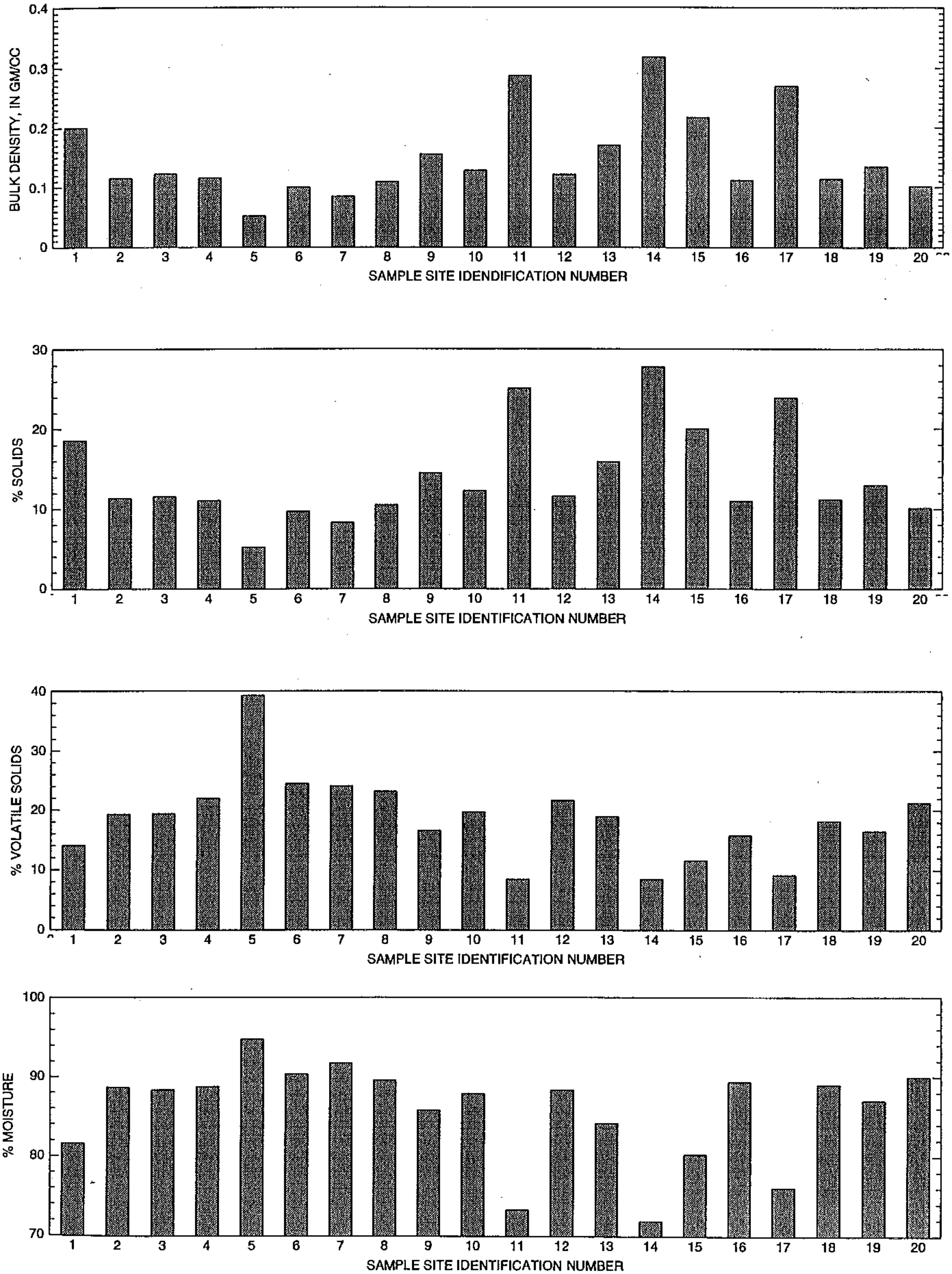
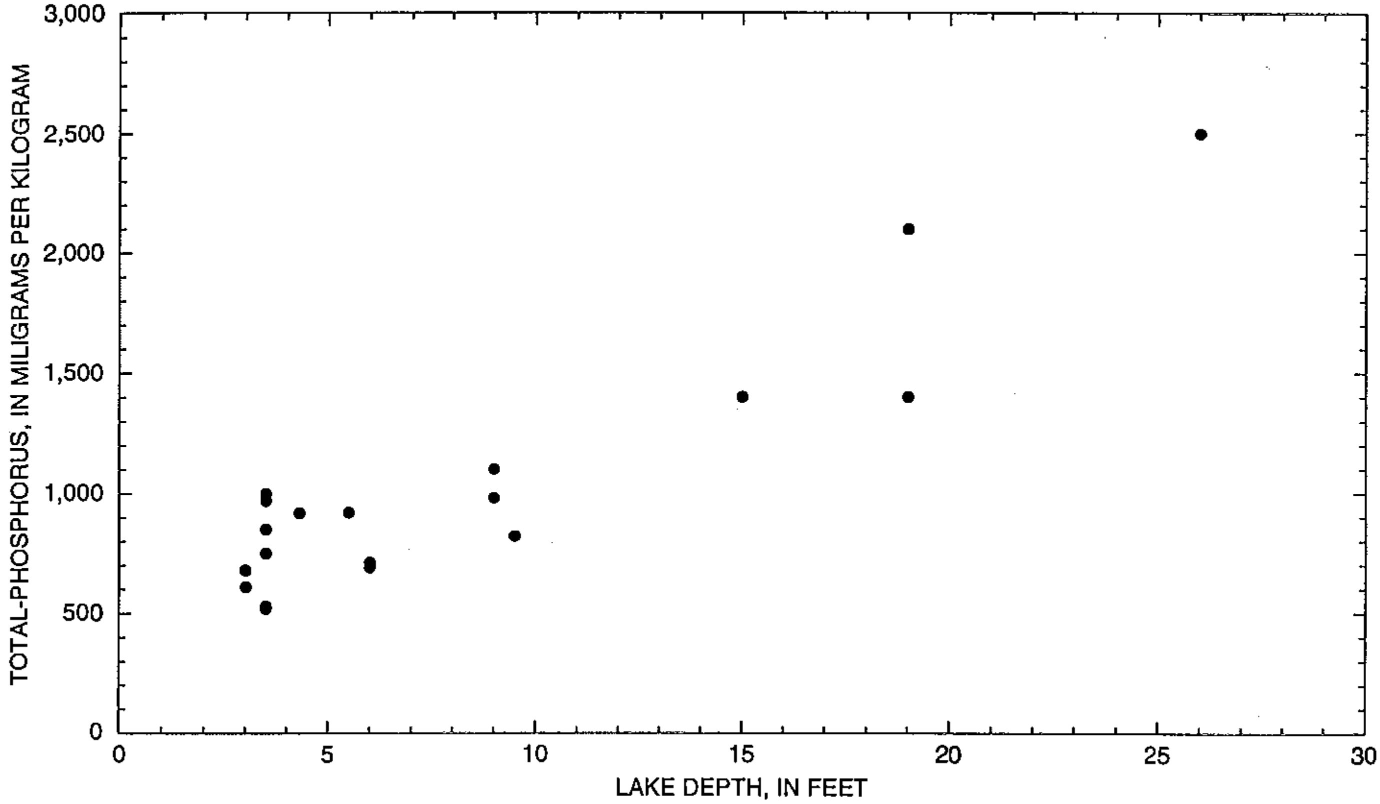
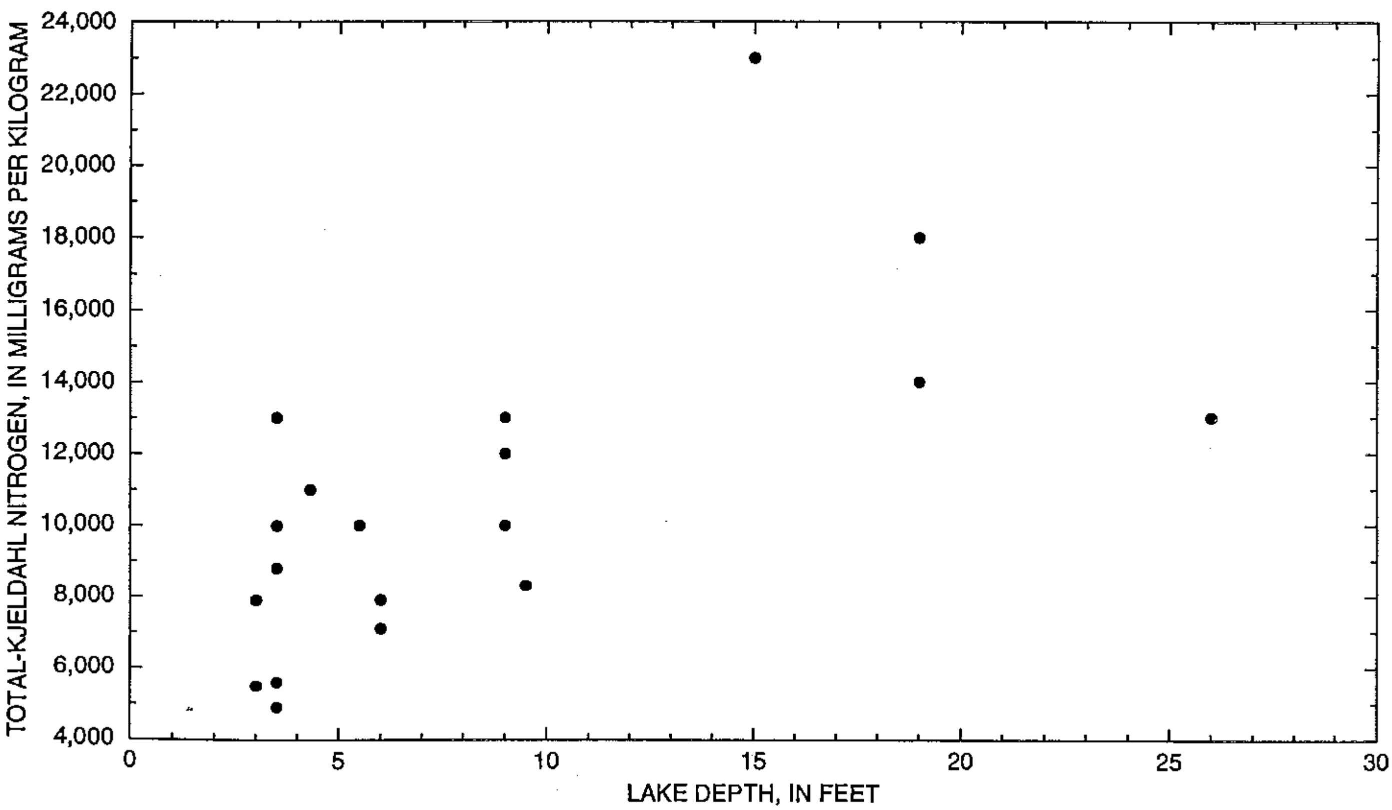


Figure 4. Relations of total-phosphorus and Kjeldahl nitrogen concentrations in lake-bed sediments to lake depth at sampling sites in Little Green Lake on August 21, 1997.





APPENDIX D

LAKE RESIDENT SURVEY & SUMMARY OF RESULTS

RAMAKER
& ASSOCIATES, INC.
Consulting Engineers

806 Water Street
Sauk City, Wisconsin 53583
Tel: 1-608-643-4100
Fax: 1-608-643-7999

URGENT!

SURVEY OF LITTLE GREEN LAKE RESIDENTS

I. PERSONAL INFORMATION

1. How many people reside in your household and what are their ages?
   ___ people ages:_______________

2. What type of lake resident are you?
   ___Year-round ___Seasonal/Part-time

3. If a seasonal/part-time resident:
   a) What season(s) do you most often spend time on Little Green Lake?
   ___Spring ___Summer ___Fall ___Winter

   b) How many days per month (on average) do you spend time on Little Green Lake?
   ___days/month

4. How many years have you owned lakefront property on Little Green Lake?
   ___0-5 years ___ 6-10 years ___11-15 years ___16-20 years ___ 20+ years

5. In which state and county are you a permanent resident?
   State_______________ County_________________

6. If you are responsible for lawn care on your property, do you apply fertilizers and/or pesticides?
   ___Yes ___No

7. Do you own farmland adjacent to Little Green Lake?
   ___Yes ___No

II. LAKE USE PREFERENCES

1. What were the top three reasons you chose to purchase property on Little Green Lake? (List the letters of your top three choices)
   A. To enjoy the activities mentioned in the previous question
   B. Cost of the property
   C. Distance from home
   D. Low number of lake users
   E. Because of neighbors & friends on lake
   F. Family tradition/inheritance
   G. Other (please specify)______________________
   1st ___ 2nd ___ 3rd ___

2. What three lake uses do you value most as a Little Green Lake property owner? (List the letters of your top three choices)
   A. Fishing/ice fishing
   B. Motor boating
   C. Cross-country skiing
   D. Swimming/snorkeling
   E. Water skiing
   F. Hunting/trapping
   G. Commercial business
   H. Agricultural business
   I. Jet skiing
   J. Observing wildlife
   K. Non-motor boating
   L. Investment
   M. Scenic view/tranquility
   N. Entertaining
   O. Snowmobiling
   P. Other (please specify)______________________
   1st____ 2nd____ 3rd____

3. If you are an angler, please rank the following species (1 = most important, 6 = least important) according to their overall value to Little Green Lake?
   ___Muskellunge
   ___Walleye
   ___Largemouth Bass
   ___Smallmouth Bass
   ___Panfish (i.e., bluegill)
   ___Other (please specify)______________________

4. If you are an angler, what is the average size (in inches) of each type of fish that you most often catch on Little Green Lake?
   Muskellunge ___ inches
   Walleye ___ inches
   Largemouth Bass ___ inches
   Smallmouth Bass ___ inches
   Panfish (i.e., bluegill) ___ inches
   Other (please specify) ___ inches ______________________

III. OPINIONS ON LAKE QUALITY

1. On summer WEEKENDS, how crowded do you generally feel when you are on Little Green Lake?
   ___Not crowded
   ___Slightly crowded
   ___Moderately crowded
   ___Extremely crowded

2. On summer WEEKDAYS, how crowded do you generally feel when you are on Little Green Lake?
   ___Not crowded
   ___Slightly crowded
   ___Moderately crowded
   ___Extremely crowded

3. Rank the following (1 = most important, 11 = least important) according to their level of importance to you:
   ___Water quality/clarity
   ___Fishing success/habitat
   ___Swimming
   ___Motor boating
   ___Non-motor boating
   ___Wildlife viewing/habitat
   ___Overall ecosystem health
   ___Tourism
   ___Natural shoreline/vegetation
   ___Winter recreation
   ___Other (please specify)___________________________

4. How have the following changed since you've owned property on Little Green Lake?

	BETTER	SAME	WORSE
Water quality/clarity:	___	___	___
Fishing success (panfish):	___	___	___
Fishing success (large gamefish):	___	___	___
"Nuisance" aquatic weed growth:	___	___	___
"Nuisance" algae growth:	___	___	___
Smell of water:	___	___	___
Motor boating traffic/conflicts:	___	___	___
Non-motor boating traffic/conflicts:	___	___	___
Conflicts between anglers and boaters:	___	___	___
Overall noise/traffic/congestion:	___	___	___
Muckiness of lake bottom:	___	___	___
Scenic views (from land):	___	___	___
Scenic views (from lake):	___	___	___

5. Which of the following conditions do you feel is a problem at Little Green Lake (please rank: 1 = biggest problem, 12 = smallest problem)? Please explain why each is a problem.
   ___Algae____
   ___Smell of water___________________________________
   ___Fish size____
   ___Fish quantity____________________________________
   ___Water level too high_____________________________
   ___Water level too low______________________________
   ___Muddy water______________________________________
   ___Weed growth______________________________________
   ___Mucky lake bottom________________________________
   ___Shoreline development____________________________
   ___Noise/traffic/congestion_________________________
   ___Other (please specify)___________________________

6. If you feel Little Green Lake is degrading, list the top three possible causes for the degradation.
   A. Faulty septic systems
   B. Lawn fertilizer/pesticide use
   C. Construction site runoff of sediment
   D. Barnyard manure runoff
   E. Runoff of agricultural fertilizers/pesticides/soil
   F. Shoreline erosion
   G. Boat wakes and propeller wash
   H. Lake level fluctuations
   I. Shoreline development pressures
   J. In-lake recycling of nutrients (i.e., phosphorus)
   K. Other (please specify)___________________________

   1st___ 2nd___ 3rd___

7. Do you believe that some areas on Little Green Lake are worse than other areas?
   ___ Yes ___No

8. If you answered "Yes" above, which areas of Little Green Lake do you feel are in the worst condition? Why?

____
____
____

9. Do you feel that improving conditions at a specific area on the lake would be a benefit to Little Green Lake as a whole? Why?
   ___ Yes ___ No

____
____

10. Overall, how would you rate Little Green Lake's water quality during the summer months?
___ Poor ___ Fair ___ Good ___ Excellent

11. Overall, how would you rate the fishing at Little Green Lake?
___ Poor ___ Fair ___ Good ___ Excellent

12. What do you perceive to be the most negative aspect of Little Green Lake?

____

____

13. What do you perceive to be the most positive aspect of Little Green Lake?

____

____

IV. OPINIONS ON LAKE USE/MANAGEMENT

1. What forms of public access are most needed on Little Green Lake? (List the letters of your top three choices)
   A. None
   B. Public boat landing with ramp
   C. Private boat rental service
   D. Public fishing from pier/shore
   E. Scenic views from road or park
   F. Carry-in landings
   G. Launch with restroom
   H. Beach/Park
   I. Trails near lake
   J. Other (please specify)____________________________

   1st_____ 2nd_____ 3rd_____

2. Do you feel that you have a voice in decision-making matters regarding the management of Little Green Lake? If not, please explain.
   ___ Yes ___ No

   ____

   ____

3. Do you feel that you are adequately informed of lake-management decisions? If not, how should Little Green Lake residents be kept informed.
   ___ Yes ___ No

   ____

   ____

4. List in order of importance who you think is responsible for managing Little Green Lake.
   A. Federal government
   B. State government
   C. Local government (i.e., county, village, town)
   D. Inland lake management district
   E. Lake property owner's association
   F. Lake residents
   G. All equally
   H. Other (please specify)________________________

   1st___ 2nd___ 3rd___

5. List in order of importance who you think should be responsible for funding the management of Little Green Lake.
   A. Federal government
   B. State government
   C. Local government (i.e., county, village, town)
   D. Inland lake management district
   E. Lake property owner's association
   F. Lake residents
   G. General public that uses the lake (user fees)
   H. All in proportion to their use of the lake
   I. Other (please specify)___________________________

   1st___ 2nd___ 3rd___

6. Do you agree that there needs to be more cooperation among Little Green Lake residents when dealing with lake management issues?

   ___Strongly agree ___Agree ___Neutral ___Disagree ___Strongly disagree

7. What do YOU think should be done to enhance the lake environment? Please explain your answer.

____

____

____

8. What do you think is a reasonable time period to see a visible improvement in Little Green Lake (i.e., water quality) once a project has been undertaken?

   ___Within the same year
   ___Within 1-2 years
   ___Within 3-5 years
   ___Within 6-10 years
   ___Within 10-20 years
   ___More than 20 years

9. What do you expect this lake management plan to accomplish?

____

____

10. Do you have other concerns or questions that you would like to see addressed?

____

____

____

____

THANK YOU FOR YOUR INPUT!

Please provide your name so that Ramaker & Associates, Inc. will be able to determine who has and has not returned a completed survey. Note that all names will be held confidential in order to maintain the anonymity of the respondents.

Name(s):____

Return survey to:

RAMAKER & ASSOCIATES, INC.
806 Water Street
Sauk City, WI 53583
Fax: (608) 643-7999
Phone: (608) 643-4100

SURVEY ANALYSIS
OF LITTLE GREEN LAKE RESIDENTS

August 9, 1997

SURVEYS DISTRIBUTED: **230**
RESPONSE RATE: **54%**

I. PERSONAL INFORMATION

1. A) Average number of people/household:
   2.61 people

   B) Average age/household:
   51 years old

2. Type of lake resident:

62%	Seasonal
38%	Year-round

3. A) Seasons of the years most often spent on the lake by seasonal & part-time residents:

100%	summer
64%	spring
61%	fall
23%	winter

   B) Average number of days/month spent on lake for seasonal & part-time residents:
   9 days/month

4. Number of years of lakefront property ownership:

36%	20+ years
29%	0-5 years
19%	6-10 years
12%	11-15 years
5%	16-20 years

5. State & county of permanent residency:

36%	Green Lake County, WI
12%	Milwaukee County, WI
8%	Washington County, WI
7%	Cook County, IL

6. Lake residents that apply fertilizers and/or pesticides:
   17%

7. Lake residents with farmland adjacent to lake:
   3%

II. LAKE USE PREFERENCES

1. Top three reasons for choosing to purchase property on lake:

1st choice

29%	Distance from home
26%	Enjoy activities on lake

2nd choice

32%	Cost of property
25%	Distance from home

3rd choice

23%	Cost of property
21%	Distance from home

2. Top three most valued lake uses:

1st choice

52%	Fishing
27%	Scenic view/tranquility

2nd choice

22%	Fishing
21%	Motor boating

3rd choice

20%	Scenic view/tranquility
17%	Observing wildlife

3. Most valued fish species (percent that ranked the given species 1st or 2nd):

69%	Walleye
49%	Panfish
45%	Muskellunge
42%	Largemouth Bass
15%	Smallmouth Bass

4. Average size (in inches) of each fish species caught on lake:

Muskellunge:	32.4 inches
Walleye:	14.7 inches
Largemouth Bass:	12.6 inches
Smallmouth Bass:	10.4 inches
Panfish:	6.4 inches

III. OPINIONS ON LAKE QUALITY

1. Crowded feeling on summer WEEKENDS:

39%	Slightly crowded
34%	Moderately crowded
18%	Not crowded
9%	Extremely crowded

2. Crowded feeling on summer WEEKDAYS:

86%	Not crowded
12%	Slightly crowded
3%	Moderately crowded

3. Rankings according to level of importance by category (percent ranked 1st or 2nd):

81%	Water quality
59%	Fishing success/habitat
24%	Overall ecosystem health
21%	Motor boating
19%	Swimming
12%	Wildlife viewing
10%	Natural shoreline/vegetation
5%	Winter recreation
3%	Non-motor boating
2%	Tourism

4. Changes observed since owning lakefront property:

Water quality/clarity:

49%	Worse
34%	Same
18%	Better

Fishing success (panfish):

50%	Same
44%	Worse
6%	Better

Fishing success (large gamefish):

52%	Worse
45%	Same
3%	Better

Nuisance aquatic weed growth:

72%	Worse
23%	Same
6%	Better

Nuisance algae growth:

71%	Worse
25%	Same
5%	Better

Smell of water:

55%	Worse
41%	Same
4%	Better

Motor boating traffic:

56%	Same
43%	Worse
2%	Better

Non-motor boating traffic:

83%	Same
14%	Worse
3%	Better

Conflicts between anglers and boaters:

65%	Same
32%	Worse
3%	Better

Overall noise/traffic/congestion:

52%	Same
46%	Worse
2%	Better

Muckiness of lake bottom:

60%	Worse
39%	Same
1%	Better

Scenic views (from land):

81%	Same
11%	Better
8%	Worse

Scenic views (from lake):

72%	Same
14%	Worse
14%	Better

5. Ranking of perceived problems (percent that ranked the given problem 1st or 2nd):

77%	Algae
69%	Weed growth
31%	Smell of water
22%	Mucky lake bottom
13%	Noise/traffic/congestion
12%	Muddy water
10%	Fish size
9%	Fish quantity
8%	Water levels too low
7%	Shoreline development
-2%	Water levels too high

6. Top three possible causes resulting in lake degradation:

1st choice

29%	Runoff of agricultural fertilizers, pesticides, soil
25%	Faulty septic systems

2nd choice

25%	Runoff of agricultural fertilizers, pesticides, soil
24%	Barnyard manure runoff

3rd choice

23%	Runoff of agricultural fertilizers, pesticides, soil
19%	In-lake recycling of nutrients

7. Some areas on lake are worse than other areas:
   71%

8. Areas of lake that are in the worst condition:
   Bays & shallow areas

9. Improving conditions at a specific area on the lake would benefit lake as a whole:
   49%

10. Lake water quality during the summer months:

53%	Poor
30%	Fair
13%	Good
4%	Excellent

11. Fishing on lake:

57%	Fair
32%	Good
9%	Poor
3%	Excellent

12. Most negative aspect of the lake:
    Weeds; algae; muck; power craft; smell of water

13. Most positive aspect of the lake:
    Solitude; scenic views; organized effort to manage; fishing; small size; nice homes/neighbors

IV. OPINIONS ON LAKE USE/MANAGEMENT

1. Top three forms of public access that are most needed:

1st choice

60%	None
15%	Public boat landing with ramp

2nd choice

21%	Beach/Park
19%	Trails near lake

3rd choice

28%	Beach/Park
19%	Trails near lake

2. Have a voice in decision-making matters regarding the management of the lake:
   54% NO
   (65% of the seasonal/part-time residents answered NO)
   Reasons: not around all year; board has own agenda; not enough meetings; meetings held at bad times; never asked for opinion; DNR has too much control

3. Adequately informed of lake-management decisions:
   46% NO
   (66% of the seasonal/part-time residents answered NO)
   Suggestions: newsletters; posted meeting minutes; flyers to permanent address; publicize meetings better

4. Top three entities believed to be responsible for managing the lake:

1st choice

32%	Lake property owners' association
16%	Inland lake management district

2nd choice

24%	Local government
23%	Lake property owners' association

3rd choice

23%	Local government
22%	State government

5. Top three entities that should be responsible for funding lake management projects:

1st choice

37%	State government
13%	General public that uses the lake (user fees)

2nd choice

35%	Local government
16%	State government

3rd choice

17%	General public that uses the lake (user fees)
17%	Lake property owners' association

6. There is a need for more cooperation among lake residents when dealing with lake management issues:

42%	Agree
40%	Strongly agree
17%	Neutral

7. Opinion on what should be done to improve the lake:
   (responses were widely varied)

8. Reasonable time period to see a visible improvement in the lake once a project has been undertaken:

50%	Within 3-5 years
44%	Within 1-2 years
3%	Within the same year
2%	Within 6-10 years
1%	Within 10-20 years

9. Expectations from lake management plan:
   (responses were widely varied)

10. Other concerns:
    Sewer & water issue