Long Lake Management Plan

Phases I - IV: Lake Management Plan

Prepared for
Long Lake Protection and Rehabilitation District

Prepared by
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with assistance from
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October 2001

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Acknowledgements

The Long Lake Management Plan, Phases 1 through 4, was completed with the assistance of the Long Lake Protection and Rehabilitation District. Board members for the District are:

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A special thanks to the following volunteers for their help during the project:

Richard Shearer	Runoff monitoring, snowmelt monitoring
Terry Hunt	Lake Sampling
Jerry Prokop	Lake Sampling
Tom Corbet	Runoff Monitoring
Dick Wallis	Runoff Monitoring
Roger and Deb Swanson	Lake Level Monitoring
Jeanne Wallis	Precipitation Monitoring
Kari Larson	Precipitation Monitoring
Darrell and Margo Otte	Macrophyte Survey

Thanks also to Jeff Timmons and Dave Peterson of the Polk County Land and Water Resources Department for providing information about Long Lake's tributary watershed. Thanks to Dan Ryan of the Wisconsin Department of Natural Resources for help and support throughout the project.

Executive Summary

Data collected during 2000 were evaluated to determine the lake's current water quality. The average summer total phosphorus concentration (91.6 µg/L) from the epilimnion (i.e., surface waters) of Long Lake was within the hypereutrophic (i.e., extremely nutrient-rich) category, indicating the lake has the potential for problematic algal blooms throughout the summer period. The lake's average summer chlorophyll *a* concentration (28.2 µg/L) from the epilimnion was within the hypereutrophic (i.e., very highly productive) category, indicating undesirable algal blooms occur during the summer period. The average summer Secchi disc measurement (1.2 meters) was within the eutrophic category, indicating the average recreational-use impairment during the summer period was moderate. Secchi disc measurements during mid-July through August were within the hypereutrophic category and indicated moderate to severe recreational use-impairment.

Good water quality was noted during the early-summer and poor water quality was noted during the mid-through late-summer period. Of particular interest are the significant increases in epilimnetic (surface water) phosphorus concentrations in late-June and again in mid-August. Late-June epilimnetic increases coincided with the die-off of Curly leaf pondweed within the lake. Mid-August epilimnetic phosphorus increases coincided with an apparent lake mixing event in which phosphorus-rich bottom waters were added to the lake's epilimnion (surface waters).

The watershed tributary to Long Lake is approximately 1,411 acres or approximately 5 times the surface area of the lake (i.e., approximately 277 acres). The lake's watershed is largely agricultural (63 percent), but also has significant amounts of open space (20 percent) and residential areas (16 percent).

The lake's annual hydrologic budget indicates Long Lake receives water from three sources:

- Direct precipitation on the lake – 622 acre-feet (55 percent)
- Watershed runoff – 476 acre-feet (42 percent) (includes 433 acre-feet from snowmelt runoff)
- Net groundwater inflow – 39 acre-feet (3 percent)

Annual water loss is limited to evaporation and groundwater seepage, since the lake has no outlet.

The lake's annual phosphorus budget indicates the total phosphorus load to Long Lake is 593 kilograms. Sources of phosphorus include:

- Agricultural and developed areas within the tributary watershed – 195 kg (33 percent)
- Septic systems around the lake – 24 kg (4 percent)
- Barnyards in the tributary watershed – 38 kg (6 percent)
- Die-off of Curly leaf pondweed in late-June – 174 kg (29 percent)
- Internal load of phosphorus from the sediments in mid-August – 100 kg (17 percent)
- Atmospheric loading of phosphorus directly on the lake surface – 62 kg (10 percent)

Development of a management plan for Long Lake and its watershed is recommended to improve and/or to protect the lake's water quality to the greatest extent possible. The following project to develop a management plan for Long Lake is recommended:

- Establish a long-term water quality goal for Long Lake
- Develop a management plan for Long Lake and its watershed which achieves its long-term water quality goal
- Explore various potential management scenarios and their impacts on the water quality of Long Lake, focusing on:
  - Management of Curly leaf pondweed to reduce phosphorus loading from dying plants
  - Management of internal phosphorus loading from lake sediments, and
  - Prevention of increased watershed runoff
- Perform cost-benefit analysis of management scenarios

Long Lake Management Plan—Phases 1-4

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1.0 Introduction

Long Lake (Figure 1) is considered a significant water resource by the Long Lake Protection and Rehabilitation District, The Wisconsin Department of Natural Resources (WDNR), and area residents. The lake is located in Polk County, Wisconsin. Long Lake's surface area is approximately 277 acres with a maximum depth of 18 feet. Although Long Lake has no stream inlet or outlet, two ditches (along with overland flow from other areas of the watershed) add stormwater to the lake during storm events. The lake experiences problematic algal blooms during the summer months. Seasonal and permanent residences surround the entire lake.

In recognition of the lake's value and current water quality problems, the Long Lake Protection and Rehabilitation District completed a study of the lake over the course of several project phases, described below:

- **Phase 1:** A macrophyte survey of the lake was conducted in mid-June, 2000 in order to characterize the type and extent of macrophyte coverage in the lake. The macrophyte survey was completed by Barr Engineering Company, with assistance from volunteers. In addition, a concentrated inflow point on the south side of the lake (see Figure 1) was monitored for flow and water quality constituents. Inflow monitoring was performed by volunteers.

- **Phase 2:** A second concentrated inflow point on the north side of the lake (see Figure 1) was monitored for flow and water quality constituents. The monitoring was performed by volunteers.

- **Phase 3:** A water quality survey of Long Lake was conducted during spring and summer, 2000 to establish the current water quality conditions of the lake. Samples were collected by volunteers. Volunteers also collected information on the daily lake levels and precipitation in and around the lake throughout the year. The location of the lake level and precipitation gauges are shown in Figure 1. A membership survey intended to determine the lake residents' opinions about Long Lake's water quality and how they are affected by it was circulated and completed by residents as well.

- **Phase 4:** All of the data gathered in Phases 1 through 3 of the project, as well as watershed land use information gathered during Phase 4, were used to estimate the lake's annual water and total phosphorus budgets.

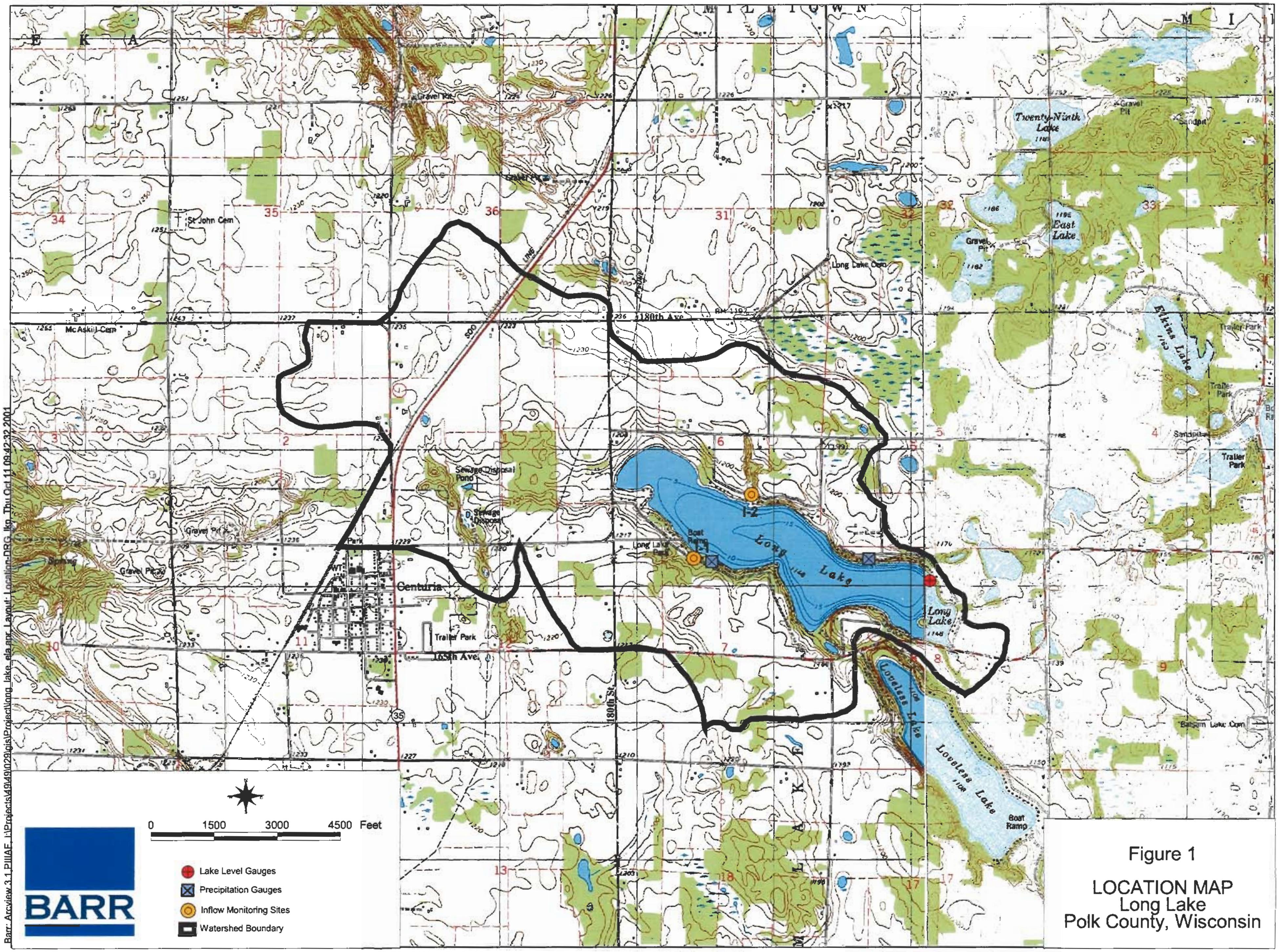


Figure 1

LOCATION MAP
Long Lake
Polk County, Wisconsin

This report discusses the Long Lake Management Plan project methodology, results, and recommendations that are based on the findings from Phases 1 through 4. This report will answer the following two questions:

1. What is the general condition of the lake?

2. Are there water quality problems?

To answer the first question, the report begins with a description of methods of data collection and analysis. The results of the lake monitoring efforts are then summarized in tables, figures, and accompanying descriptions. To answer the second question, data are analyzed and compared to established water quality standards for lakes.

A third and final question will be answered in intended subsequent projects to develop a lake management plan.

3. Can the lake's water quality be improved by implementing management practices to reduce phosphorus loads to the lake and/or protected from degradation by controlling future development?

A background section is also included in the report. Section 3.0 covers general concepts in lake water quality.

2.0 Methods

2.1 Lake Water Quality Data Collection

In 2000, a representative lake sampling station was selected for Long Lake (i.e., at the deepest location in the lake). Water chemistry samples were collected during the spring and summer period. Spring samples were collected because average summer conditions are related to conditions immediately following spring overturn of the lake. Collection of summer samples was scheduled to span the lake's period of elevated biological activity. Samples were collected by trained volunteers. Nutrient samples (i.e., phosphorus and nitrogen species) and chlorophyll *a* samples were collected at spring overturn (shortly after ice-out) and seven times during the summer period (June through early-September). pH samples were collected on one occasion.

Table 1 lists the 12 water quality parameters measured in the lake, and specifies at what depths samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, and Secchi disc transparency were measured in the field on every sampling event; whereas water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total nitrogen, chlorophyll *a,* and pH.

All sample concentrations and field measurements are presented in Appendix A.

Table 1 Long Lake Water Quality Parameters

Parameters	Depth (meters)
Dissolved Oxygen	Surface to bottom profile
Temperature	Surface to bottom profile
Specific Conductance	Surface to bottom profile
pH	0-2
Chlorophyll *a*	0-2
Secchi Disc	---
Total Phosphorus	0-2 in spring; 0-2 and throughout water column at 4 different depths during the summer
Soluble Reactive Phosphorus	0-2
Total Nitrogen	0-2

2.2 Inflow Monitoring

Grab samples were taken during an early snowmelt event in late-February, 2000 and analyzed for total phosphorus content from the inflow points on both the north and south sides of the lake.

The inflow locations to Long Lake were also monitored during spring and summer 2000 by sampling stations. These stations were intended to continuously measure the flows (during both baseflow conditions and storm events) that entered the lake. During storm events, water quality samples were to be taken and analyzed to give an idea of the amount of total phosphorus carried to the lake during the storm event.

The station on the north side of the lake was installed in late March, 2000 and was taken out in July, 2000 due to a road reconstruction project that would have compromised the validity of the flow data collected there. During the course of its service, no flow was recorded at this station. In other words, no runoff passed this station between March and July, 2000.

The station on the south side of the lake was also installed in late March, 2000 and was taken out in November, 2000. No baseflow was recorded at this site. However, three (albeit small) runoff events were recorded by the station on June 20, July 9 and July 26. Water quality samples from these storms were collected for the July 9 and July 26 events.

2.3 Macrophyte Survey

A macrophyte survey of Long Lake was conducted on June 14, 2000. The sampling protocol for the survey followed the rake sampling methodology developed by Jessen and Lound (1962), outlined in "Wisconsin Department of Natural Resources Long-Term Trend Lake Monitoring Methods" (Bureau of Water Resources Management, July 1987), as modified by Deppe and Lathrop (1992). The method outlines the procedure used by the plant specialist to determine the presence, frequency and density of different plant species.

A total of 25 transects were established at approximately 500-foot intervals of shoreline in the lake, extending from the shoreline to the maximum depth of plant growth (See Figure 2). Various types of information were collected along each transect, including: sediment type, the identity and abundance of plant species, and maximum rooting depths.

At three locations containing Curly leaf pondweed, samples were collected to determine plant stem density. Collections occurred at locations with light, typical, and heavy Curly leaf pondweed densities. All stems within a 1 square foot quadrat were collected at each location. The number of Curly leaf pondweed stems and the number of other plant stems were recorded. The samples were taken to the laboratory and all plants from each sample location were dried. Dried Curly leaf pondweed stems from each location were then analyzed for total phosphorus content.

2.4 Lake Level Monitoring

Two lake level staff gages were installed during March and volunteers read the gages on a daily basis through the end of November. The gages were located on the east side of the lake, as shown on Figure 1. The staff gage readings were used to determine daily lake volume changes.

Lake level measurement data are presented in Appendix B.

2.5 Precipitation Monitoring

Precipitation data were collected by volunteers during the period April through December. Gage locations are shown on Figure 1. Daily precipitation amounts were used in the determination of the lake's hydrologic budget.

Precipitation data are presented in Appendix C.

2.6 Membership Survey

The Long Lake Protection and Rehabilitation District, with assistance from Barr Engineering, developed a questionnaire to survey all property owners in the Long Lake Protection and Rehabilitation District. The purpose of the survey was to evaluate the members' impressions of the current and desired clarity of the lake, the current and desired activities in the lake, and the lake management goals they deemed to be the most important. In September, 2001, the survey was sent to 160 property owners around Long Lake. A total of 42 completed surveys were returned (26% return rate). A copy of the survey and a statistical summary of the survey responses are shown in Appendix D.

2.7 Evaluation of the Tributary Watershed

The Polk County Land Conservation Department provided watershed divide, soils, and some land use information for the Long Lake watershed. In July 2001, Barr staff completed a watershed survey, which established the existing land use conditions used to complete the water and total phosphorus budget calculations. Watershed loading from septic systems and barnyards located within the Long Lake watershed were also included in the phosphorus budget calculations. The watershed divides used in this study were originally developed by the Wisconsin Department of Natural Resources.

Transect
12 Transect Number

500 0 500 1000 Feet

Figure 2
TRANSECT LOCATIONS

2.8 Hydrologic Budget Determination

A hydrologic (water) budget was developed for Long Lake from January through December, 2000. This water budget was determined by measuring or estimating the important components of the budget. The important components of the budget include:

- Precipitation
- Surface Runoff
- Evaporation
- Groundwater Flow
- Change in Lake Storage

Change in lake storage (i.e., change in lake levels) and precipitation were measured by volunteers from April to December, 2000 as discussed in Sections 2.4 and 2.5.

Evaporation from the lake water surface area during the study period was estimated using the Meyer Watershed Model (Molsather et al., 1977), which incorporates methods developed by Adolph Meyer (1944). This method uses average monthly temperature, wind speed, and relative humidity to predict monthly evaporation from water surfaces. Monthly temperature, wind speeds, and humidity used for input in the Meyer Watershed Model were taken from 2000 data from the Minneapolis/St. Paul International Airport National Weather Service station. Average monthly temperature readings from the Minneapolis/St. Paul airport and average monthly precipitation from the study area were also used as input for the model. (MSP precipitation data was used for the study area from January to March, 2000.)

The yield of surface water runoff from the Long Lake watershed from April to December, 2000 was determined by the SCS Method. Knowing the types of land use in the area and the daily amounts of precipitation that fell on the watershed, the resulting inches of daily runoff from the watershed could be estimated. Converting inches of watershed runoff to a runoff volume to Long Lake simply involved multiplying the inches of runoff by the watershed area. From January to March all of the snow that fell on the watershed was assumed to reach the lake during snowmelt events.

Groundwater flow (inflow minus outflow) was determined by deduction. The total volume of water from all other sources was compared with the observed changes in lake water level. The difference between the water volume from all other sources and the observed lake level changes was attributed to net changes in groundwater (i.e., inflow minus outflow).

2.9 Phosphorus Budget Determination

The phosphorus budget for Long Lake was determined by calculating or estimating the important components of the budget. The important components of the budget include:

- Watershed Surface Runoff from Forested, Cropland, Residential, and Pasture/CRP Land Uses
- Barnyards
- Atmospheric Wet and Dry Deposition on the Lake Surface
- Septic System Loading
- Groundwater
- Internal Loading

The watershed surface runoff component was estimated using an annual phosphorus export coefficient for each land use type within the lake's subwatersheds. These coefficients are shown below. Each coefficient selected for Long Lake agrees closely with literature research results. Hence, one or more references, in parentheses, follows each coefficient to identify the research results which agree closely with the coefficients.

- Agricultural- Row Crops: 0.504 kg/ha/yr (Bradford, 1974; Alberts et al., 1978)
- Pasture/Grassland: 0.202 kg/ha/yr (Harms et al., 1974)
- High Density Urban (Used for the Highway): 1.2 kg/ha/yr (Walker, 1985)
- Medium Density Urban: 0.303 kg/ha/yr (Much and Kemp, 1978; Mattraw and Sherwood, 1977)
- Rural Residential: 0.10 kg/ha/yr (Panuska and Wilson, 1994)
- Wetlands: 0.10 kg/ha/yr (Panuska and Lilly, 1995; Corsi, et al., 1997)
- Forest: 0.045 kg/ha/yr (Taylor et al., 1971; Nicholson, 1977; Dillon and Kirchner, 1975)

Annual phosphorus loading from barnyards throughout the Long Lake tributary watershed were estimated from information presented in the Nonpoint Source Control Plan for the Balsam Branch

Priority Watershed Project, WDNR, WDOA and the Polk County Land Conservation District, 1995.

An atmospheric wet and dry deposition rate of 0.56 kg/ha/yr (Tetra Tech 1982), was applied to the surface area of Long Lake.

Phosphorus export rate computation computations, used in the WILMS model and published by the U.S. EPA for septic systems, were used to estimate an annual load from drain fields (Panuska, 1994). The equation used for Long Lake estimated the septic system load as follows:

Total Septic System Load (kg/yr) = Ec_{st} * Number of capita-years * (1-SR)

Where:

Ec_{st}	=	export coefficient to septic tank systems (0.5 kg/capita/yr)
Number of capita-yrs.	=	# of people occupying a dwelling each year
	=	[(# of permanent residents/dwelling) * (# of permanent dwellings)] + [(# of seasonal residents/dwelling) * ($\underline{x}$ days/yr/365) * (# of seasonal dwellings)]
SR	=	weighted soil retention coefficient (85 for most likely value used in model)

Septic system loadings are a function of the number of both permanent and seasonal dwellings, as well as the degree to which the septic systems are functioning properly. There are 169 residences around the lake- each on an individual septic system. Of these, one third were considered permanent dwellings, with 3 residents per house living at Long Lake year-round. Two-thirds of the residences were considered to be seasonal dwellings, with 5 residents per house living at Long Lake roughly only one third of the year. The most likely soil retention coefficients of 90 and 40 were chosen for properly and improperly functioning systems, respectively. Ten percent of the septic systems were assumed to be improperly functioning, yielding a weighted soil retention coefficient of 85. The assumptions made regarding the septic system inputs agree well with the estimates made for Balsam Lake in Polk County, Wisconsin (Bursik, 1996).

The groundwater flow component of the phosphorus budget was determined using the inflow volume from the hydrologic budget and an average total phosphorus concentration of 0.020 mg/L, based on nearby sampling data collected by the WDNR (1988) and published by the Wisconsin Geological and Natural History Survey (1990).

Internal loading was comprised of Curly leaf pondweed die-off and sediment phosphorus release from the lake's sediments. The load contributed to the lake from die-off of Curly leaf pondweed was estimated in the following manner. A survey of Curly leaf pondweed coverage and abundance was completed at 25 transects, as described in the methods section. The data were extrapolated to estimate and map Curly leaf pondweed coverage and density in the lake's littoral area. From the map, lake areas containing light (52 acres), typical (36 acres), and heavy (15 acres) density Curly leaf pondweed coverage were determined. The stem density for each of the three density categories was determined from a stem survey completed during the mid-June macrophyte survey. Three sites were surveyed and all Curly leaf pondweed stems found within a 1 square foot quadrant within each area were counted. Stem survey results indicated a stem densities of 30, 41, and 59 stems per square foot are representative of light, typical, and heavy densities. The Curly leaf pondweed stems collected in the survey were dried and analyzed for total phosphorus. The average total phosphorus content of the Curly leaf pondweed stems was 2,000 mg/kg. The average stem weight of a Curly leaf pondweed stem was estimated to be 0.35 gram and was based upon a three year study of Big Lake, located in Polk County, Wisconsin (Barr, 2001). Curly leaf pondweed coverage, stem densities in the coverage area, average stem weight, and average total phosphorus content per stem were used to estimate the total phosphorus load from Curly leaf pondweed die-off.

Internal phosphorus loading from the lake's sediments was estimated by deduction. The in-lake phosphorus concentration resulting from all other sources were compared to the observed phosphorus concentration in the lake. The difference between the two concentrations was attributed to the load from the lake's sediments (an internal load).

It should be noted that the manure pit on the south side of the lake has been shown to contribute no loading to Long Lake. Rather, test wells placed around the pit indicate that the groundwater in the area flows away from Long Lake and toward Loveless Lake. The farm is now closed, although loading is expected to continue for the next several years. (Jeff Timmons, Polk County Land and Water Resources Department, Personal Communication, 2001).

3.0 General Concepts in Lake Water Quality

There are many concepts and terminology that are necessary to describe and evaluate a lake's water quality. This section is a brief discussion of those concepts, divided into the following topics:

- Eutrophication
- Trophic states
- Limiting-nutrients
- Nutrient recycling and internal loading
- Stratification
- Lake Zones
- Riparian Zone
- Watershed

To learn more about these eight topics, one can refer to any text on limnology (the science of lakes and streams).

3.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake becomes more fertile, algae and weed growth increases. This slow process of eutrophication results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants results in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds (macrophytes).

3.2 Trophic States

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient "status" of lakes. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, chlorophyll *a* concentrations, and Secchi disc transparencies. A TSI value is obtained from any one of these three parameters. TSI values range upward from zero, describing the condition of the lake in terms of its trophic status (i.e., its degree of fertility). Four trophic status designations for lakes are listed below with corresponding TSI value ranges:

1. ***Oligotrophic*** **[TSI < 37]**	Clear, low productivity lakes with total phosphorus concentrations less than or equal to 10 µg/L.
2. ***Mesotrophic*** **[38 < TSI < 50]**	Intermediate productivity lakes with total phosphorus concentrations greater than 10 µg/L, but less than 25 µg/L.
3. ***Eutrophic*** **[51 < TSI < 63]**	High productivity lakes generally having 25 to 57 µg/L total phosphorus.
4. ***Hypereutrophic*** **[64 < TSI]**	Extremely productive lakes that are highly eutrophic, disturbed and unstable (i.e., fluctuating in their water quality on a daily and seasonal scale, producing gases, off-flavor, and toxic substances, experiencing periodic anoxia and fish kills, etc.) with total phosphorus concentrations above 57 µg/L.

Determining the trophic status of a lake is an important step in diagnosing water quality problems. Trophic status indicates the severity of a lake's algal growth problems and the degree of change needed to meet its recreational goals. Additional information, however, is needed to determine the cause of algal growth and a means of reducing it.

3.3 Limiting-Nutrients

The quantity or biomass of algae in a lake is usually limited by the water's concentration of an essential element or nutrient- the "limiting-nutrient." (For rooted aquatic plants, most nutrients are derived from the sediments.) The limiting-nutrient concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the plant, will limit plant growth. It follows then, that identifying the limiting-nutrient will point the way to controlling algal growth.

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content of lake water and algae provides ratios of N:P. By comparing the ratio in water to the ratio in the algae, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with N:P ratios greater than 12. Laboratory experiments (bioassays) can demonstrate which nutrient is limiting by growing the algae in lake water with various concentrations of nutrients added. Bioassays, as well as fertilization of in-situ enclosures and whole-lake experiments, have repeatedly demonstrated that phosphorus is usually the nutrient that limits algal growth in fresh waters. Reducing phosphorus in a lake, therefore, is required to reduce algal abundance and improve water transparency. Failure to reduce phosphorus concentrations will allow the process of eutrophication to continue at an accelerated rate.

3.4 Nutrient Recycling and Internal Loading

Phosphorus enters a lake from either runoff from the watershed or direct atmospheric deposition. It would, therefore, seem reasonable that phosphorus in a lake can decrease by reducing these external loads of phosphorus to the lake. All lakes, however, accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as "internal loading." The relative amounts of phosphorus coming from internal and external loads vary with each lake. Phosphorus released from internal loading can be estimated from depth profiles (measurements from surface to bottom) of dissolved oxygen and phosphorus concentrations. Die-off of macrophytes in the lake can also be an internal source of phosphorus. Curly leaf pondweed, for example is known to be responsible for significant phosphorus loads in some lakes.

3.5 Stratification

The process of internal loading is dependent on the amount of organic material in the sediments and the depth-temperature pattern, or "thermal stratification," of a lake. Thermal stratification profoundly influences a lake's chemistry and biology. When the ice melts and air temperature warms in spring, lakes generally progress from being completely mixed to stratified with only an upper warm well-mixed layer of water (epilimnion), and cold temperatures in a bottom layer (hypolimnion). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in midsummer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic). Complete loss of oxygen changes the chemical conditions in the water and allows phosphorus that had remained bound to the sediments to reenter the lake water.

As the summer progresses, phosphorus concentrations in the hypolimnion can continue to rise until oxygen is again introduced (recycled). Dissolved oxygen concentration will increase if the lake sufficiently mixes to disrupt the thermal stratification. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration to the hypolimnion to allow for growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed. In shallow lakes this can occur throughout the summer, with sufficient wind energy (polymixis). In deeper lakes, however, only extremely high wind energy is sufficient to destratify a lake during the summer and complete mixing only occurs in the spring and fall (dimixis). Cooling air temperature in the fall reduces the epilimnion water temperature, and consequently increases the density of water in the epilimnion. As the epilimnion water density approaches the density of the hypolimnion water very little energy is needed to cause complete mixing of the lake. When this fall mixing occurs, phosphorus that has built up in the hypolimnion is mixed with the epilimnion water and becomes available for plant growth.

3.6 Lake Zones

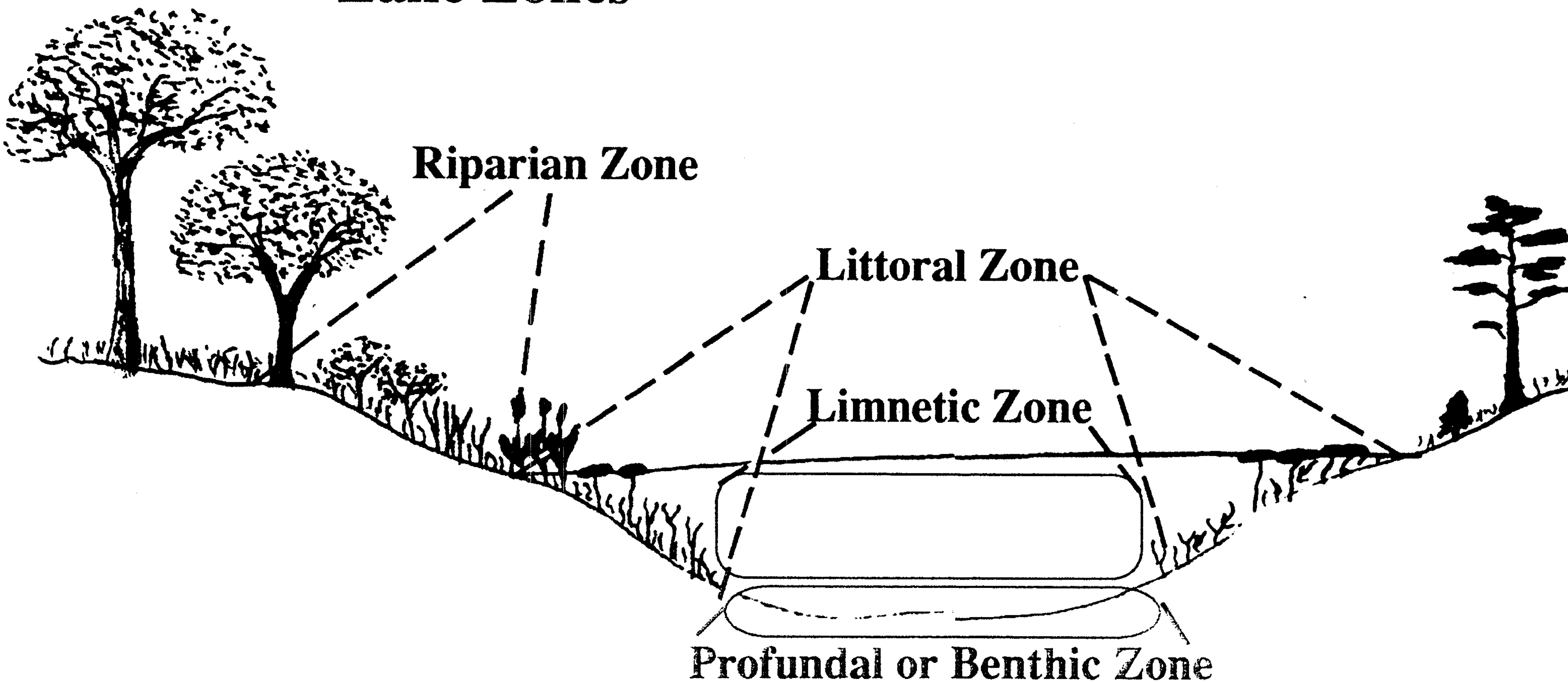
Lakes are not homogenous, but are rather comprised of several different habitats for aquatic life. Each type of habitat or lake zone impacts the overall health of the lake. Lake zones (See Figure 3) include:

- **Littoral Zone-** The shallow transition zone between dry land and the open water area of the lake is the littoral zone. The shallow water, abundant light, and nutrient-rich sediment provide ideal conditions for plant growth. Aquatic plants, in turn, provide food and habitat for many animals such as fish, frogs, birds, muskrats, turtles, insects, and snails. Lakes with clearer water may have aquatic plants growing at greater depths than lakes with poor water clarity. As a result, the littoral zone may vary depending on the lake's water clarity as well as its depths.
- **Profundal Zone**- the bottom zone in the deeper areas of the lake (i.e., in water deeper than the littoral zone). Deposition and decomposition of organic material occurs in this zone. This area often lacks oxygen because decomposition uses up available oxygen. A related term is benthic zone.

- **Limnetic Zone**-the open water area of the lake in water deeper than the littoral zone. It is located from the lake's surface to the depth at which the profundal zone begins. This zone is inhabited by phytoplankton, zooplankton, and/or fish. The microscopic algae or phytoplankton provide the foundation of the food pyramid of the lake. The zooplankton (i.e., small animals) feed upon the phytoplankton and provide a food source for higher life forms such as fish.

Each of the lake zones is important for lake health. None can be neglected or negatively impacted without influencing the entire lake ecosystem.

Lake Zones



Source: The Lakes of Barron County:
A Report on their Status in 1996

Figure 3

3.7 Riparian Zone

Riparian zones (see Figure 4) are extremely important to the lake and to the plants living there. Riparian vegetation is that growing close to the lake and may be different from the terrestrial or upland vegetation. The width of the riparian zone varies depending on many variables, including soils, vegetation, slopes, soil moisture, water table, and even by location on the lake. For example, north shore vegetation may provide little or no shade, while vegetation on the southern shore may offer shade and cover well into the lake.

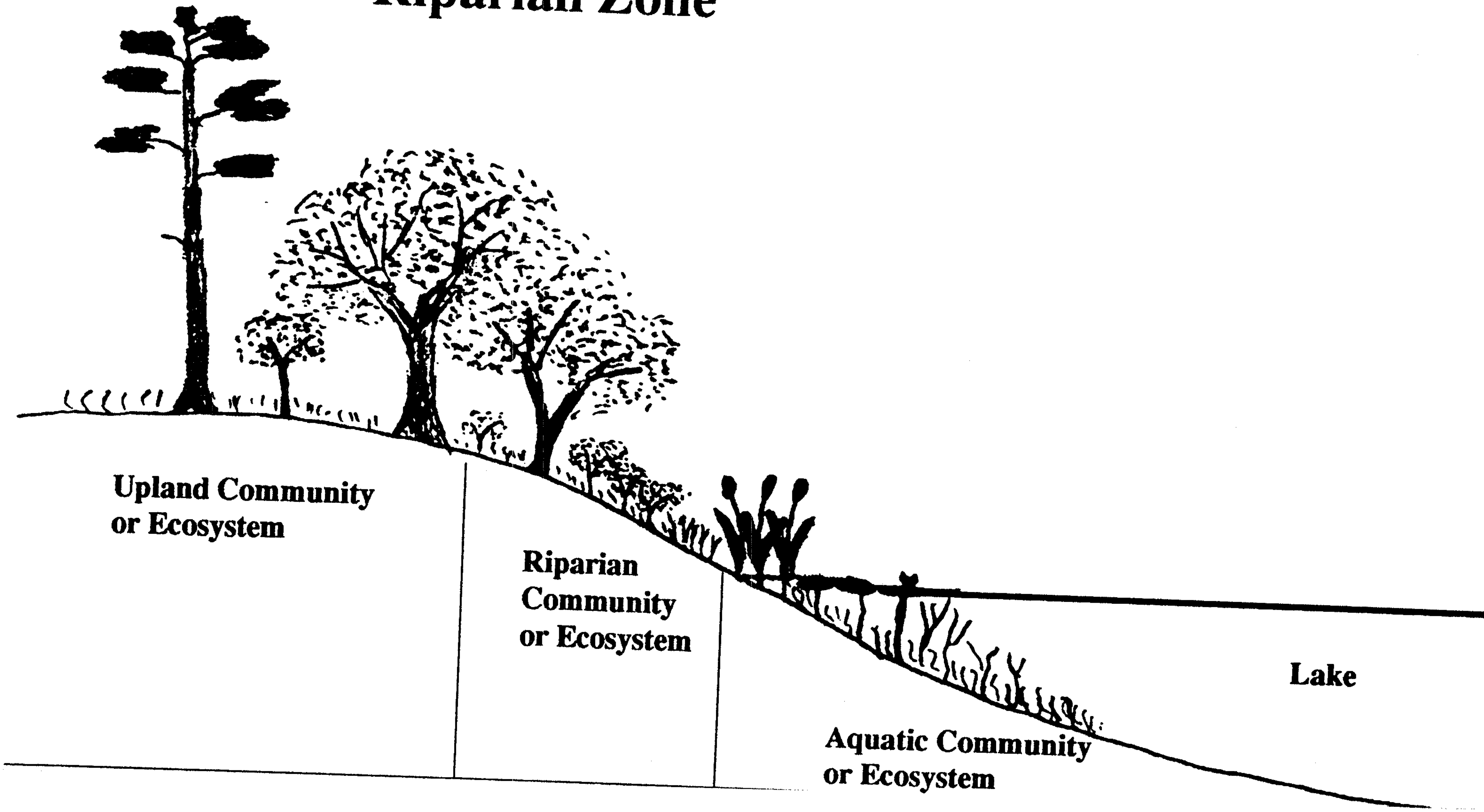
The riparian area and riparian vegetation is important for several reasons:

- Acts as a filter from outside impacts.
- Stabilizes the bank with an extensive root system.
- Helps control or filter erosion
- Provides screening to protect visual quality and hides man's activities and buildings.
- Provides the natural visual backdrop as seen from the lake.
- Provides organic material to the lake's food web. Leaves, needles, and woody debris are fed upon by bacteria, fungi, and aquatic insects. This energy flows upward through the food web.
- Offers cover and shade for fish and other aquatic life.
- Provides valuable wildlife habitat

Riparian zones are the areas most often impacted, and riparian vegetation is lost when man enters the picture. Cabins, homes, lawns, and boat houses replace riparian vegetation. Additional riparian vegetation is eliminated to provide a wider vista from the front deck, or it is mowed and its value to the lake is lost.

The loss of riparian vegetation results in deterioration of many lake values. Water quality is impacted, wildlife habitat is lost, scenic quality suffers, fish habitat may be impacted, bank stability is weakened, and the potential for erosion increases. Riparian vegetation filters phosphorus from runoff waters, thereby protecting the lake's water quality. The loss of riparian vegetation results in increased phosphorus loads to the lake, which causes water quality degradation.

Riparian Zone



Source: The Lakes of Barron County:
A Report on their Status in 1996

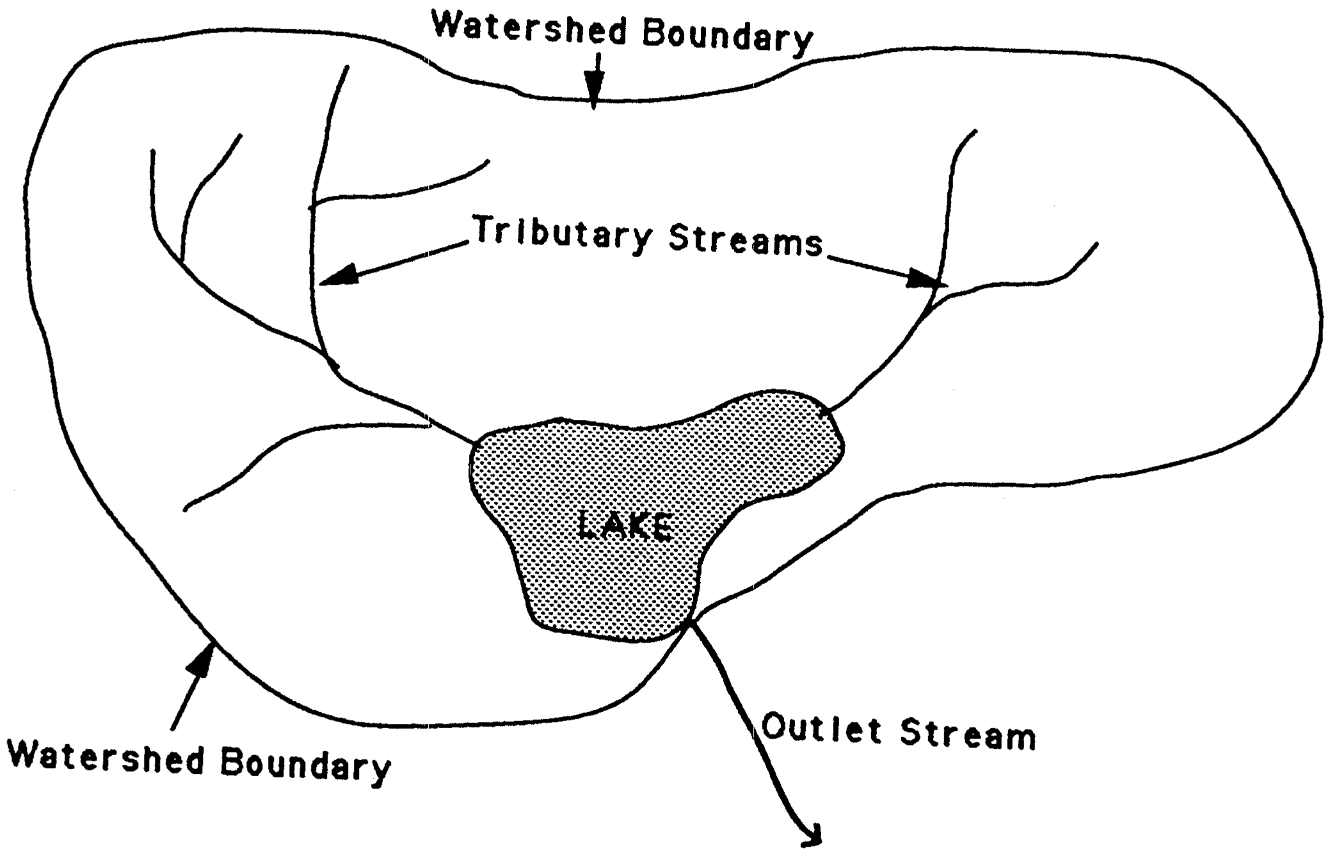
Figure 4

3.8 Watershed

The land area that drains to the lake is called a watershed (See Figure 5). The watershed may be small, as is the case of small seepage lakes such as Long Lake (i.e., Seepage lakes have no stream inlet or outlet. The lake's watershed includes the land draining directly to the lake); or large, as in drainage lakes (i.e., Drainage lakes have both stream inlets and outlets. The lake's watershed includes the land draining to the streams besides the land draining directly to the lake). Water draining to a lake may carry pollutants that affect the lake's water quality. Consequently, water quality conditions of the lake are a direct result of the land use practices within the watershed. Poor water quality may reflect poor land use practices or pollution problems within the watershed. Good water quality conditions suggest that proper land uses are occurring in the watershed.

All land use practices within a lake's watershed impact the lake and determine its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby, affecting the lake's water quality differently. An understanding of a lake's water quality, therefore, must go beyond an analysis of the lake itself. An understanding of a lake's watershed, phosphorus exported from the watershed, and the relationship between the lake's water quality and its watershed must be understood.

Watershed Map of a Lake



Source: The Lakes of Barron County: A Report on their Status in 1996

Figure 5

4.0 Results and Discussion

4.1 Phosphorus

Phosphorus is the plant nutrient that most often limits the growth of algae. Phosphorus-rich lake water indicates a lake has the potential for abundant algal growth, which can lead to lower water transparency and a decline in hypolimnetic oxygen levels in a lake.

Algal growth is generally phosphorus-limited in waters with nitrogen (N) to phosphorus (P) ratios greater than 12. To determine the nutrient-limiting algal growth in Long Lake, N:P ratios for Long Lake were evaluated and the average N:P ratio determined (i.e., 15.3) from March through September. Based on the data presented in Table 2, Long Lake appears to be phosphorus-limited.

Table 2 2000 Long Lake Surface Water N:P Ratios

Date	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	N:P Ratio
3/27	0.690	0.042	16.4
6/5	0.610	0.049	12.4
6/19	0.810	0.061	13.3
7/10	1.570	0.078	20.1
7/24	1.900	0.107	17.8
8/7	1.750	0.122	14.3
8/21	1.870	0.132	14.2
9/6	1.480	0.106	14.0
		Average N:P	**15.3**

Total phosphorus data collected from the epilimnion (i.e., surface waters) of Long Lake during 2000 were generally within the hypereutrophic (i.e., extremely nutrient-rich) category. Data collected during early-June, however, were on the borderline for the hypereutrophic/eutrophic categories (See Figure 6). The average summer phosphorus concentration was within the hypereutrophic category, indicating the lake has the potential for problematic algal blooms throughout the summer period.

Of particular interest are the significant epilimnetic increases in phosphorus concentration in late-June and again in mid-August. Late-June epilimnetic phosphorus increases coincided with the die-off of Curly leaf pondweed within the lake. Mid-August epilimnetic phosphorus increases coincided with an apparent lake mixing event in which phosphorus-rich bottom waters were added to the lake's epilimnion (surface waters).

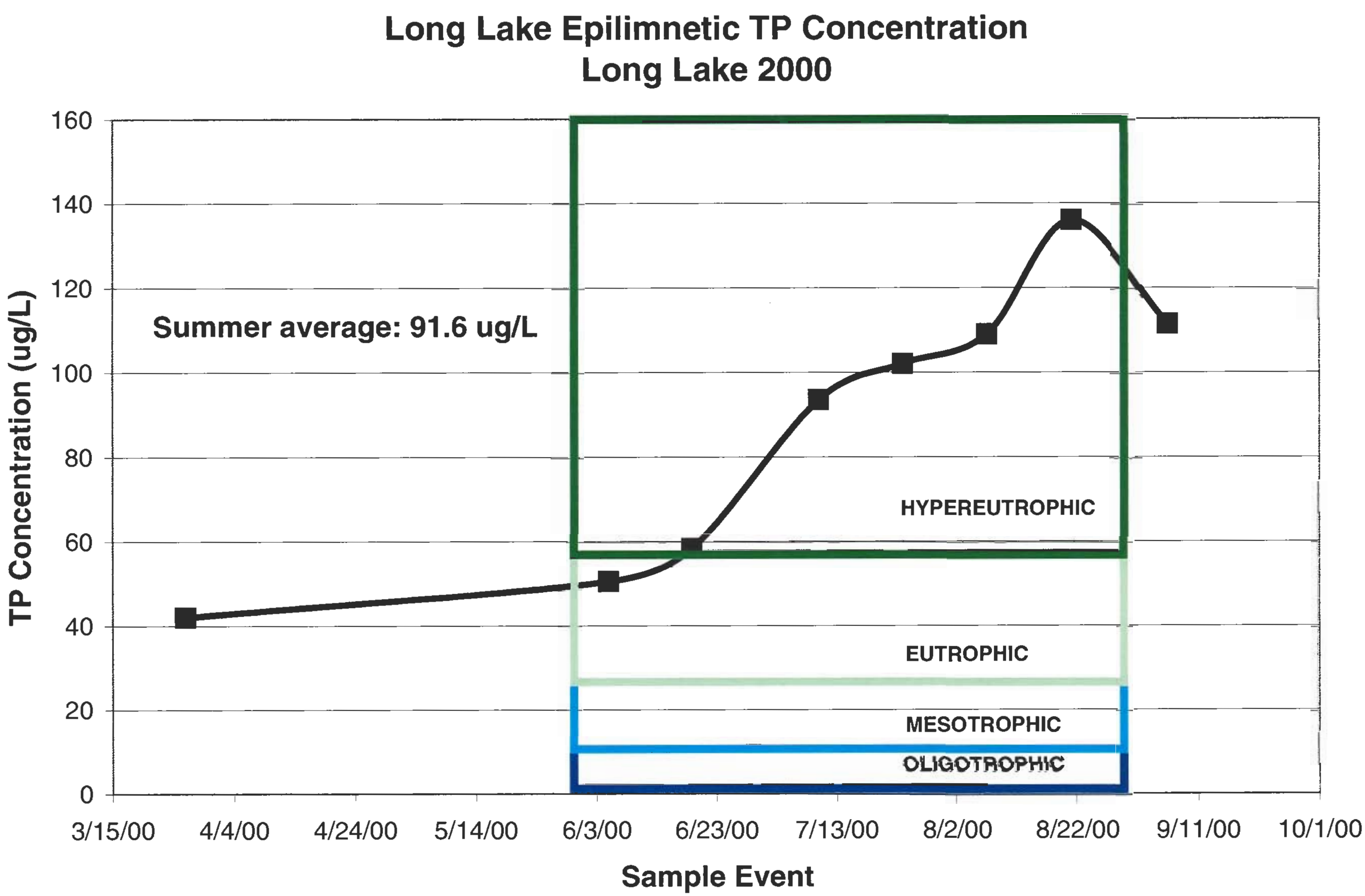


Figure 6

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4.2 Chlorophyll *a*

Chlorophyll a is a measure of algal abundance within a lake. High chlorophyll a concentrations indicate excessive algal abundance (i.e., algal blooms), which can lead to recreational use impairment.

The 2000 Long Lake chlorophyll *a* data indicate the lake's average summer chlorophyll concentration was within the hypereutrophic (i.e., very highly productive) category and exceeded nuisance levels (>20 μg/L) (See Figure 7). The data indicate undesirable algal blooms occur during the summer period. Concentrations on individual sample dates included values in the eutrophic (i.e., highly productive) category during June and August and values in the hypereutrophic (i.e., very highly productive) category during July. The seasonal pattern of chlorophyll *a* concentrations is similar to phosphorus concentrations suggesting that the lake's algal growth is directly related to phosphorus levels. The algal population starts the summer at lower levels, then rapidly climbs to eutrophic levels by the end of June, and increases to hypereutrophic levels by mid-July. The relatively low concentration of chlorophyll *a* in early-August may be explained by a temporary crash of the algal population. The algal population recovered and reached hypereutrophic levels again by early-September. In general, the chlorophyll data indicate a relatively high algal yield resulted from the lake's available phosphorus.

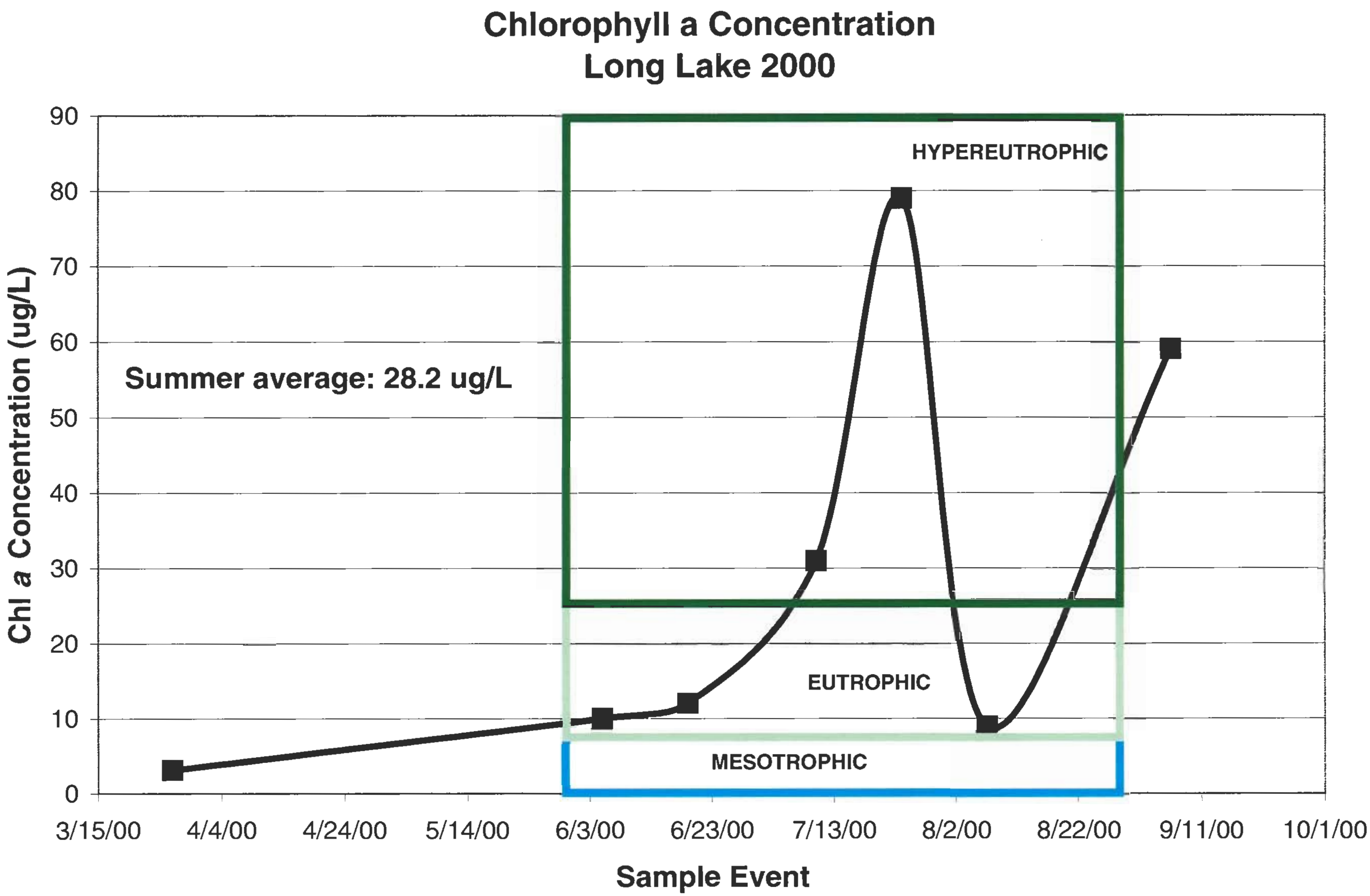

Figure 7

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4.3 Secchi Disc Transparency

Secchi disc transparency is a measure of water clarity. Perceptions and expectations of people using a lake are generally correlated with water clarity. Results of a survey completed by the Metropolitan Council of the Twin Cities area (Osgood, 1989) revealed the following relationship between a lake's recreational use impairment and Secchi disc transparencies:

- *No impairment occurs at Secchi disc transparencies greater than 4 meters (13 feet).*
- *Minimal impairment occurs at Secchi disc transparencies of 2 to 4 meters (7 to 13 feet).*
- *Moderate impairment occurs at Secchi disc transparencies of 1 to 2 meters (3 to 7 feet).*
- *Moderate to severe use-impairment occurs at Secchi disc transparencies less than 1 meter (3 feet).*

Secchi disc measurements in Long Lake were generally within the eutrophic category (i.e., transparency from 0.85 to 2 meters). The seasonal patterns suggest the lake's water transparency is largely determined by algal abundance. Secchi disc transparency is high in the beginning of the summer, then falls to eutrophic levels by mid-June. Hence, recreational use impairment was minimal during the early summer and moderate by mid-June. Secchi disc measurements during late-July through late-August were less than 1 meter, indicating moderate to severe recreational use impairment. The summer average Secchi disc measurement (i.e., 1.2 meters) was within the eutrophic category. The average recreational use impairment in Long Lake was moderate (See Figure 8).

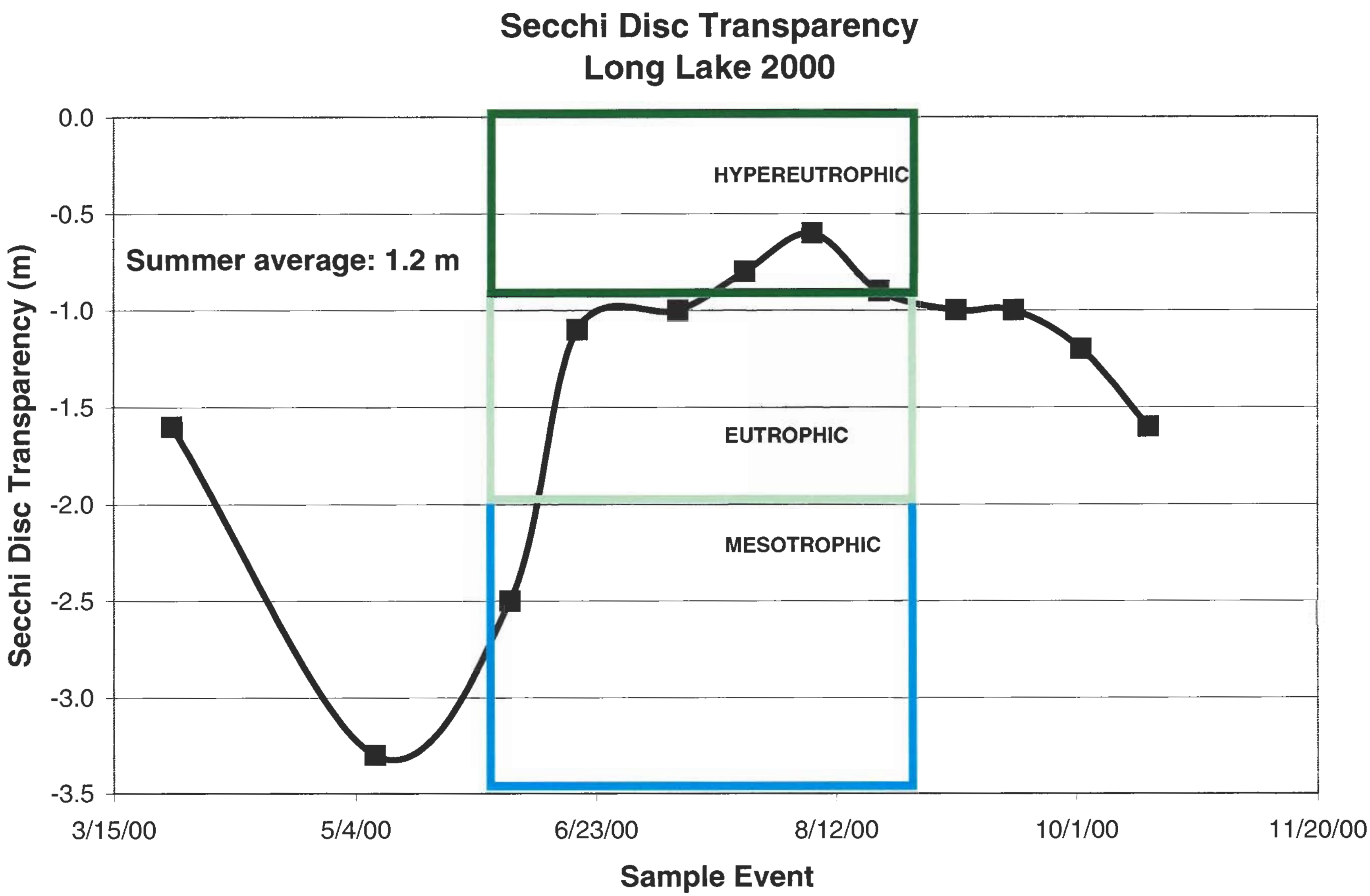

Figure 8

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4.4 Temperature, Dissolved Oxygen, Specific Conductance, and Total Phosphorus Isopleth Diagrams

Isopleth diagrams represent the change in a parameter relative to depth and time. For a given time period, vertical isopleths indicate complete mixing and horizontal isopleths indicate stratification.

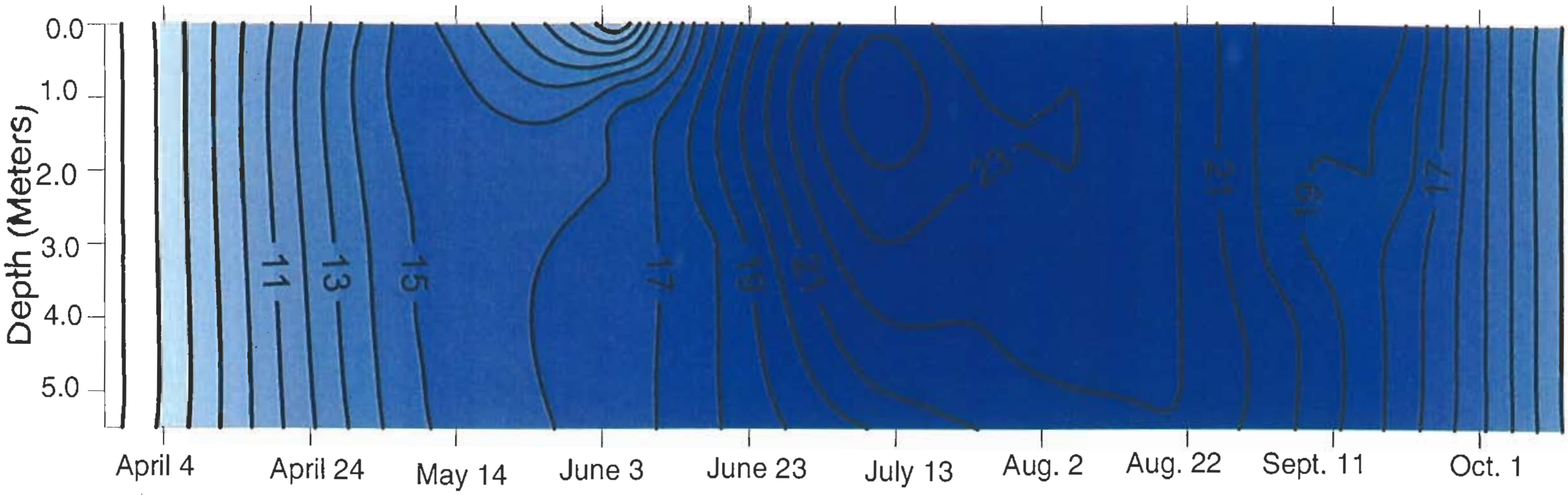
Isopleth diagrams are useful for showing patterns with depth and time when sufficient depth profile data are available. Isopleth diagrams of temperature, dissolved oxygen, and specific conductance were prepared for Long Lake. The temperature isopleth diagram (See Figure 9) indicates the lake was mixed completely during the spring (i.e., same temperature from surface to lake bottom) and exhibited weak stratification throughout the summer period (i.e., temperature layers from surface to lake bottom).

The dissolved oxygen isopleth diagram (See Figure 9) shows that the lake was well oxygenated from surface to near the bottom from April through late-July. A dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish. Oxygen concentrations below 5.0 mg/L were observed near the bottom of the lake in early-July and throughout the water column from August through the end of the monitoring period. Therefore, fish could inhabit the entire lake during the April through June period and all but the lake's near bottom waters during July without experiencing oxygen related stress. From early-August until the end of the monitoring period, however, the fish in Long Lake may have experienced low oxygen stress.

Specific conductance is directly related to the amount of dissolved inorganic chemicals (minerals, nutrients, metals, and other inorganic chemicals) in the water. Specific conductance levels are a reflection of the soils and bedrock in the lake's watershed. They also indicate the level of internal loading (i.e., the resuspension of phosphorus from the sediments to the lake water). The specific conductance isopleth diagram (Figure 10) shows that the lake's conductivity was uniform throughout the water column during the spring. In early summer, however, the conductivity of the surface waters was higher than those lower in the lake's water column. Later in the summer, during July, the opposite trend is observed; the lake's bottom waters have a higher conductivity than the surface waters. After mid-August, the lake is more mixed- it has a more uniform distribution. This may be indicative of internal mixing in the lake that brings nutrients stored at the bottom of the lake up to the surface waters (called internal loading).

The total phosphorus isopleth diagram (Figure 10) shows a similar trend. The lake's total phosphorus concentration is the same throughout the water column in the spring, when the lake is still fully mixed. As the summer progresses, the total phosphorus concentrations become more and more stratified until mid-August. The build-up of phosphorus in the lake's bottom waters during June through mid-August resulted from the release of phosphorus from the lake's sediments. A decrease in the lake's bottom phosphorus concentration occurred in mid-August, when it appears that the lake is re-mixed. This mixing event coincides with the increase in the total phosphorus concentration seen in the epilimnion in mid-August (see Figure 6).

Long Lake - 2000
Temperature Isopleth (°C)



Long Lake - 2000
Dissolved Oxygen Isopleth (mg/L)

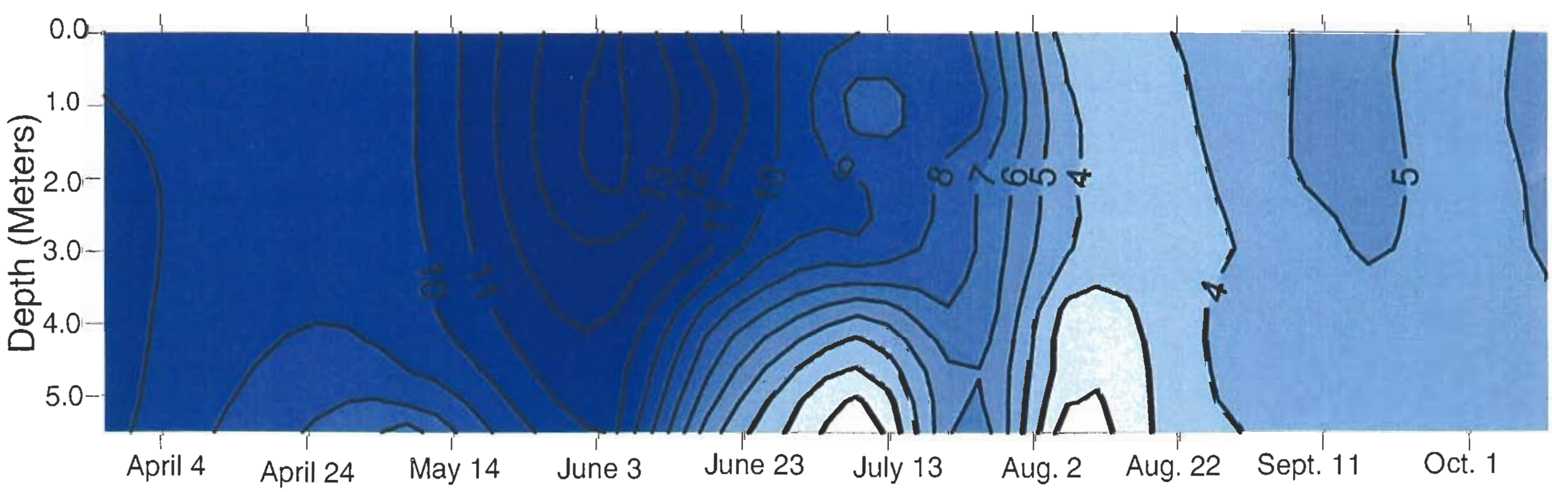
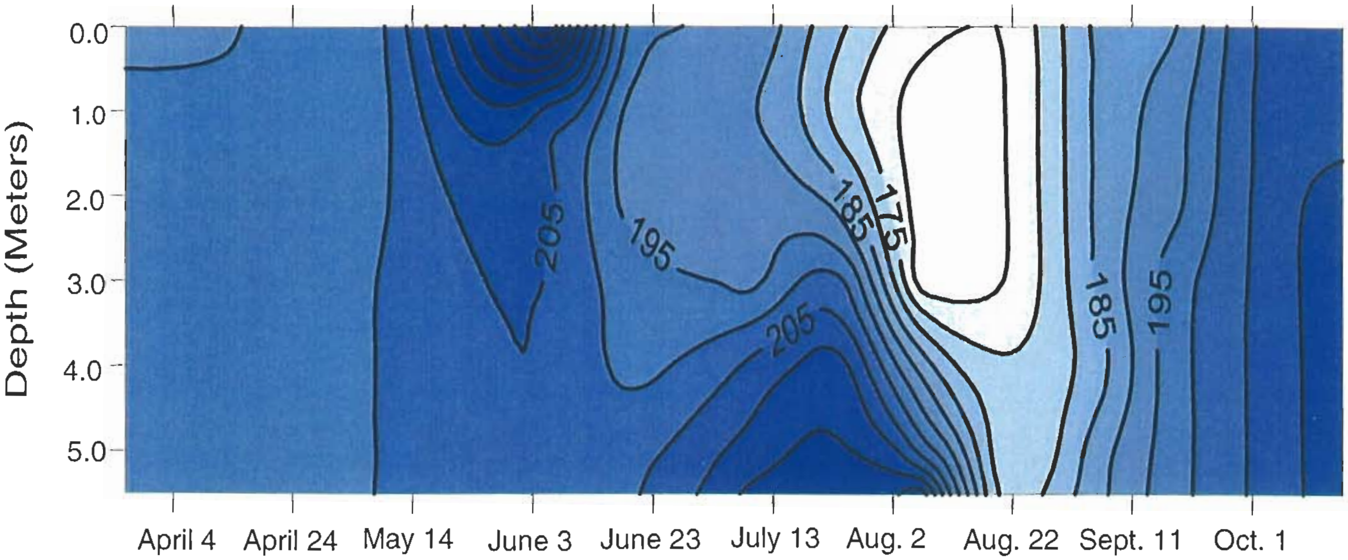


Figure 9

Long lake - 2000
Specific Conductivity Isopleth (@ 25° C)



Long Lake - 2000
Total Phosphorus Isopleth (µg/l)

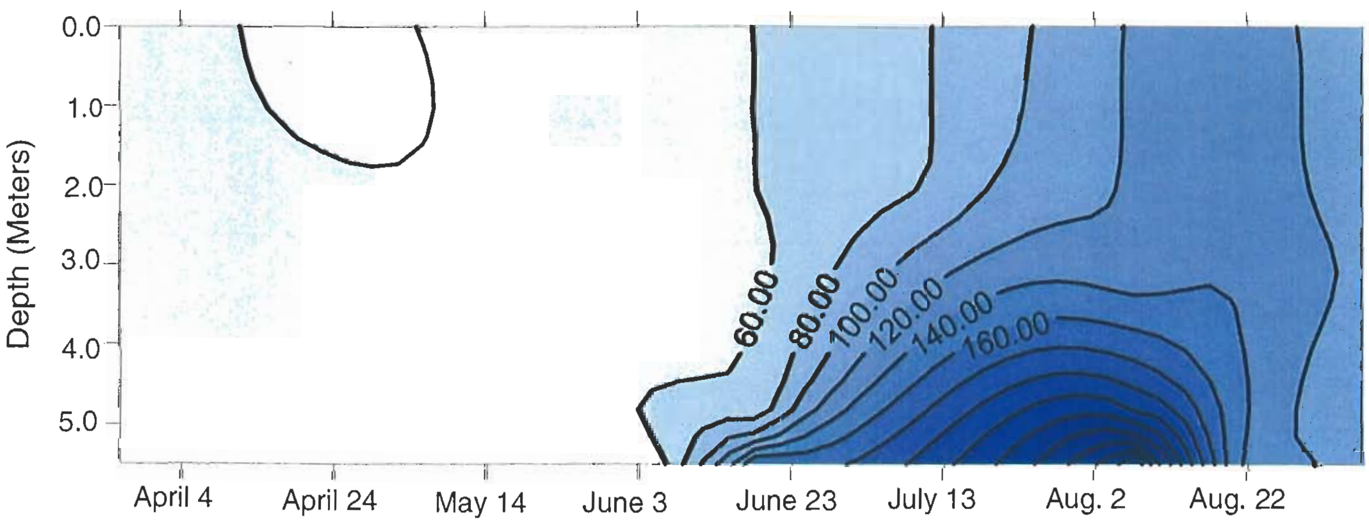


Figure 10

4.5 Macrophytes

Aquatic plants (i.e., macrophytes and phytoplankton) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. They are the primary producers in the aquatic food chain, providing food for other aquatic life. Macrophytes describe the aquatic plants growing in the shallow (littoral) area of the lake.

Figures 11 through 13 show the results of the June 14, 2000 macrophyte survey for Long Lake. Results of the 2000 Long Lake macrophyte survey indicated the lake contained a diverse assemblage of 16 macrophyte species representing the four macrophyte types – submersed plants, floating-leaf plants, emergent plants, and the alga, *Chara*. Figure 11 shows the types of macrophytes that were found in the lake. Of the four types of plants, submergent plants were dominant and were present on approximately 103 acres of lake surface (37 percent). Floating-leaf plants were present on approximately 59 acres of lake surface area (21 percent). Emergent plants and the alga, *Chara*, were present on 13 (5 percent) and 11 acres (4 percent) of lake surface area, respectively.

In 2000, macrophyte growth was found throughout the lake's littoral region. Macrophyte density ranged from 0 to 100 percent at monitoring locations. Approximately one third of the littoral region noted light densities (i.e., 0 to 40 percent), one third noted a typical density (40 to 60 percent), and one third noted a heavy density (60 to 100 percent). Densest macrophyte growth occurred in the southeast and northwest ends of the lake (See Figure 12).

The maximum depth of macrophyte growth in 2000 was 13 to 15 feet. Macrophytes covered approximately 37 percent of the lake's surface.

One measure of macrophyte abundance is the frequency of occurrence of a species measured as the percentage of sample locations containing a species. The two most frequently occurring species were:

- *Potamogeton crispus* (Curly leaf pondweed) was found in 92 percent of the sample locations
- *Lemna trisulca* (Star duckweed) was found in 55 percent of the sample locations

All other species were found in 1 to 25 percent of sample locations.

Macrophytes in Long Lake consisted of 15 native species (i.e., species historically present in this region) and one exotic (i.e., not native) species, *Potamogeton crispus* (Curly leaf pondweed). Exotic or non-native species are undesirable because their natural control mechanisms are not introduced with the species. Consequently, exotic species frequency exhibit rapid unchecked growth patterns.

Curly leaf pondweed is an exotic perennial, rooted, submersed aquatic vascular plant which was first noted in Minnesota about 1910 (Moyle and Hotchkiss 1945). Native to Eurasia, Africa, and Australia, this species has been found in most of the United States since 1950, and is currently found in most parts of the world (Catling and Dobson 1985).

Curly leaf pondweed is detrimental to lakes for three reasons:

- It tends to crowd out native aquatic macrophyte species
- Dense colonies of the weed may interfere with recreational activities on the lake
- After Curly leaf pondweed dies out in late-June, it sinks to the lake bottom and decays. When dense colonies of the weed decay, oxygen depletion and release of phosphorus occur.

Estimated 2000 Curly leaf pondweed coverage was 103 acres. Greatest coverage by Curly leaf pondweed occurred in the southeast end of the lake, followed by the northeast end of the lake (Figure 13).

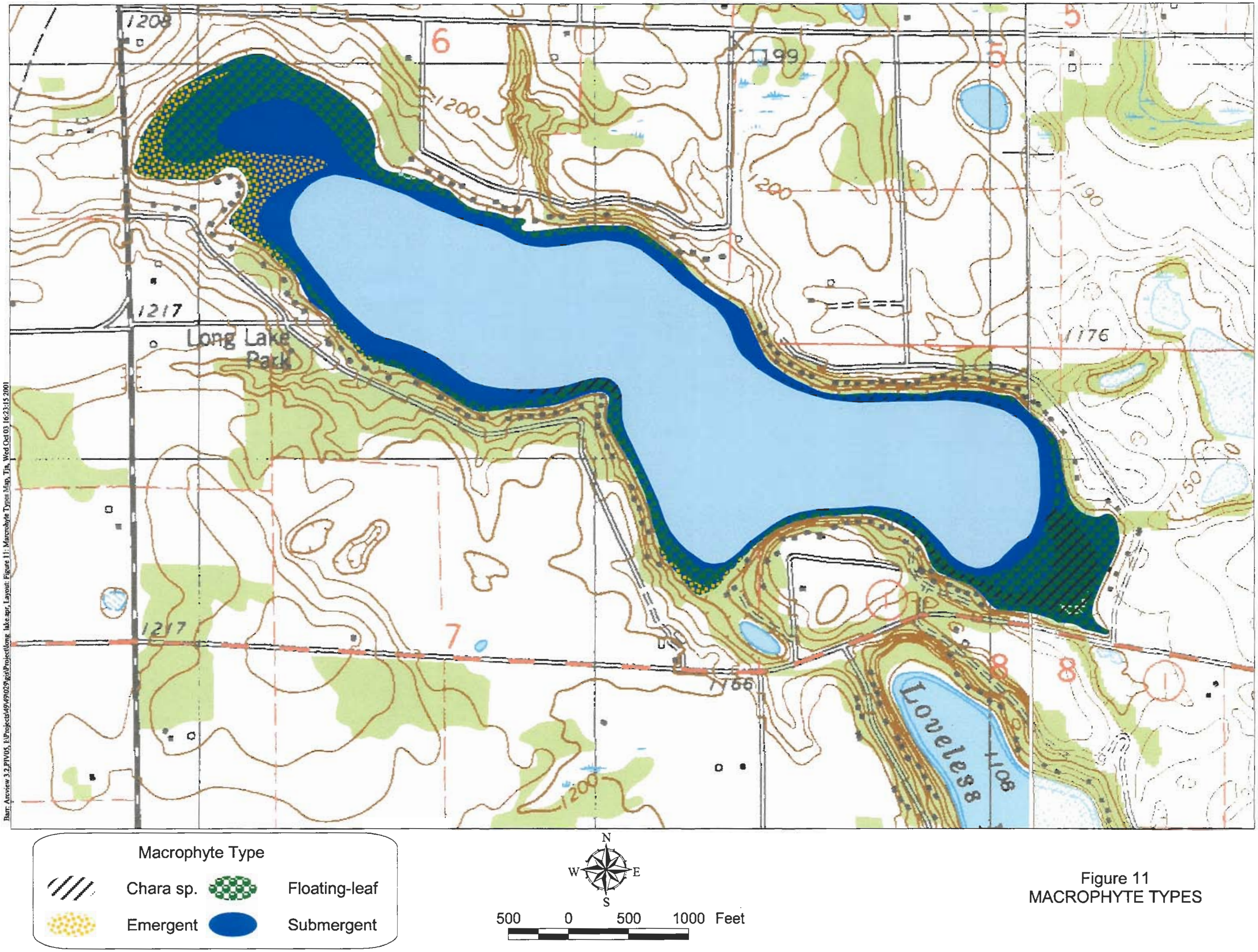


Figure 11
MACROPHYTE TYPES

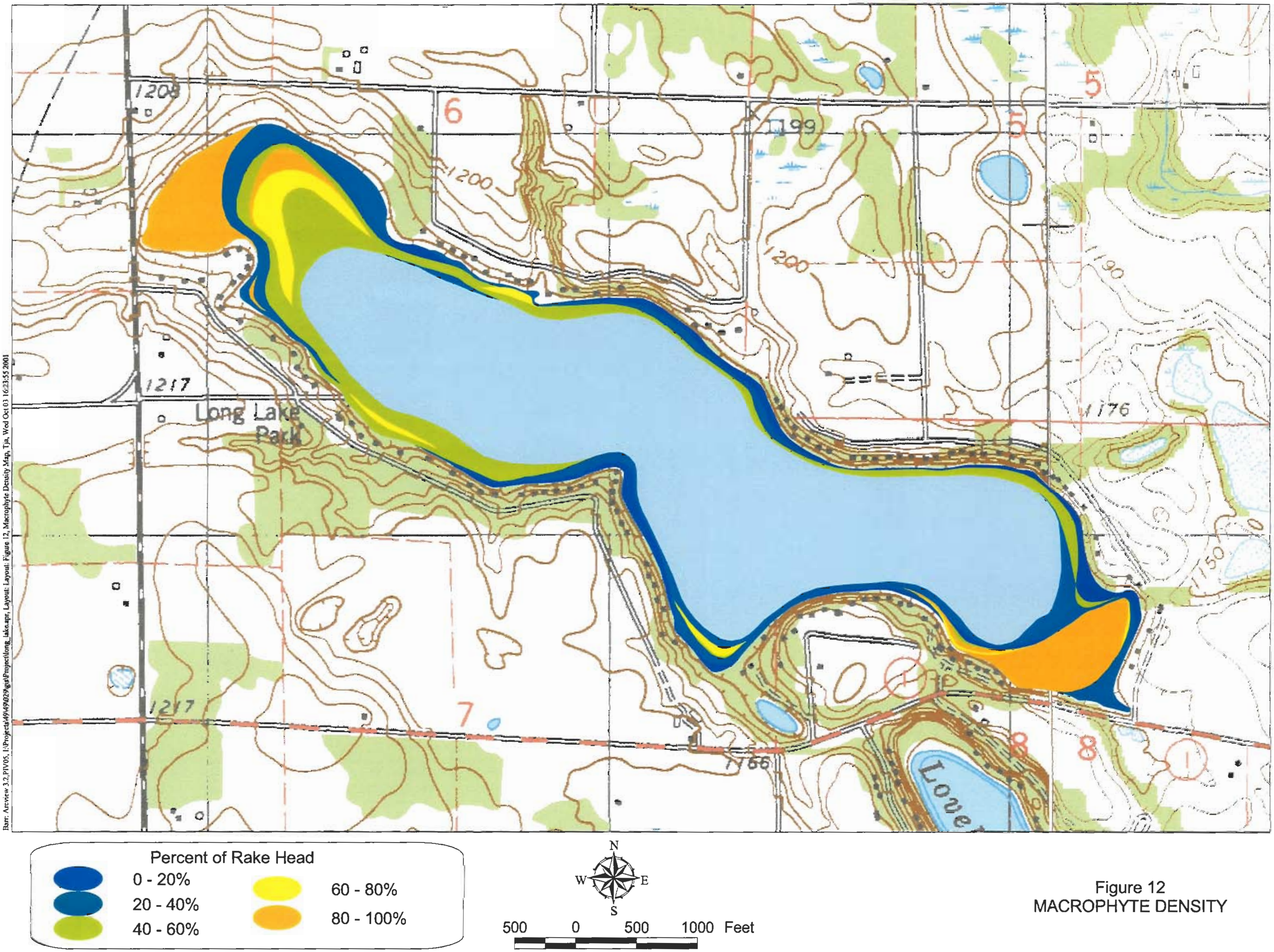


Figure 12
MACROPHYTE DENSITY

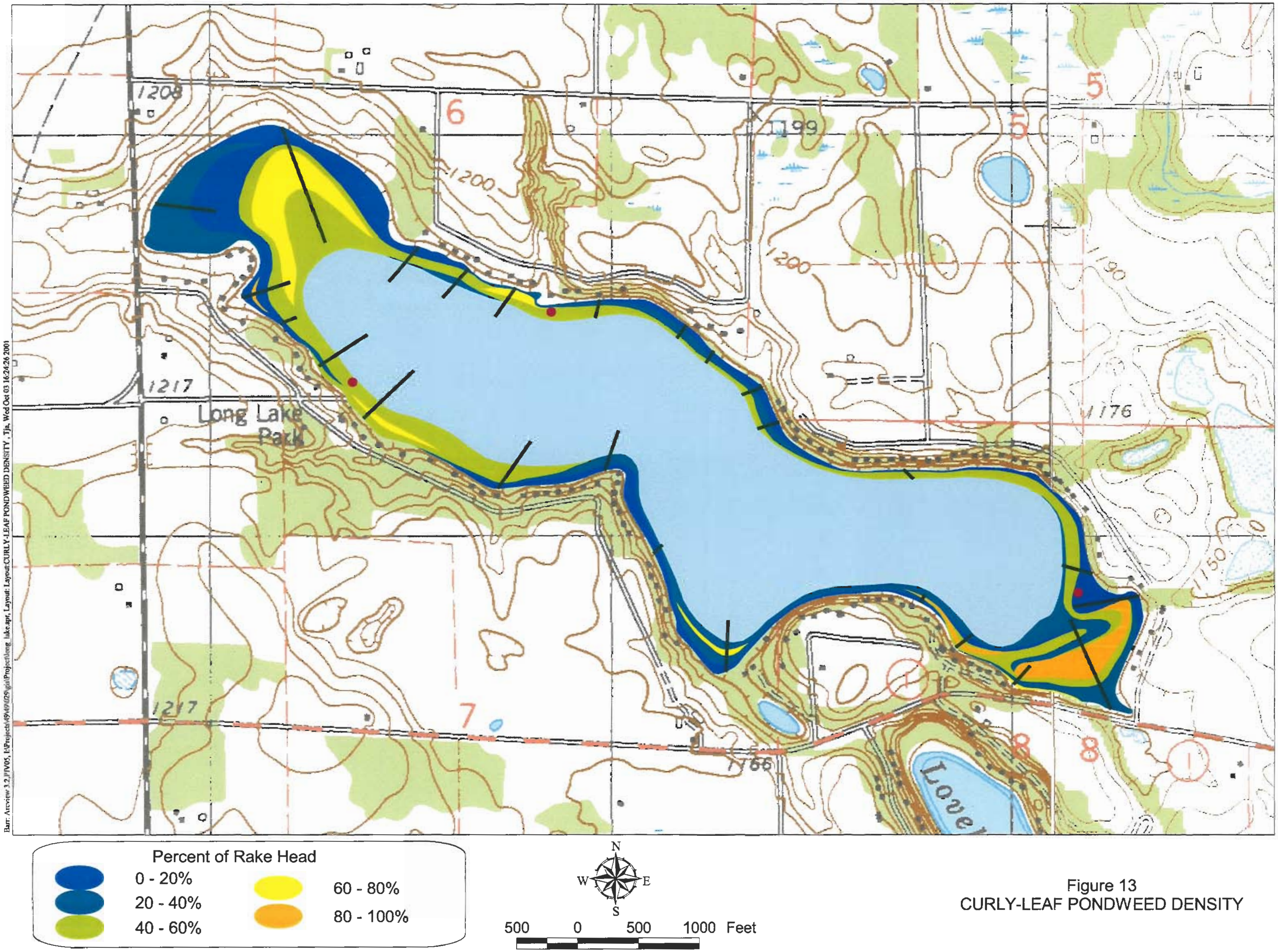


Figure 13
CURLY-LEAF PONDWEED DENSITY

4.6 Watershed Evaluation

The land area that drains to a lake is called its watershed. All land use practices within a lake's watershed impact the lake and determine its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed.

The watershed tributary to Long Lake is approximately 1,411 acres. This area excludes the lake, which has a surface area of approximately 277 acres. Long Lake notes a ratio of watershed area to lake surface area of 5 to 1. The lake's watershed is largely agricultural (i.e., approximately 63 percent) but also has significant areas of open space and residential developments (20 and 16 percent, respectively) (See Figures 14 and 15).

4.7 Hydrologic Budget

Sources of water to Long Lake include:

- Direct precipitation on the lake – 622 acre-feet (55 percent)
- Watershed runoff – 476 acre-feet (42 percent) (includes 433 acre-ft from snowmelt runoff)
- Net groundwater inflow – 39 acre-feet (3 percent)

As the water sources indicate, direct precipitation contributes most of the water to the lake, followed by watershed runoff (mostly from snowmelt) and groundwater. Figure 16 graphically shows the relative contribution of Long Lake's water sources.

Annual water loss is limited to evaporation and groundwater seepage since the lake has no outlet. The estimated annual evaporation and net groundwater seepage volumes from April to December, 2000 are 772 acre-ft and 134.1 acre-ft, respectively[1]

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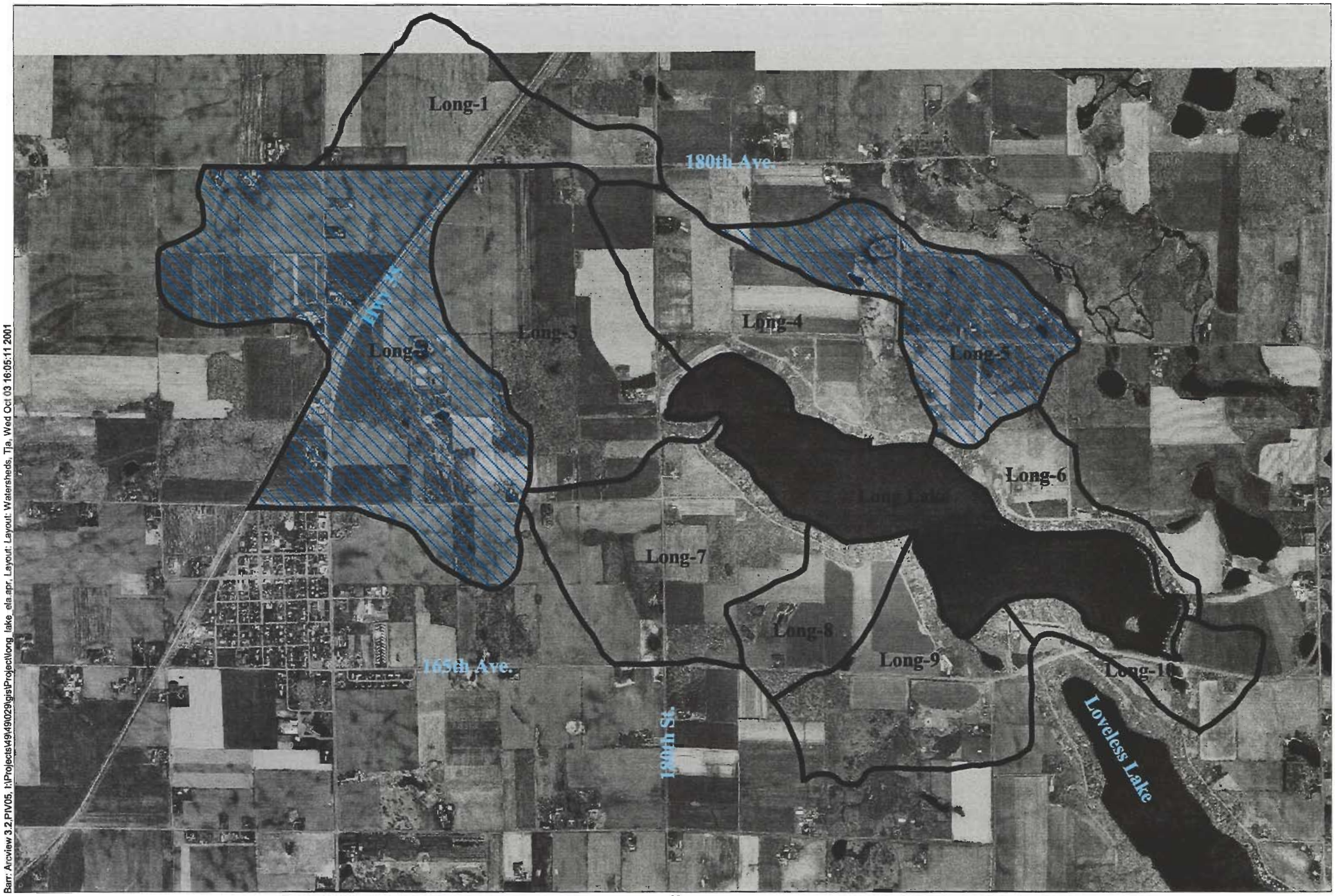
1. Assumes that there is no groundwater seepage out of the lake from January through March, 2000.



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Long Lake Subwatersheds

Drainage Flows to the Lake

Internally Drained
(Drainage Does Not Flow to the Lake)

N W E S

1000 0 1000 2000 Feet

Figure 14
LONG LAKE WATERSHED

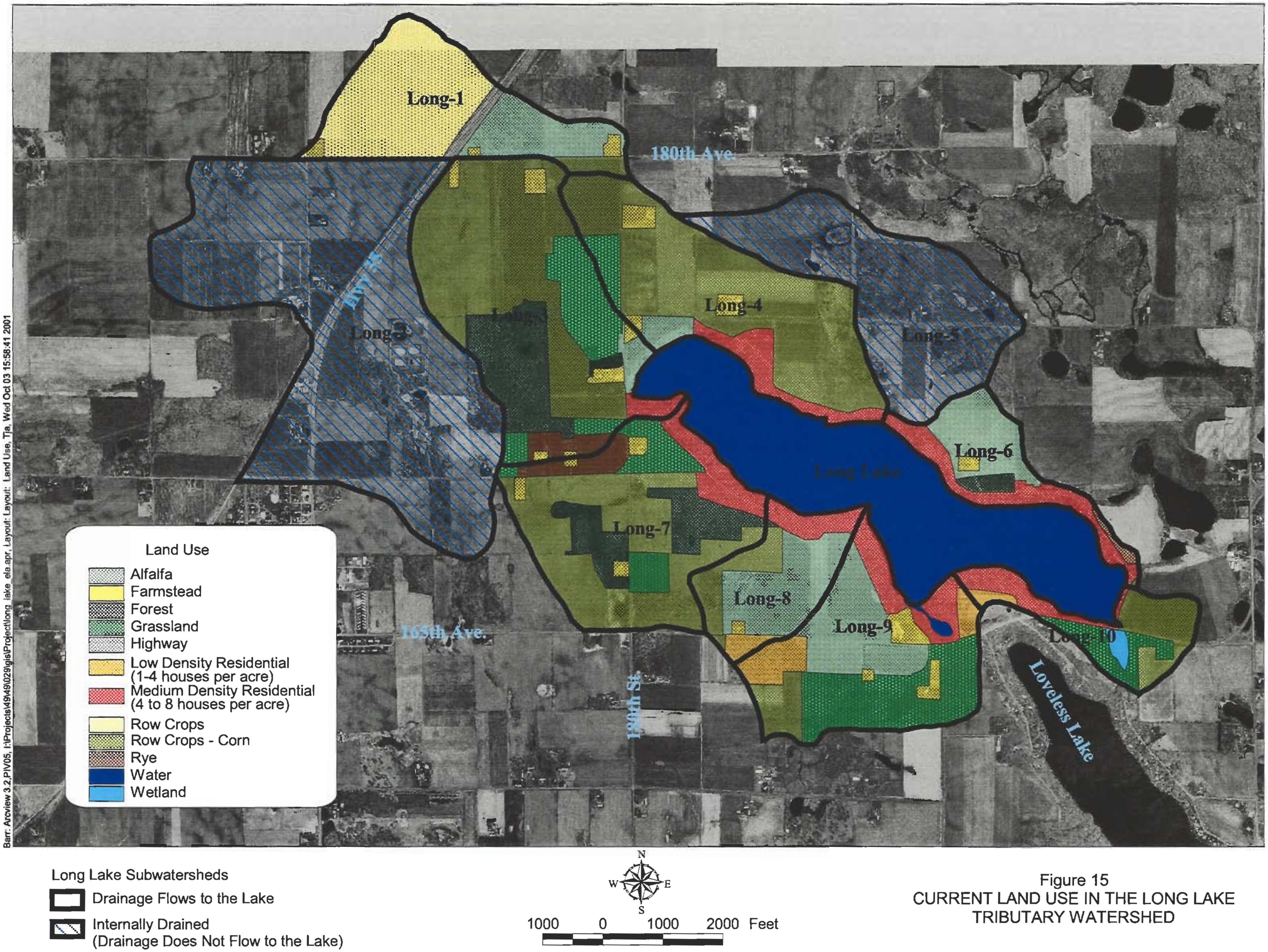

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Figure 15
CURRENT LAND USE IN THE LONG LAKE TRIBUTARY WATERSHED

Long Lake Sources of Water
2000

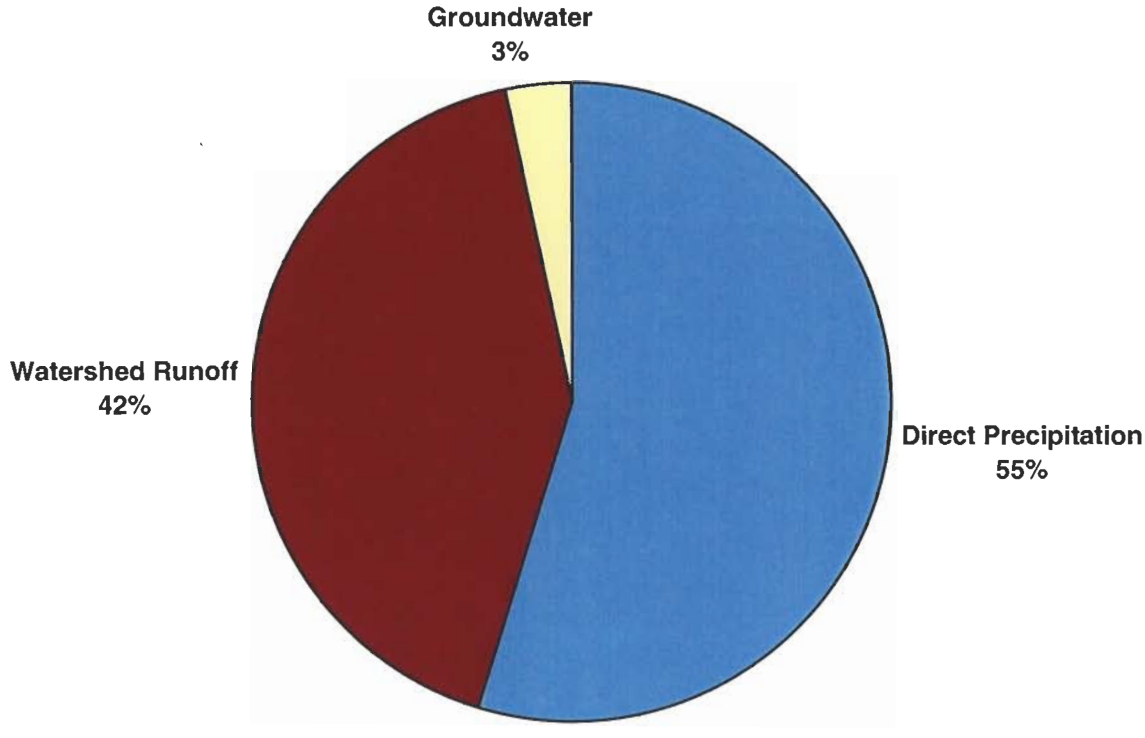

Figure 16

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4.8 Phosphorus Budget

In order to define the annual phosphorus budget for Long Lake, the sources of phosphorus from the tributary watershed and from within the lake itself were identified. For Long Lake, the sources of phosphorus were:

- Agricultural and developed areas within the tributary watershed – 195 kg
- Septic systems around the lake – 24 kg
- Barnyards in the tributary watershed –38 kg
- Die-off of Curly leaf pondweed in late-June – 174 kg
- Internal load of phosphorus from the sediments in mid-August – 100 kg
- Atmospheric loading of phosphorus directly on the lake surface – 62 kg

Based on all of this information, the annual total phosphorus load to Long Lake can be estimated at approximately 590 kg. The phosphorus contribution from each identified source can be summarized as follows:

- 43% from watershed runoff (including runoff over different types of land use, as well as from septic systems and barnyards)
- 29% from Curly leaf die-off
- 18% from lake sediment internal loading
- 10% from atmospheric loading

The data indicate that loads from Curly leaf and the Lake's sediments are the largest sources of phosphorus to the lake (47 percent), followed closely by watershed loading (43 percent). Even though atmospheric loading comprises most of the lake's annual water load, the low phosphorus content of rainwater limits the annual phosphorus load from atmospheric deposition to 10 percent. Figure 17 graphically shows the relative contribution of Long Lake's phosphorus sources to the overall phosphorus budget.

Long Lake Sources of Phosphorus
2000

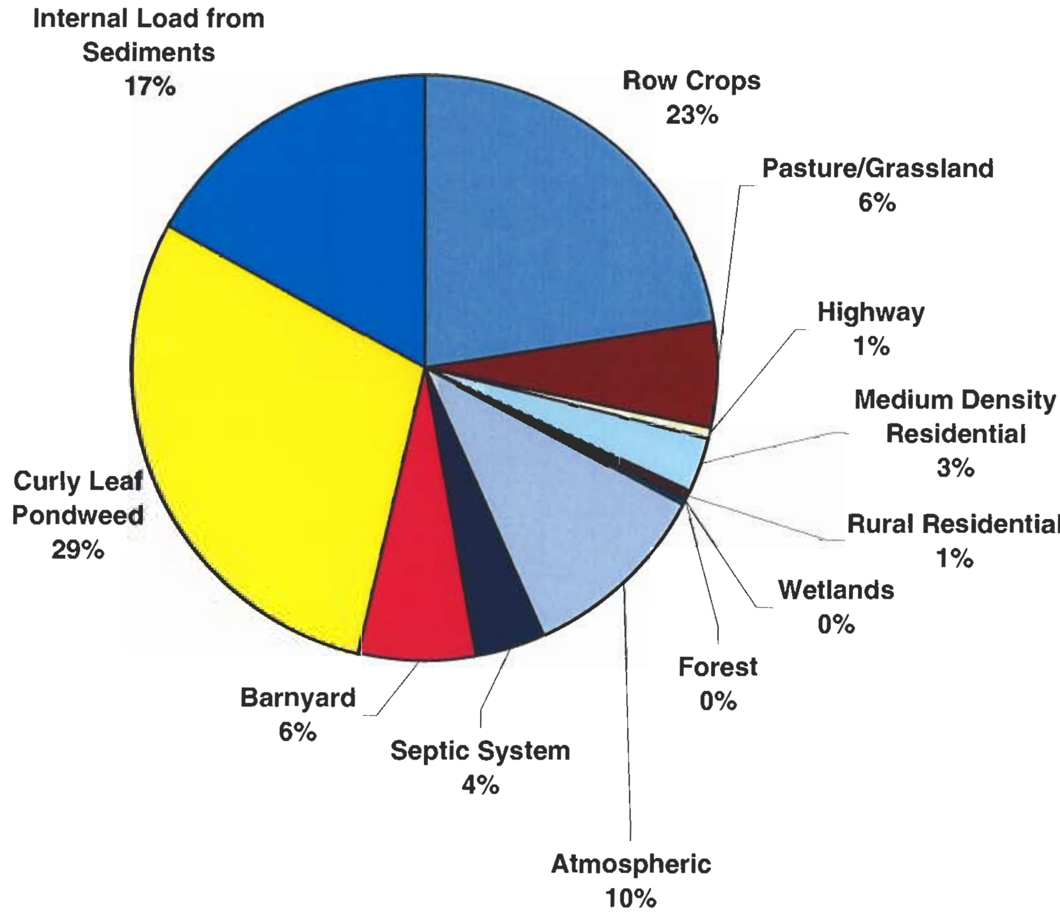

Figure 17

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4.9 Membership Survey

Members of the Long Lake Protection and Rehabilitation District were surveyed to determine their:

- Perception of the Lake's current water clarity
- Desired future lake water clarity
- Current recreational activities
- Desired recreational activities
- Lake Management Goals

The survey results indicated that most people consider the current clarity of the lake to be "cloudy" or "murky" and the desired clarity of the lake "clear". Few members (14%) desired that the lake be "crystal clear".

The survey also indicated that the current uses of the lake are diverse, and are summarized below in terms of the percent of members that indicated their participation in each activity category.

- 90-100%: Appreciating Peace and Tranquility
  Observing Wildlife
  Enjoying the View
  Fishing
- 80-90%: Swimming
  Motorized Boating
- 60-70%: Non-Motorized Canoeing, Rowing
  Water Skiing
- 50-60%: Snorkeling
  Sailing, Wind Surfing
  Jet Skiing
- 10% or less: Scuba Diving
  Other Activities, such as Pontooning, Wake Boarding and Water Tubing

The members' desired activities for the lake were similar to the current activities detailed above.

The members were asked about the lake management goals that are important to them. Their responses are shown in Table 3.

Table 3 Lake Management Goals of Interest to Membership Survey Participants

Lake Management Goal	Responses	% of Total Responses
Increase weed growth	0	0%
Protect existing weed growth	10	24%
Protect existing water quality of the lakes	17	40%
Protect aesthetics (how the lake looks)	19	45%
Improve fisheries	20	48%
Improve aesthetics (how the lake looks)	27	64%
Protect existing fisheries	27	64%
Decrease weed growth	34	81%
Improve the lakes' water quality	37	88%

Members were encouraged to provide any additional comments. Their comments were:

"I would suggest mandatory checking of all on-site sewage disposal systems every 2-4 years."

"Need fish habitation/structure."

"Lake and weed control seemed better this year."

"Mention to people that they should not burn trash and garbage in their burning barrels."

"Decrease algae growth."

5.0 Recommendations

An evaluation of 2000 Long Lake water quality data indicates the lake has hypereutrophic (very poor) water quality. The data indicate the lake is phosphorus-limited (i.e., the lake's water quality is determined by its phosphorus concentration). A reduction in the lake's phosphorus concentration is expected to result in an improvement in the lake's water quality and an increase in the lake's phosphorus concentration is expected to result in water quality degradation. The phosphorus concentration in the lake is a result of phosphorus added to the lake from its tributary watershed and from the lake itself.

Development of a management plan for Long Lake and its watershed is recommended to improve and/or protect the lake's water quality to the greatest extent possible. The following project to develop a management plan for Long Lake is recommended:

- Establish a long-term water quality goal for Long Lake;
- Develop a management plan for Long Lake and its watershed which achieves its long-term water quality goal;
- Explore various potential management scenarios and their impacts on the water quality of Long Lake; focusing on:
  - Management of Curly leaf pondweed to reduce phosphorus loading from dying plants,
  - Management of internal phosphorus loading from lake sediments, and
  - Prevention of increased watershed runoff
- Perform cost-benefit analyses of management scenarios

References

Alberts, E.E., Schuman, G.E., and Burwell, R.E., et al., 1978. *Seasonal Runoff Losses of Nitrogen and Phosphorus from Missouri Valley Loess Watersheds.* J. Environ. Qual. 7(2):203-208.

Barr Engineering Company. 2001. *Big Lake Protection Grant LPT-67: Big Lake Macrophyte Plan Implementation. Volume 2: Appendices.* Prepared for Church Pine, Round, and Big Lake Protection and Rehabilitation District.

Bradford, R.R., 1974. *Nitrogen—Phosphorus Losses from Agronomy Plots in North Alabama.* U.S. Environmental Protection Agency, EPA-660/2-74-033.

Bursik, C. 1996. Personal Communication. Balsam Branch Priority Watershed. Polk County Land Conservation Department.

Carlson, R.E. 1977. *A Trophic State Index for Lakes.* Limnology and Oceanography, 22:2.

Catling, P.M. and I. Dobson. 1985. *The Biology of Canadian Weeds. 69. Potamogeton crispus L.* Can. J. Plant Sci. Rev. Can. Phytotechnie. Ottawa: Agricultural Institute of Canada, 65 (3): 655-668.

Corsi, S.R., D.J. Graczyk, D.W. Owens, and R.T. Bannerman. 1997. *Unit-Area Loads of Suspended Sediment, Suspended Solids, and Total Phosphorus from Small Watersheds in Wisconsin.* U.S. Department of the Interior, U.S. Geological Survey, Fact Sheet FS-195-97.

Deppe, E.R. and R.C. Lathrop. 1992. *A Comparison of Two Rake Sampling Techniques for Sampling Aquatic Macrophytes.* Research Management Findings, 32:1-4.

Dillon, P.J., and Kirchner, W.B. 1975. *The Effects of Geology and Land Use on the Export of Phosphorus from Watersheds.* Water Research 9:135-148.

Harms, L.L., J.N. Dornbush, and J.R. Andersen, 1974. Physical and Chemical Quality of Agricultural Land Runoff. Journ. Water Poll. Contr. Fed. 46:2460-2470.

Jessen, R. and R. Lound. 1962. *An Evaluation of a Survey Technique for Submerged Aquatic Plants.* Game Investigational Report. Minnesota Department of Conservation.

Mattraw, H.C., and Sherwood, C.B. 1977. *Quality of Storm-water Runoff from a Regional Area,* Broward County, Florida. Jour. Research U.S. Geol. Survey, 5(6):823-834.

Meyer, A.F., 1944. Elements of Hydrology, Second Edition. John Wiley and Sons. New York, New York.

Molsather, L.R., L.J. Kremer, and D.E. Palmer. 1977. *Hydrologic Impacts of Land Use Decisions.* Paper presented at American Society of Civil Engineers Convention. Preprint #2999, p.27.

Moyle, J.B. and N. Hotchkiss. 1945. *The Aquatic and Marsh Vegetation of Minnesota and its Value to Waterfowl.* Minnesota Department of Conservation Technical Bulletin No. 3, 122 p.

Much, R.R., and Kemp, G. 1978. *Characterization of Non-Point Waste Sources, Report #6, Summary of Non-Point Waste Loads.* Fox Valley Water Quality Planning Agency, Wisconsin. 135 pp.

Nicholson, J.A. 1977. *Forested Watershed Studies, Summary Technical Report.* PLUARG Technical Report Series, 23 pp.

North American Lake Management Society (NALMS). 1988. *Lake and Reservoir Management: A Guidance Manual.* Development for Office of Research and Development--Corvallis and for Office of Water Criteria and Standards Division. Non-point Source Branch.

Panuska, J.C. and A.D. Wilson. 1994. Wisconsin Lake Model Spreadsheet User's Manual. Wisconsin Department of Natural Resources. Lake Management Program. PUBL-WR-363-94.

Panuska, John and R. Lilly, 1995. *Phosphorus Loadings from Wisconsin Watersheds: Recommended Export Coefficients for Agricultural and Forested Watersheds.* WDNR Research Management Findings No. 38.

Taylor, A.W., Edwards, W.M., and Simpson, E.C., 1971. *Nutrients in Streams Draining Woodland and Farmland Near Coshocton, Ohio.* Water Resources Research, 7(1):81-89.

Thorson, D. 1997. *The Lakes of Barron County: A Report on their Status in 1996.* Barron County Land Conservation Department. 146pp.

Tetra Tech, Inc. 1982. *A Screening Procedure for Toxic and Conventional Pollutants: Part 1,* EPA-600/6-82-004a, 1982.

Timmons, J. 2001. Personal Communication. Polk County Land and Water Resources Department.

Walker, W.W. 1985. *Urban Nonpoint Source Impacts on a Surface Water Supply. Proceedings from Perspectives on Nonpoint Source Pollution Conference. U.S. Environmental Protection Agency. pp. 129-137.*

Wisconsin Department of Natural Resources. 1987. *Wisconsin's Department of Natural Resources Long-term Trend Lake Monitoring Methods.* Bureau of Water Resources Management. pp. 121-125.

Wisconsin Department of Natural Resources. 1988. Data. **Cited in**: Wisconsin Geological and Natural History Survey. 1990.

Wisconsin Department of Natural Resources (WDNR), Wisconsin Department of Agriculture (WDOA), and the Polk County Land Conservation Department. 1995. Nonpoint Source Control Plan for the Balsam Branch Priority Watershed Project.