Long Lake Management Plan

Phase I: Water Quality Study of Long Lake and its Watershed

Prepared for
Long Lake Preservation Association

Prepared by Barr Engineering Co.
with Assistance from:
Long Lake Preservation Association
Natural Resource Conservation Service
Wisconsin Department of Natural Resources

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Barr
Engineering Company

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Ralph Zenisek	Collection of Long Lake Water Quality Samples
Harry Mogge	Collection of Long Lake Water Quality Samples
Evert and Jan Grilley	Collection of Long Lake Water Quality Samples
Doris Tucker	Read Rain Gage
Andy Bailey	Read Rain Gage Backup Reading Long Lake Level Gage Collection of Water Quality Samples from Watershed Lakes
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Bill Genrich	Collection of Water Quality Samples from Watershed Lakes
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Ed Olund	Technical Advisor to Volunteers and Provided Equipment for Water Quality Collection Program

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Long Lake

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Executive Summary

During 1994, the Long Lake Preservation Association completed the first phase of a three phase project to develop a Lake Management Plan. The Phase I project was primarily a data collection project to evaluate the water quality of the lake and assemble requisite data for subsequent phases of the project. Consequently, water quality data, lake level data, precipitation data, and watershed land use data were collected. Ensuing phases of the project will prepare hydrologic and phosphorus budgets for existing watershed land use conditions and will prepare the management plan for Long Lake.

Water quality data collected from Long Lake during 1994 indicate that its water quality is excellent and is similar to the water quality noted in previous years. During 1994 the lake noted a trophic status designation of mesotrophic. This means it is a moderately productive lake with desirable water quality. Phosphorus was determined to be the nutrient controlling the lake's algal growth, and hence, its productivity. Phosphorus concentrations were generally within the mesotrophic category during 1994, but occasionally were noted in the eutrophic category during the late summer. Eutrophic conditions indicate the lake is vulnerable to problematic conditions, should additional water quality degradation occur. Chlorophyll data, which is a measurement of algal abundance in the lake, corroborated the lake's phosphorus data. Concentrations were in the mesotrophic category during the early summer and were within the eutrophic category during the late summer. Secchi disc transparency supported the lake's phosphorus and chlorophyll data. All average measurements were within the mesotrophic category. However, most locations noted at least one measurement within the mildly eutrophic category during the late summer. The data indicate the lake has excellent water quality currently, but also indicate the importance of lake management to prevent additional increases in the lake's algal population. The data indicate the lake is most vulnerable to problematic conditions during the late summer period when recreational demand is at is peak.

Uncontrolled development of the lake's watershed would likely result in significant degradation. Most of the 38,000 acre Long Lake watershed is currently undeveloped. Cropland comprises less than 10 percent of the watershed, and highly erodible land constitutes approximately one percent of the watershed. Residential development is restricted to a fringe immediately adjacent to Long Lake consisting of about 600 residences and several resorts. The remaining portion of the watershed primarily consists of natural woodland.

Development of a lake management plan affords the opportunity to establish long-term water quality goals for the lake. Different watershed development scenarios can be evaluated to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options. Diligent management of the lake and its watershed will preserve the current water quality and the current balance in the lake's ecosystem.

Introduction

Long Lake is known as one of the premier, high quality fisheries in the northwestern end of the state and has been dubbed the "Walleye Capital of Wisconsin". Located on the headwaters of the Brill River in southeastern Washburn County, it is the largest lake in the county. The lake is approximately 19 miles in length, has a shoreline length of approximately 99 miles, and a surface area of 3,290 acres. The lake has a maximum depth of 74 feet and an average depth of 26 feet. Its 38,000 acre watershed is largely undeveloped. Watershed development consists of approximately 600 residences and several resorts along the lake's shoreline and some agricultural use near the lake. The Tomahawk Scout Reservation has preserved approximately 3,000 acres of land in its natural state, including approximately 8 miles of shoreline. Several streams and lakes contribute water flow to Long Lake including Slim Creek, Twin Lake, Big Devil Lake, Harmon Lake, Mud Lake, Little Mud, and a small tributary in Section 16. The lake has five developed public boat landings.

In ancient times, the Long Lake basin consisted of at least three glacially formed lakes and their interconnecting streams. In the late 1800s, a dam was constructed to raise the water level approximately 8 feet, fusing these separate bodies of water into one whole. Loggers then used the lake to transport logs downstream. The raised water level, however, has resulted in a complex body of water. The lake contains several basins, and basin depths vary from 8 to 74 feet.

Since its "discovery" in the late 1800s as a logging site, development around the lake has been slowed and controlled. However, the Long Lake Preservation Association (LLPA) is concerned that additional development in the Long Lake watershed may result in degradation of the lake's fishery. The LLPA collected a limited amount of water quality data during 1991 through 1993 to determine the existing water quality of the lake. The data (Appendices J through V) suggest Long Lake would be assigned a trophic status of Mesotrophic, thus ascertaining its excellent water quality. However, the data suggest that algal blooms during the late summer months result in mildly eutrophic conditions in some portions of the lake. The data indicate the lake's water quality is vulnerable to degradation should uncontrolled watershed development occur. Therefore, the LLPA initiated a three phase project to develop a management plan, designed to preserve the existing water quality of the lake. The three phases of the project include:

- Phase I—Collection of data

- Phase II—Preparation of hydrologic and phosphorus budgets for existing watershed land use conditions.

- Phase III—Preparation of the lake management plan.

This report discusses the methodology, results, and conclusions from the Phase I portion of the Lake Management Plan development. The Phase I project was primarily a data collection project to evaluate the water quality of Long Lake and assemble requisite data for the Phase II project. Consequently, water quality data, lake level data, precipitation data, and watershed land use data were collected.

The methods used for the Phase I portion of the Lake Management Plan project are discussed in the following sections of this report. Included in the discussion are:

- Water Quality Survey of Long Lake
- Macrophyte Survey of Long Lake
- Collection of Lake Level Data
- Collection of Precipitation Data
- Evaluation of the Tributary Watershed

Water Quality Survey of Long Lake

The 1994 water quality survey of Long Lake was designed to provide an understanding of the interacting physical, chemical, and biological processes controlling the water quality of Long Lake. This information will be used for model calibration during the Phase II project. It was also designed to provide baseline water quality information for the lake which will help the LLPA complete its Lake Management Plan in the Phase III portion of the project.

The 1994 sampling program involved measurements and/or collection of samples from Long Lake at spring overturn (within two weeks of ice-out) and biweekly until ice-in. In addition, measurements were made during January and March of 1995. Barr Engineering Company provided training for LLPA volunteers, who collected the water quality data.

Long Lake has five distinct basins, and samples were collected from each of the five basins. Samples were collected from the deepest portion of each basin, because this location best represented the limnological properties of the basin. Sample locations are shown on Figures 1 through 6.

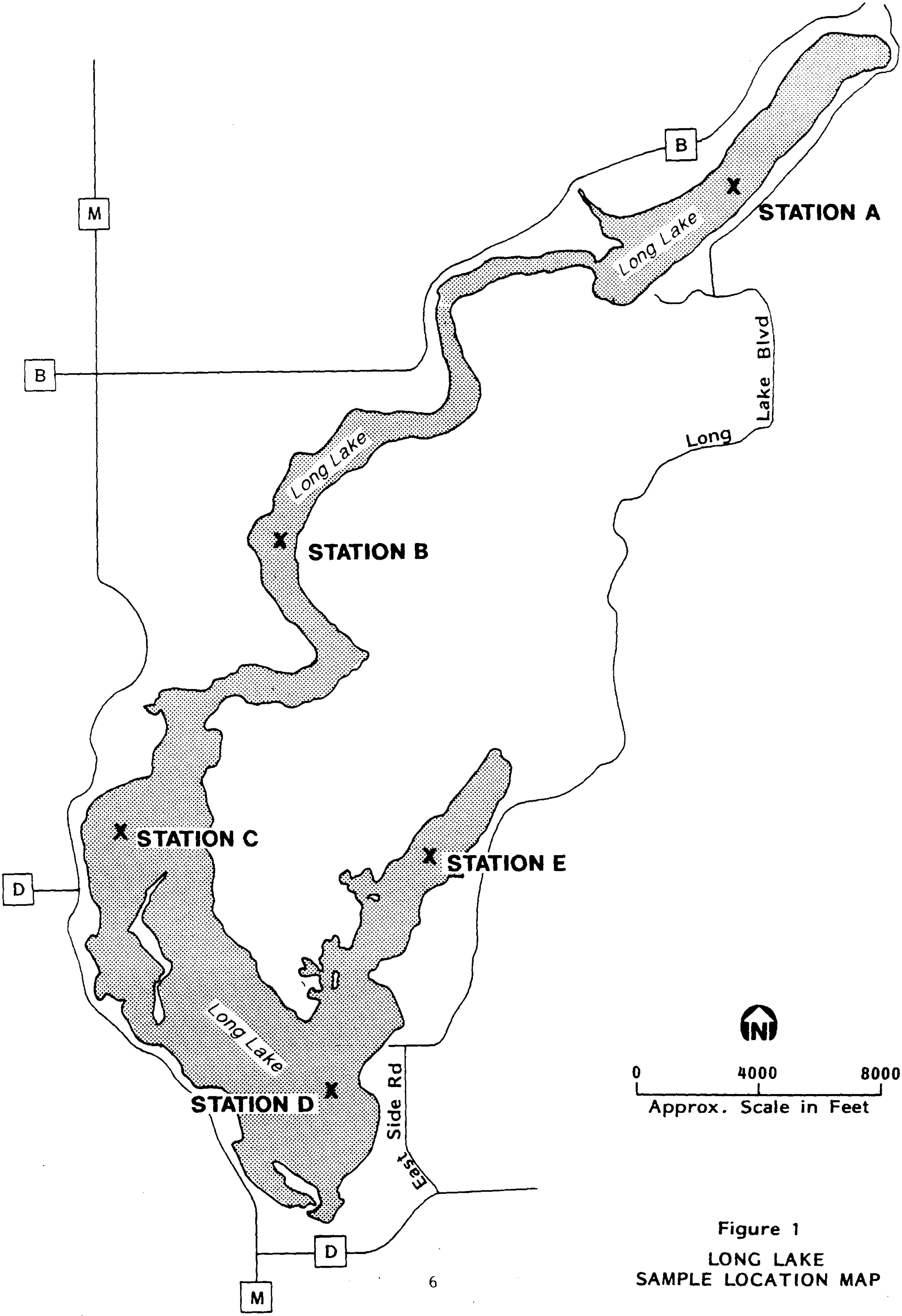
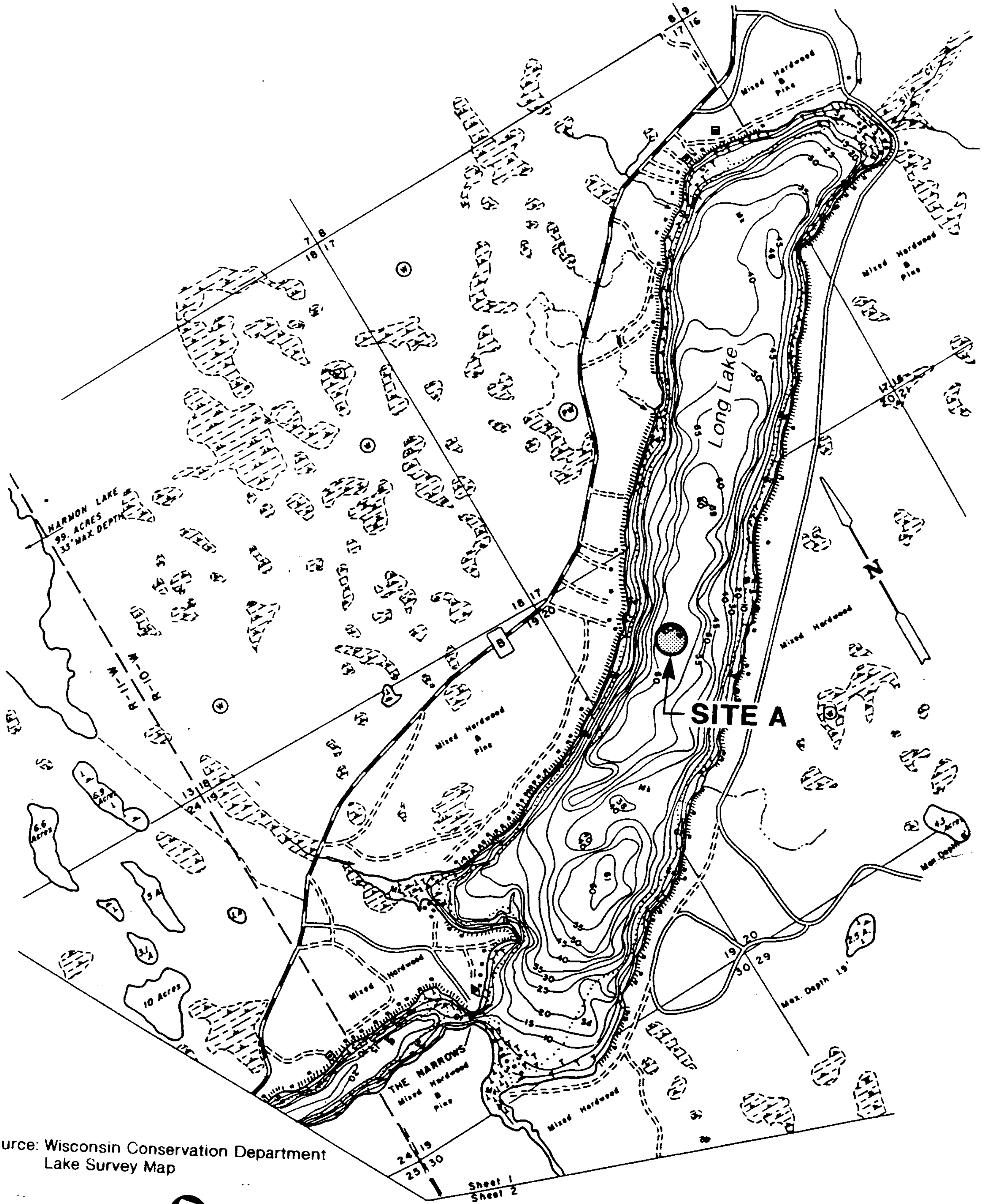


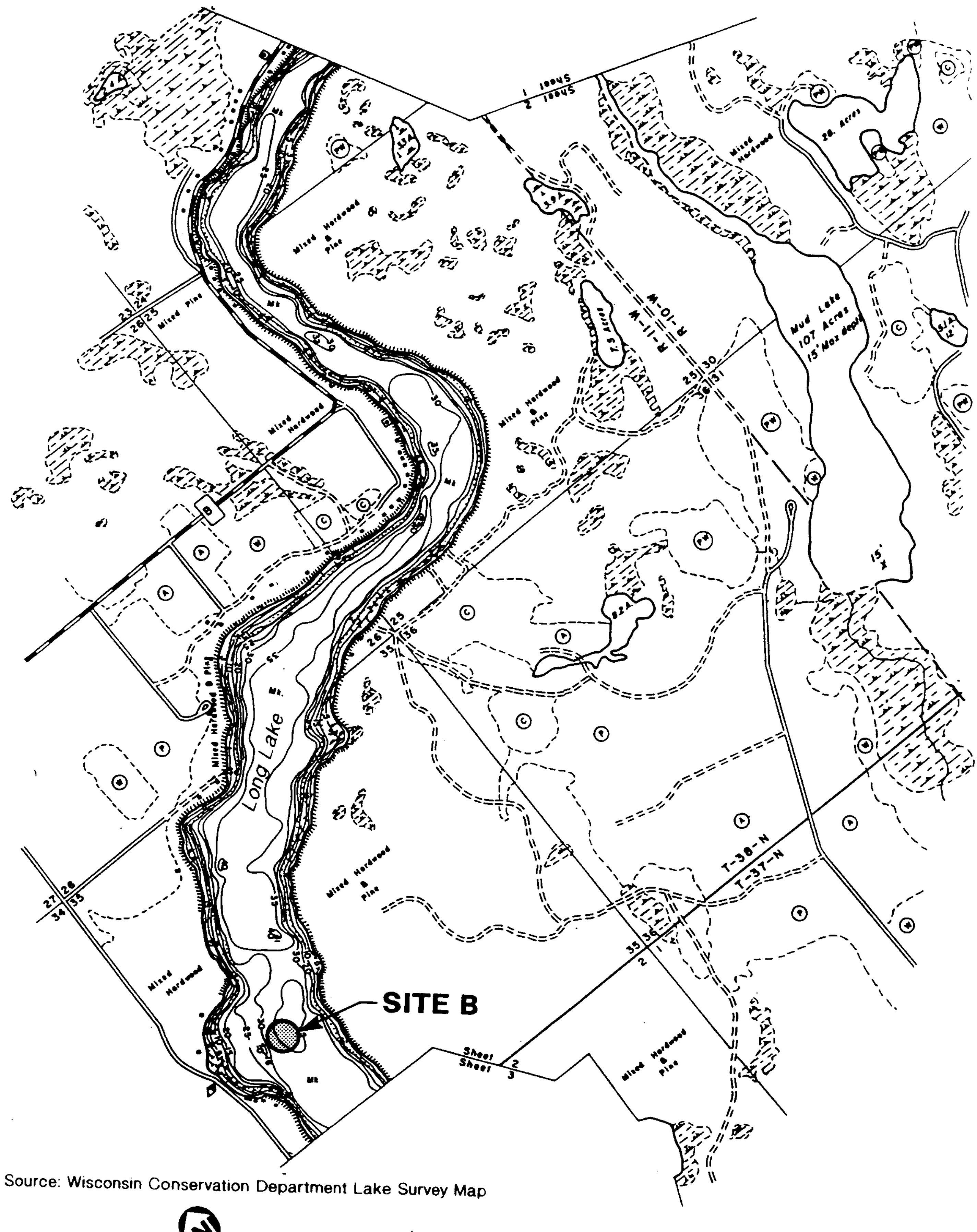
Figure 1
LONG LAKE
SAMPLE LOCATION MAP



Source: Wisconsin Conservation Department
Lake Survey Map

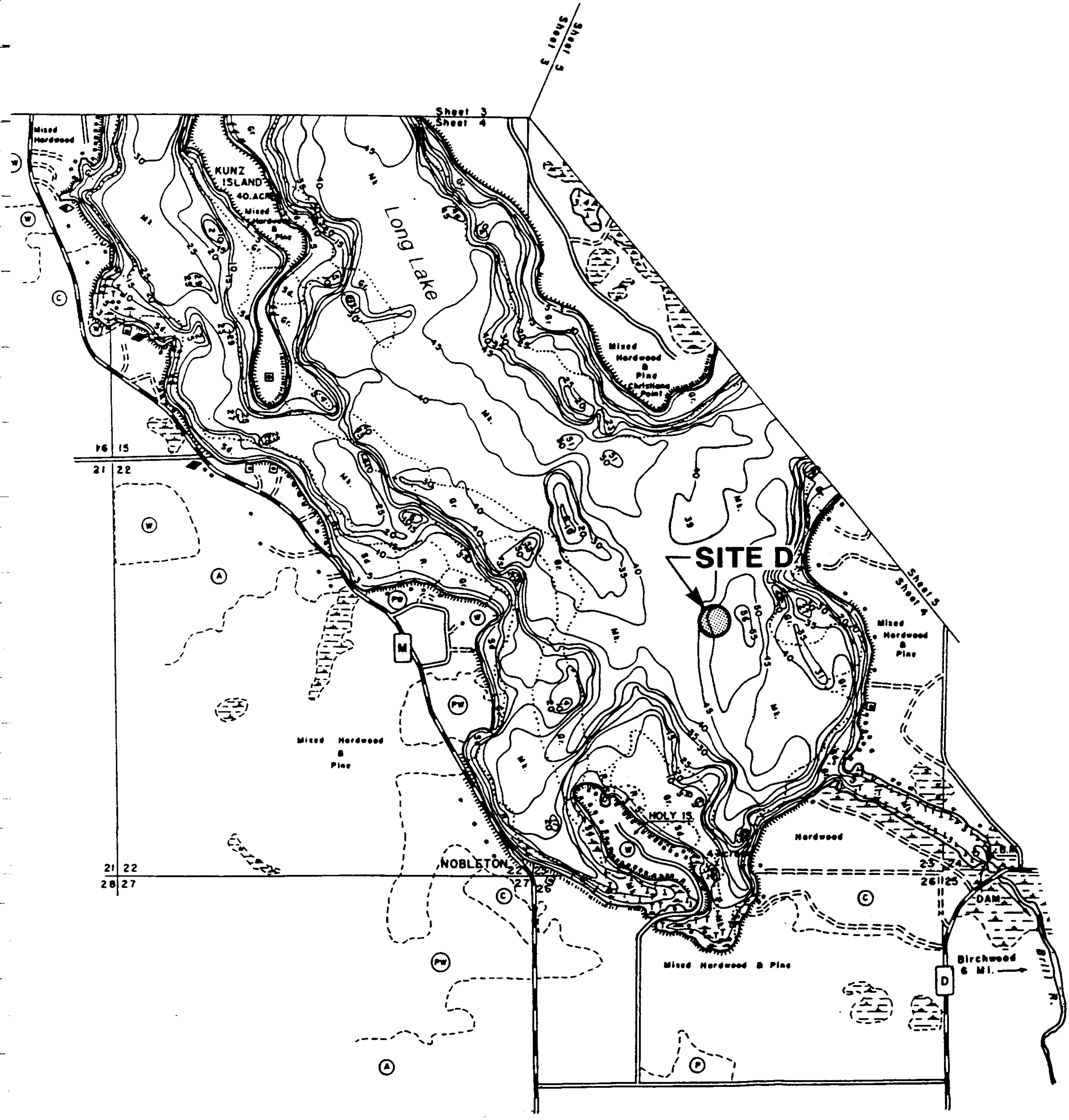
0 1600 3200
Scale in Feet

Figure 2
SITE A LOCATION MAP



Source: Wisconsin Conservation Department Lake Survey Map

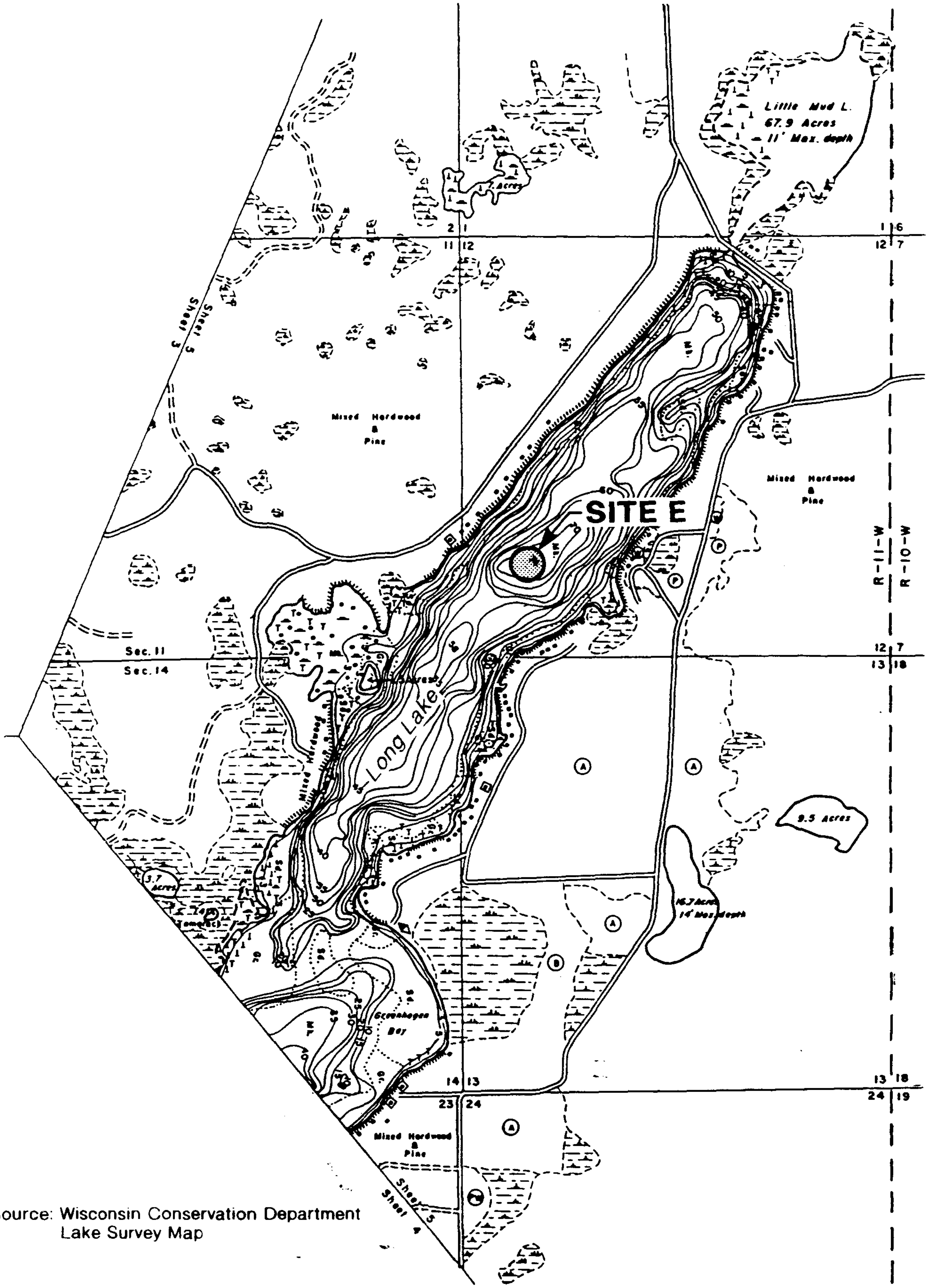
Figure 3
SITE B LOCATION MAP



Source: Wisconsin Conservation Department Lake Survey Map

0 1600 3200
Scale in Feet

Figure 5
SITE D LOCATION MAP



Source: Wisconsin Conservation Department
Lake Survey Map

0 1600 3200
Scale in Feet

Figure 6
SITE E LOCATION MAP

Water temperature, specific conductance, and dissolved oxygen concentrations were determined in each basin on a biweekly basis from ice-out to ice-in. In addition, measurements were made during the early winter (i.e., January of 1995) and the late winter (i.e., March of 1995) period. Measurements were made along a profile at depth intervals of 1 meter. The limits of Secchi disc visibility were measured in each basin on each ice-free sampling date to ascertain water transparency.

Water samples were collected from Long Lake following ice-out and biweekly during the summer (late June through late August). Samples collected on each sample date are shown in Table 1. Samples were collected from 0-2 meters (i.e., integrated composite samples) and analyzed for all parameters shown in Table 1. In addition, total phosphorus samples were collected from above and below the thermocline whenever it existed and from one-half meter above the lake bottom. When no thermocline was noted, one mid-column sample was collected and analyzed for total phosphorous.

Long Lake Macrophyte Survey

A macrophyte (i.e., aquatic weed) survey was completed during late July by Barr Engineering Company with assistance from the LLPA. The purpose of the survey was to determine species composition, abundance, and locations of growth within Long Lake. Figure 7 shows the macrophyte sample locations. The methodology used in the study is based upon Jessen and Lound (1962) and outlined in "Wisconsin's Department of Natural Resources Long-Term Trend Lake Monitoring Methods," (Bureau of Water Resources Management, July 1987). Details of the survey are as follows:

- In advance of the survey, 20 representative transects were chosen to characterize the lake's macrophyte community. Four transects within each of the lake's five basins were selected.

- A Global Positioning System unit was used in the field to determine the latitude and longitude of each transect. Readings were taken at a point on each transect, and a compass bearing was measured.

- Each transect was divided into the following depth categories:
  0 to 1.5 feet
  1.5 to 5.0 feet
  5 to 10 feet (or to the maximum rooting depth).

Table 1. Long Lake Water Quality Parameters Collected on Each Sample Date

Parameter	Ice-Out	Late June	Early July	Late July	Early August	Late August
Secchi Disc	x	x	x	x	x	x
Temperature	x	x	x	x	x	x
Dissolved Oxygen	x	x	x	x	x	x
Specific Conductance	x	x	x	x	x	x
pH	x	--	--	--	--	x
Total Phosphorus	x	x	x	x	x	x
Soluble Reactive Phosphorus	x	x	--	x	--	x
Nitrate & Nitrite Nitrogen	x	x	x	x	--	x
Ammonia Nitrogen	x	x	x	x	--	x
Total Kjeldahl Nitrogen	x	x	x	x	--	x
Alkalinity	x	--	--	--	--	x
Chlorophyll <u>a</u>	x	x	x	x	x	x

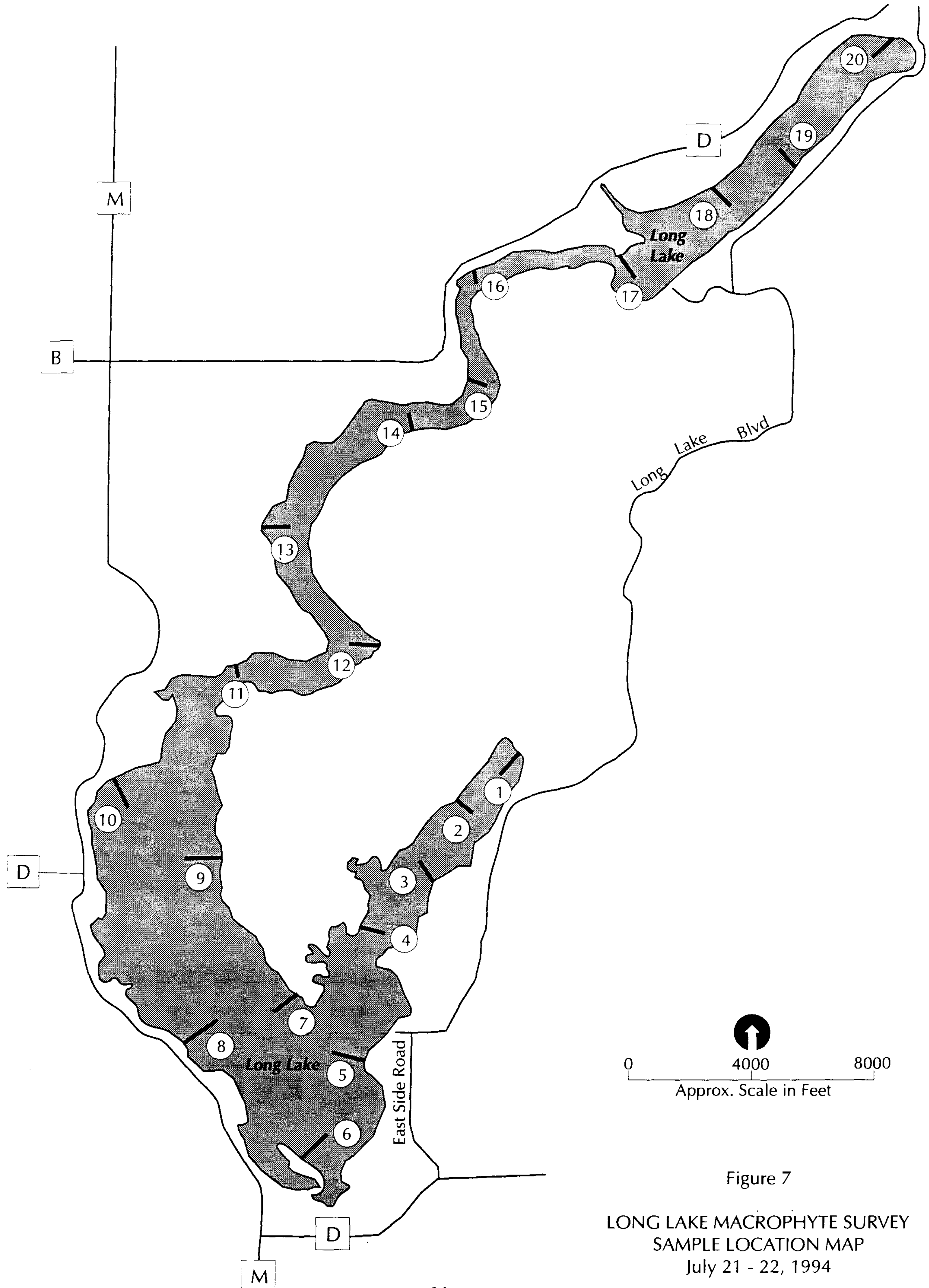


Figure 7

LONG LAKE MACROPHYTE SURVEY
SAMPLE LOCATION MAP
July 21 - 22, 1994

- Four samples were taken at each depth zone to determine the presence and abundance of species. The sample point at each depth zone consisted of a six-foot diameter circle divided into four quadrants. A tethered garden rake with an extended handle (16 feet) was used to collect a sample from each quadrant.

- Collection of samples, identification of species, and determination of density ratings for each species occurred at all sampling points. References used for species identification are shown in Table 2. Density ratings were given in accordance with the following criteria:

Rake Recovery of Species	Density Rating
Rake full on all 4 casts.	5
Rake partly full on all 4 casts.	4
Species present on 3 casts.	3
Species present on 2 casts.	2
Species present on 1 cast.	1

- Maximum rooting depths were observed at all transects.

Collection of Precipitation Data

Precipitation data were collected from two locations shown on Figure 8. Daily rain gage measurements were made during each precipitation event. Measurements were made during the April through November period. The measurements will be used during the Phase II portion of the project to complete the lake's hydrologic budget.

Collection of Lake Level Data

A staff gage was installed and surveyed in on April 21. The gage was read on a daily basis during the period April 21 through November 19. During the Phase II portion of the project, the staff gage readings, together with the rating curve established previously for the dam, will be used to determine daily lake volume changes. This information will be used to complete the hydrologic budget.

Table 2. Long Lake Macrophyte Survey—References Used for Species Identification of Plants.

A Field Guide to the Wetlands of Illinois, 1988. Illinois Department of Conservation. 244 pages.

Carlson, Richard A. and John B. Moyle, 1973. Key to the Common Plants of Minnesota. Minnesota Department of Conservation--Division of Game and Fish--Section of Technical Services, Special Publication No. 53. 64 pages.

Fassett, Norman C., 1940. A Manual of Aquatic Plants. The University of Wisconsin Press. 405 pages.

Gleason, Henry A. and Arthur Cronquist, 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Second Edition. New York Botanical Garden. 910 pages.

Mohlenbrock, Robert H., 1970. The Illustrated Flora of Illinois--Flowering Plants: Flowering Rush to Rushes. Southern Illinois University Press. 272 pages.

Mohlenbrock, Robert H., 1973. The Illustrated Flora of Illinois--Grasses: Panicum to Danthonia.

Mohlenbrock, Robert H., 1981. The Illustrated Flora of Illinois--Flowering Plants: Magnolias to Pitcher Plants. Southern Illinois University Press. 261 pages.

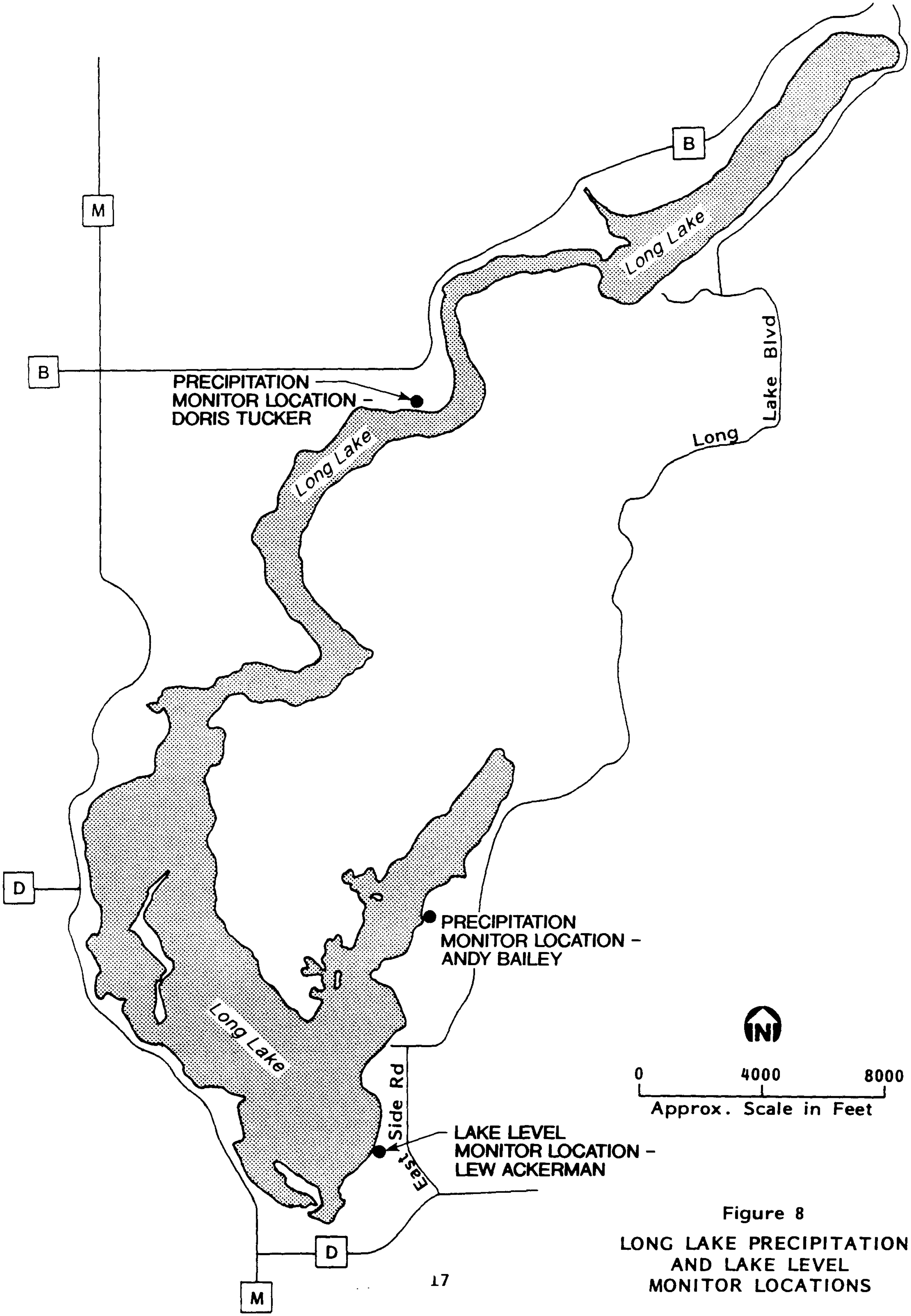


Figure 8

LONG LAKE PRECIPITATION AND LAKE LEVEL MONITOR LOCATIONS

Evaluation of the Tributary Watershed

Evaluation of watershed land use within the Long Lake tributary watershed was completed by the Natural Resource Conservation Service (Spooner Field Office). The evaluation consisted of a determination of watershed land use within each subwatershed. Specifically, acres of cropland, acres of Highly Erodible Land (HEL), and other watershed land use were determined.

Samples were collected from lakes within the Long Lake watershed to help determine average phosphorus concentrations. One lake within each subwatershed was monitored including Big Devil Lake, Harmon Lake, Slim Creek Flowage, Mud Lake, and Little Mud Lake. Sample locations are shown in Figure 9. The frequency of sample collection consisted of once following ice-out and on a monthly basis during the summer period (June through August). All samples were surface dip samples and were analyzed for total phosphorus.

The results of the Long Lake water quality study are presented in the appendices and are discussed in the following sections of this report. The following discussion:

- Presents general concepts used in assessing lake water quality;
- Assesses the existing water quality of Long Lake;
- Examines the historical water quality of Long Lake;
- Considers the water quality of lakes within the Long Lake watershed; and
- Evaluates land use within the tributary watershed.

For the purposes of this report, total phosphorus, chlorophyll a, and Secchi disc transparency have been used as the key water quality indicators.

Water Quality Concepts

Before dealing with the specifics of the water quality in Long Lake, it is useful to consider some general concepts involved in assessing lake water quality. Presented in the sections that follow are brief discussions of topics involved in the study of lakes, including:

- Eutrophication
- Trophic states
- Limiting nutrients
- Structure of lakes and ponds and nutrient recycling

Eutrophication

The water quality problems caused by sediment and nutrients from a lake's watershed are described by the word eutrophication. Eutrophication, or lake degradation, is the process whereby lakes accumulate sediments and nutrients from their watersheds. Over time, a lake naturally becomes more fertile. It is converted from oligotrophic (nutrient poor) to eutrophic (nutrient rich) status as it is progressively enriched by nutrients from its watershed. Nutrients serve as a catalyst for algae and weed growth in a lake. Biological production, aided by sediment inflow from the lake's watershed, eventually fills the lake's basin. Over a period of many years, the lake successively becomes a pond, a marsh and, ultimately, a terrestrial site.

The process of eutrophication is natural and results from the normal environmental forces that influence a lake. Natural eutrophication occurs very slowly. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. This acceleration may result from point-source nutrient loadings, such as effluent from wastewater treatment plants and septic tanks. It may also be caused by diffuse (i.e., non-point) sources of nutrients and sediments, such as stormwater runoff. Nutrients and sediments may be added to the lake via runoff from an agricultural watershed. 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).

The root cause of cultural eutrophication is uncontrolled development within a lake's watershed and/or development without the use of Best Management Practices (BMPs). Either scenario results in water quality degradation in the receiving water body. Development of a lake management plan prior to the development of a lake's watershed may prevent or minimize impacts from cultural eutrophication. It is for this reason that the Long Lake Management plan is being completed to protect the lake's current water quality and prevent or minimize impacts by cultural eutrophication. The Phase I data collection program defines the existing trophic state of the lake, so that its current stage of eutrophication may be known.

Trophic States

Because of varying nutrient status, not all lakes are in the same stage of eutrophication. Therefore, criteria have been established to evaluate lakes, such as Long Lake, to denote their nutrient "status". Four "trophic" descriptions are frequently used to describe the effects of the nutrients on the general water quality and/or trophic conditions of a water body. They are:

1. **Oligotrophic**
2. **Mesotrophic**
3. **Eutrophic**
4. **Hypereutrophic**

Oligotrophic (Greek for "food poor") describes a clear, low productivity lake. **Mesotrophic** describes an intermediate productivity lake which has relatively good water quality. **Eutrophic** (Greek for "food-rich") describes a lake rich in nutrients and having a high productivity. **Hypereutrophic** lakes are extremely high in nutrients and are extremely productive. An oligotrophic or mesotrophic condition in a lake is considered desirable, while a eutrophic or hypereutrophic condition is considered problematic.

The North American Lake Management Society (NALMS, 1988) has used Carlson's Trophic State Index to relate the trophic state of a water body to total phosphorus concentrations, chlorophyll a concentrations, and Secchi disc transparency. Therefore, Carlson's Trophic State Index of a water body may be used to indicate its stage of eutrophication (i.e., degradation). The four trophic status designations used for lakes are listed below with corresponding TSI value ranges.

1. **Oligotrophic -- [20 $\leq$ TSI $\leq$ 38]**
2. **Mesotrophic -- [38 < TSI $\leq$ 50]**
3. **Eutrophic -- [50 < TSI $\leq$ 62]**
4. **Hypereutrophic -- [62 < TSI $\leq$ 80]**

During 1994, the average Long Lake TSI value was 47. Therefore, the lake has a trophic status designation of mesotrophic.

The Limiting Nutrient

The determination of the eutrophication stage of a lake (i.e., its stage of degradation) is an important aspect of assessing its current condition. Eutrophication indicates the level of algal growth and whether or not this level of growth interferes with its recreational goals. However, it does not indicate the cause of algal growth, or a means of reducing such growth if it is considered problematic.

The quantity or biomass of algae in a lake or pond is usually limited by the water's concentration of an essential element or nutrient - the "limiting nutrient". (Rooted aquatic plants, in contrast, derive most of their nutrients from lake or pond sediments.) The limiting nutrient concept is a widely applied principle in the study of eutrophication. It is based on the idea that, in considering all of the substances needed for biological growth, only one will be present in limited quantity. The availability of this limiting nutrient will, therefore, control the rate of algal growth. It follows then, that the identification of a lake's limiting nutrient will point the way toward a management strategy to control 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 that can indicate whether one or the other of these elements is growth-limiting. By comparing the tissue concentrations of important nutrients in algae to the concentrations of the same nutrients in the ambient waters, 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. During 1994, Long Lake had an average summer N:P ratio of 22. Therefore, phosphorus was the limiting nutrient in Long Lake. It has been amply demonstrated in experiments ranging from laboratory bioassays to fertilization of in-situ enclosures to whole-lake experiments, that phosphorus is generally the nutrient that limits algal growth. Algal abundance is nearly always phosphorus-dependent. A reduction in the phosphorus concentration in a lake is therefore necessary in order 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. Phosphorus limitation also indicates that prevention of additional phosphorus loading to the lake will be necessary to protect its current water quality.

Structure of Lakes and Ponds and Nutrient Recycling

The determination of a lake's limiting nutrient is but the first step in the process of formulating a lake management strategy. Because phosphorus enters lakes and ponds from internal and/or external sources, it is necessary to determine the source of the current load. Once the source of phosphorus loading is determined, management efforts to avoid increases may be formulated. An understanding of the depth-temperature patterns, or "structure" of a lake helps one determine whether the source of phosphorus loading is primarily from external sources, internal sources, or a combination of both. Nutrient recycling from bottom sediments results in internal loading, while runoff from the tributary watershed results in external loading. Details regarding lake structure and nutrient recycling follow.

In any water body, certain physical phenomena occur that can profoundly influence its chemistry and biology. Probably the most important of these phenomena is "thermal stratification". Because the density of water decreases as it warms, warmer water tends to rise to the surface. As a result, lakes and ponds in temperate regions tend to form temperature layers, or "stratify", when they are exposed to the heat of the sun.

When the ice melts in the spring, the water temperature in a lake is usually around 4°C (~39°F) from top to bottom. At this temperature, water is most dense (heaviest). During the spring and summer months, the sun warms the surface layer of the lake causing it to become warmer and less dense (lighter). The warm surface layer of the lake is called the epilimnion. In shallow portions of a lake, the sun's rays are often able to reach the lake's bottom in most places. During the summer, the water temperature in these portions (which are usually near the shore, or in the "littoral zone") may be warm throughout.

The deeper portion of lakes typically have a thermal/density structure that differs from the shallow regions. Because sunlight does not reach the bottom of the deeper portions of the lake, these waters remain cool and more dense. Therefore, the warmer, lighter water lays near the surface and the cooler, heavier water stays at the bottom of the lake.

The cooler, deeper water layer of the lake is called the **hypolimnion**, and the warm surface zone is known as the **epilimnion**. Between the warm epilimnion and the cool hypolimnion is a transitional layer of water known as the **metalimnion**. This layer of the lake is characterized by a rapidly-declining temperature.

The significance of thermal stratification in lakes is that the density change in the metalimnion provides a physical barrier to mixing between the epilimnion and the hypolimnion. While water above the metalimnion may circulate as a result of wind action, hypolimnetic waters at the bottom generally remain isolated. Consequently, very little transfer of oxygen occurs from the atmosphere to the hypolimnion during the summer.

If the lake or pond sediments are rich in organic matter, microbial decomposition and respiration can deplete hypolimnetic waters of their dissolved oxygen. Phosphorus contained in the sediment may then be released into the water column as a result of changes in the oxidation-reduction (REDOX) potential of the system caused by oxygen depletion. Later, this phosphorus will contribute to the growth of algae in surface waters when the thermal stratification of the lake breaks down and the lake or pond mixes.

Shallow water bodies (generally less than 10 feet in depth) may circulate many times during the summer as a result of wind mixing. In contrast, the deeper parts of lakes generally become well-mixed only twice each year. This usually occurs in the spring and fall. During these periods, the lack of strong temperature/density differences allow wind-driven circulation to mix the water column throughout. During these mixing events, oxygen may be transported to the deeper portions of the lake, while dissolved phosphorus is brought up to the surface.

Recycling of nutrients from anoxic (devoid of oxygen) sediments to the surface waters of a lake or pond is most often a problem in highly-fertile water bodies. These eutrophic lakes are subject to hypolimnetic oxygen depletion during periods of stratification, with consequent recycling of phosphorus from the lake's sediments during mixing.

Temperature and dissolved oxygen data from Long Lake provide information relative to thermal stratification and the role of nutrient recycling in the lake's phosphorus load. The information indicates whether lake management efforts should focus exclusively on the tributary watershed, or should include control of internal loading.

Having this background material on the study of lakes, one is better able to consider the results of the 1994 study of Long Lake.

1994 Long Lake Water Quality

Data collected from Long Lake during 1994 indicate its water quality is excellent and is similar to the water quality noted in previous years. The water quality data are presented in Appendices A through E and are discussed in the following sections:

- Total Phosphorus
- Chlorophyll a
- Secchi Disc Transparency
- Temperature and Dissolved Oxygen Isopleths
- Phytoplankton
- Zooplankton
- Macrophyte (Aquatic Weed) Survey

Total Phosphorus

As discussed previously, total phosphorus is the nutrient limiting algal growth within Long Lake. As such, it indicates the lake's potential for algal growth, and is a good indication of the lake's level of eutrophication. Total phosphorus data collected from Long Lake during 1994 indicate the lake would have a designated trophic status of mesotrophic. This means the lake is receiving a moderate level of phosphorus loading and its water quality is excellent. Average summer epilimnetic total phosphorus concentrations from all five sample locations within Long Lake were within the mesotrophic category (See Figure 10). In addition, nearly all individual sample points from these locations were within the mesotrophic category (See Figure 11). Exceptions occurred during the late summer when concentrations at Stations C, D, and E were within the eutrophic category. These data indicate that judicious management of the lake's watershed is essential to preserving the lake's current mesotrophic trophic status.

Long Lake total phosphorus data collected at depths indicate phosphorus recycling from bottom sediments occurs during the summer months. These data, however, suggest that thermal stratification retains the recycled nutrients in the bottom waters until the fall overturn. Therefore, these nutrients are prevented from mixing with epilimnetic surface waters during the summer period. Consequently, algal concentrations during the summer months appear to be due to phosphorus loading from the lake's tributary watershed. Thus, Long Lake management efforts should focus on control of external phosphorus loading (i.e., from the watershed) rather than internal loading.

Chlorophyll a

Chlorophyll a data collected from Long Lake indicate the lake's trophic status ranges from mesotrophic to mildly eutrophic. Chlorophyll a is a pigment found within algae. Its measurement indicates the quantity of algae found within a lake, and provides a measure of a lake's level of eutrophication. Average summer chlorophyll a values from Stations B, C, and D were within the eutrophic category, while the average summer value from Station A was borderline mesotrophic/eutrophic (See Figure 12). Station E noted an average summer value within the mesotrophic category (Figure 12). These data indicate algal yield from the lake's phosphorus concentration is slightly higher than expected. As indicated previously, average phosphorus concentrations were entirely within the mesotrophic category.

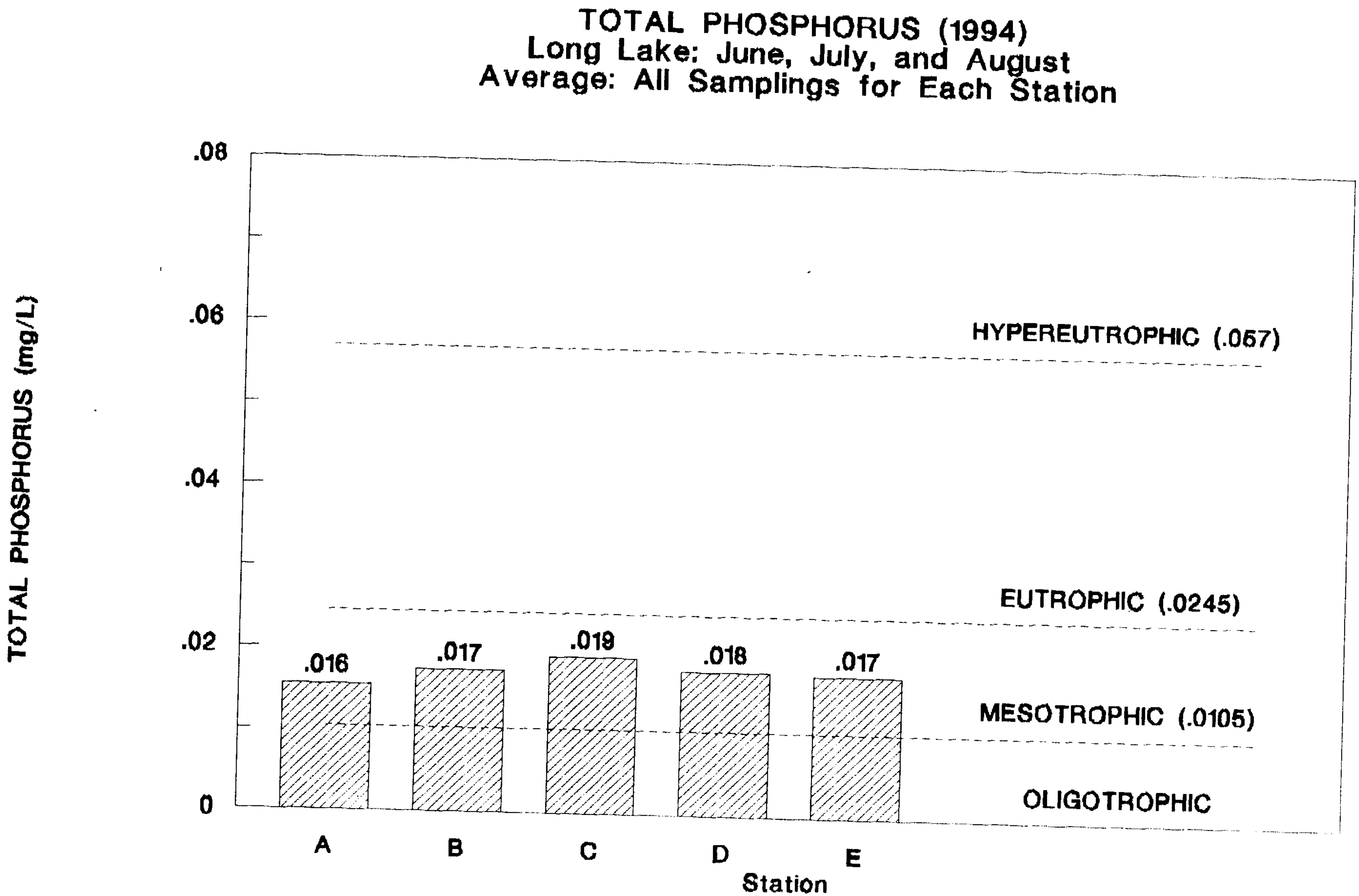

TOTAL PHOSPHORUS (1994)
Long Lake: June, July, and August
Average: All Samplings for Each Station
TOTAL PHOSPHORUS (mg/L)
.08
.06
.04
.02
0
HYPEREUTROPHIC (.057)
EUTROPHIC (.0245)
MESOTROPHIC (.0105)
OLIGOTROPHIC
.016
.017
.019
.018
.017
A
B
C
D
E
Station

Figure 10

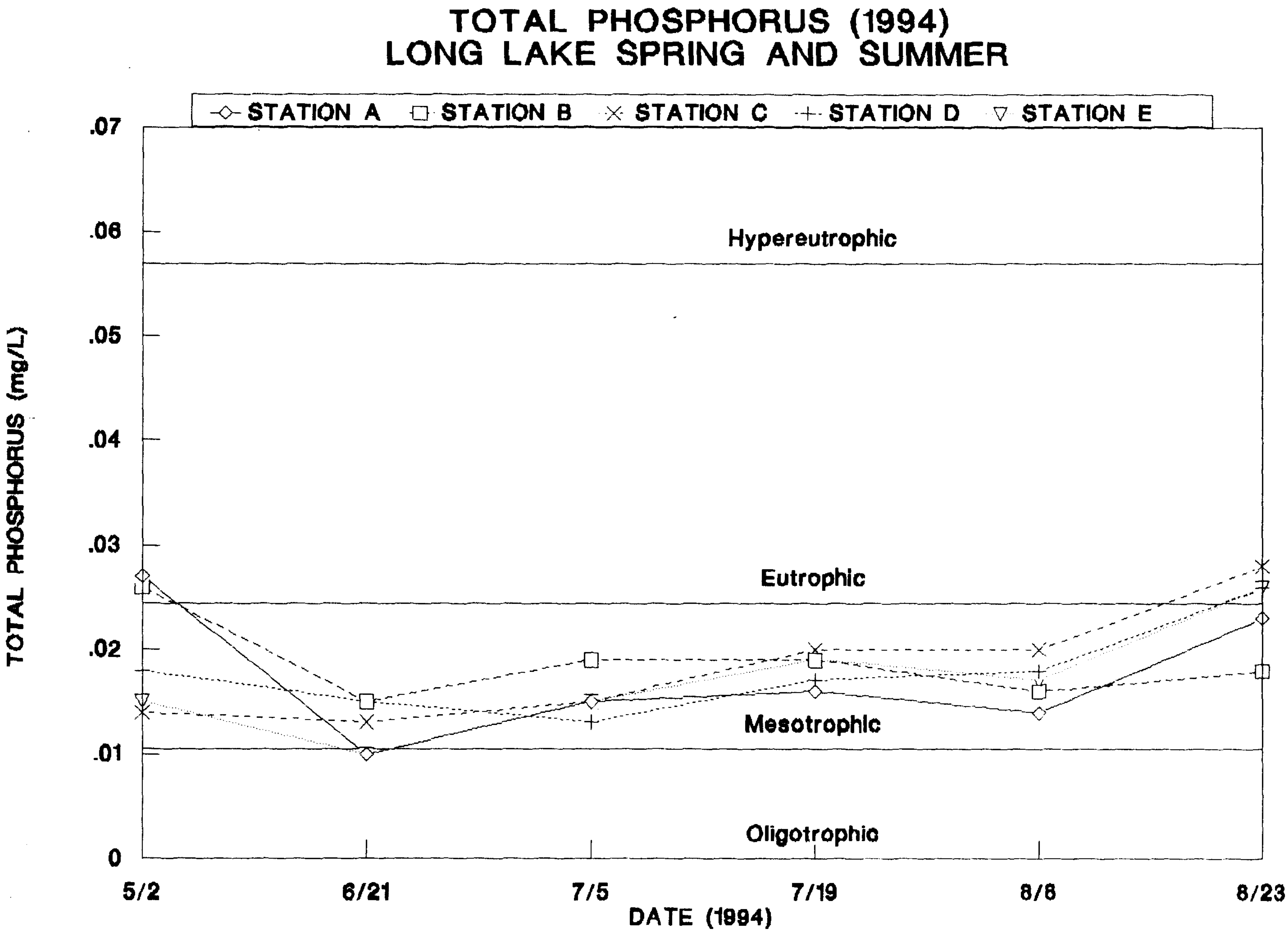

TOTAL PHOSPHORUS (1994)
LONG LAKE SPRING AND SUMMER
STATION A
STATION B
STATION C
STATION D
STATION E
TOTAL PHOSPHORUS (mg/L)
.07
.06
.05
.04
.03
.02
.01
0
Hypereutrophic
Eutrophic
Mesotrophic
Oligotrophic
5/2
6/21
7/5
7/19
8/6
8/23
DATE (1994)

Figure 11

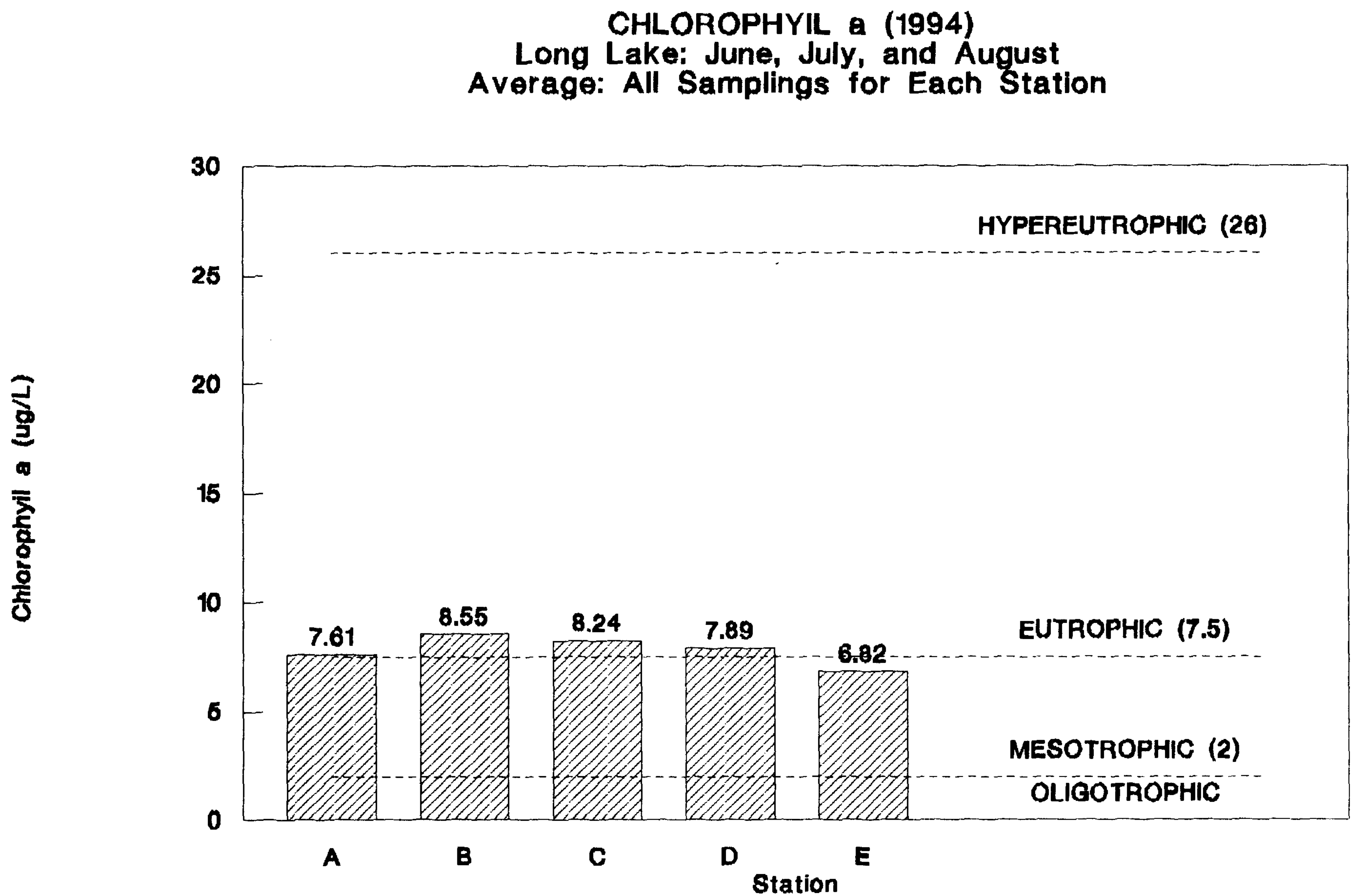

CHLOROPHYIL a (1994)
Long Lake: June, July, and August
Average: All Samplings for Each Station
Chlorophyil a (ug/L)
30
25
20
15
10
5
0
HYPEREUTROPHIC (26)
EUTROPHIC (7.5)
MESOTROPHIC (2)
OLIGOTROPHIC
7.61
8.55
8.24
7.89
6.82
A
B
C
D
E
Station

Figure 12

Algal populations increased throughout the summer at all Long Lake sample locations. Chlorophyll a values at all locations were within the mesotrophic category during the early summer and were within the eutrophic category during the late summer (Figure 13). Differences in the rate of increase of chlorophyll a values were noted at the individual sample locations. In general, stations at the northern end of the lake increased more rapidly than stations at the southern end of the lake (Figure 13).

Chlorophyll a data corroborate the phosphorus data and support the need for a management plan to prevent additional increases in the lake's algal population. The lake's current chlorophyll a concentrations are not considered problematic. However, the mildly eutrophic trophic status indicates that additional increases would likely result in problematic conditions during the summer period.

Secchi Disc Transparency

Long Lake noted excellent water transparency throughout the 1994 summer period. Secchi disc transparency provides a measure of a lake's water clarity. Because increasing eutrophication is associated with decreasing water clarity, Secchi disc measurements can provide an indication of a lake's level of eutrophication. The 1994 Long Lake average summer Secchi disc transparency values were all within the mesotrophic category (Figure 14). The mesotrophic conditions occurred despite algal growth which was higher than expected from the lake's phosphorus concentrations. Algal species differ in their impact on a lake's transparency. Consequently, a lake's transparency is sometimes better and sometimes worse than expected from its chlorophyll concentrations. In 1994, Long Lake exhibited better transparency than expected from its chlorophyll concentrations. Its summer average transparency was entirely within the mesotrophic category, while summer average chlorophyll values ranged from mesotrophic to eutrophic.

1994 water transparency measurements from Long Lake indicate the lake was suitable for all types of recreational activities throughout the summer. Individual transparency values, with few exceptions, were within the mesotrophic category (Figure 15). Most locations, however, noted at least one value within the mildly eutrophic category during the late summer period. The data indicate the lake currently has excellent water transparency, but also indicate the importance of lake management to prevent additional increases in the lake's algal population, particularly during the late summer period.

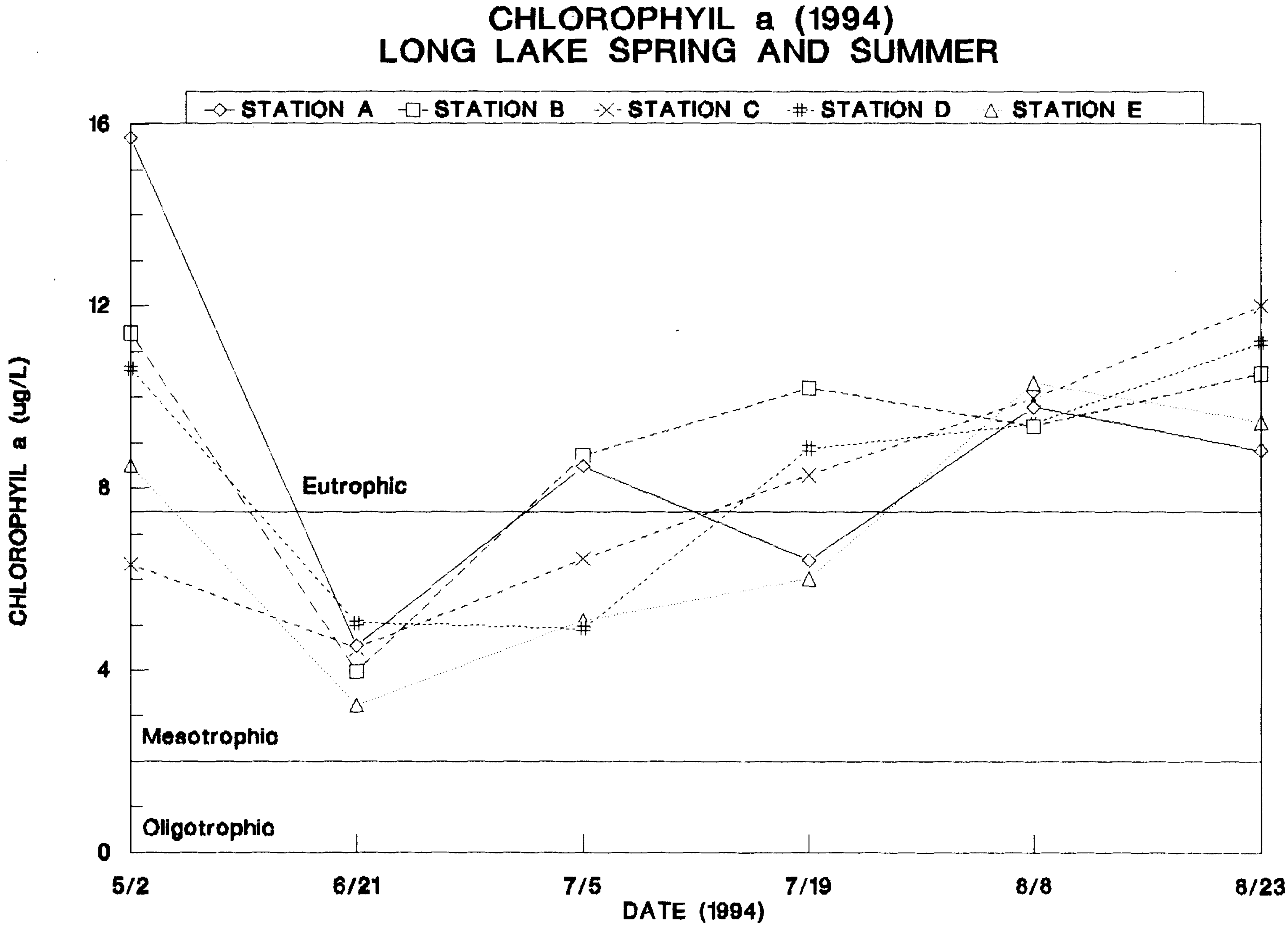

CHLOROPHYIL a (1994)
LONG LAKE SPRING AND SUMMER
STATION A
STATION B
STATION C
STATION D
STATION E
CHLOROPHYIL a (ug/L)
16
12
8
4
0
Eutrophic
Mesotrophic
Oligotrophic
5/2
6/21
7/5
7/19
8/8
8/23
DATE (1994)

Figure 13

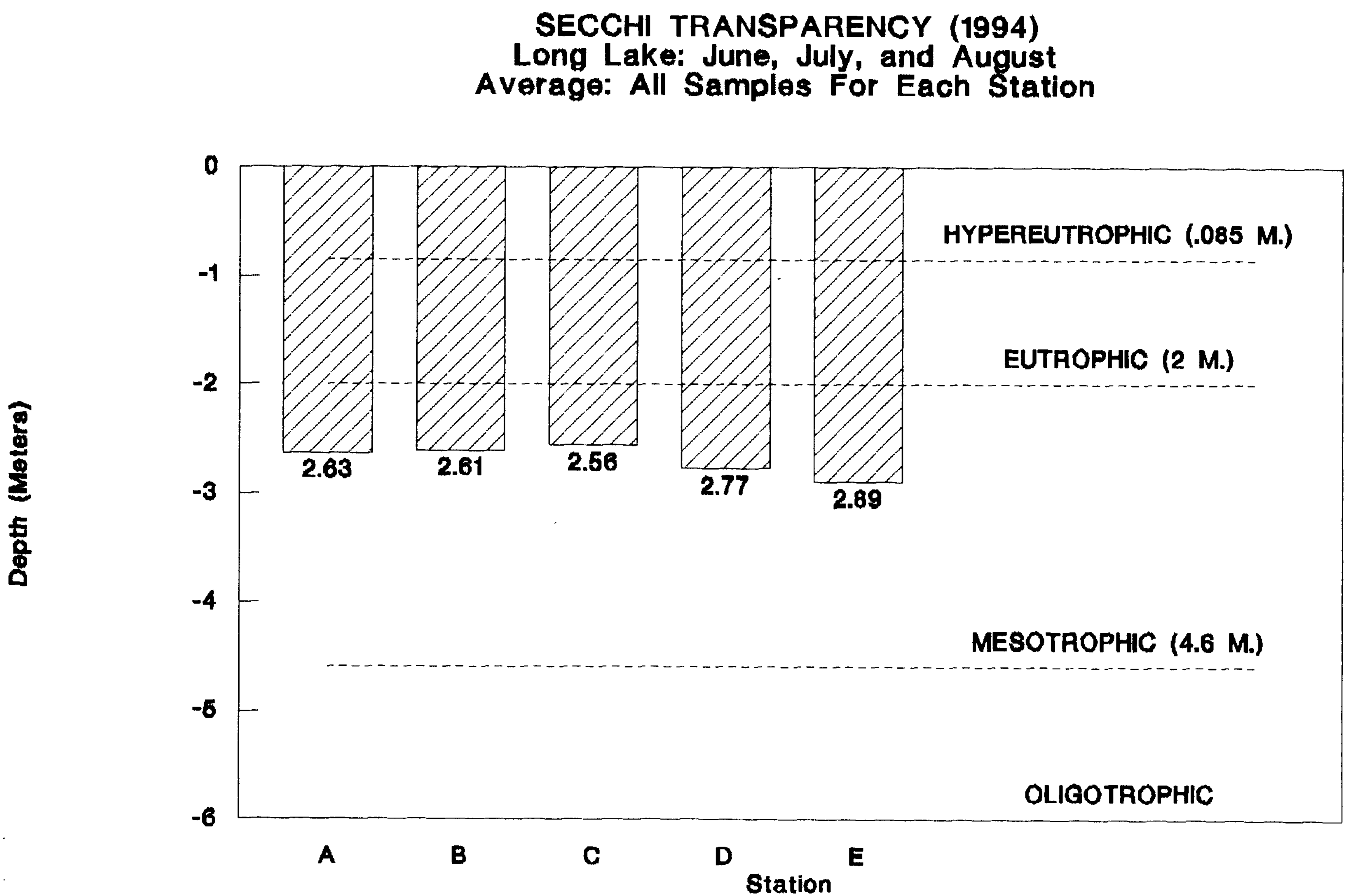

SECCHI TRANSPARENCY (1994)
Long Lake: June, July, and August
Average: All Samples For Each Station
Depth (Meters)
0
-1
-2
-3
-4
-5
-6
HYPEREUTROPHIC (.085 M.)
EUTROPHIC (2 M.)
MESOTROPHIC (4.6 M.)
OLIGOTROPHIC
2.63
2.61
2.56
2.77
2.89
A
B
C
D
E
Station

Figure 14

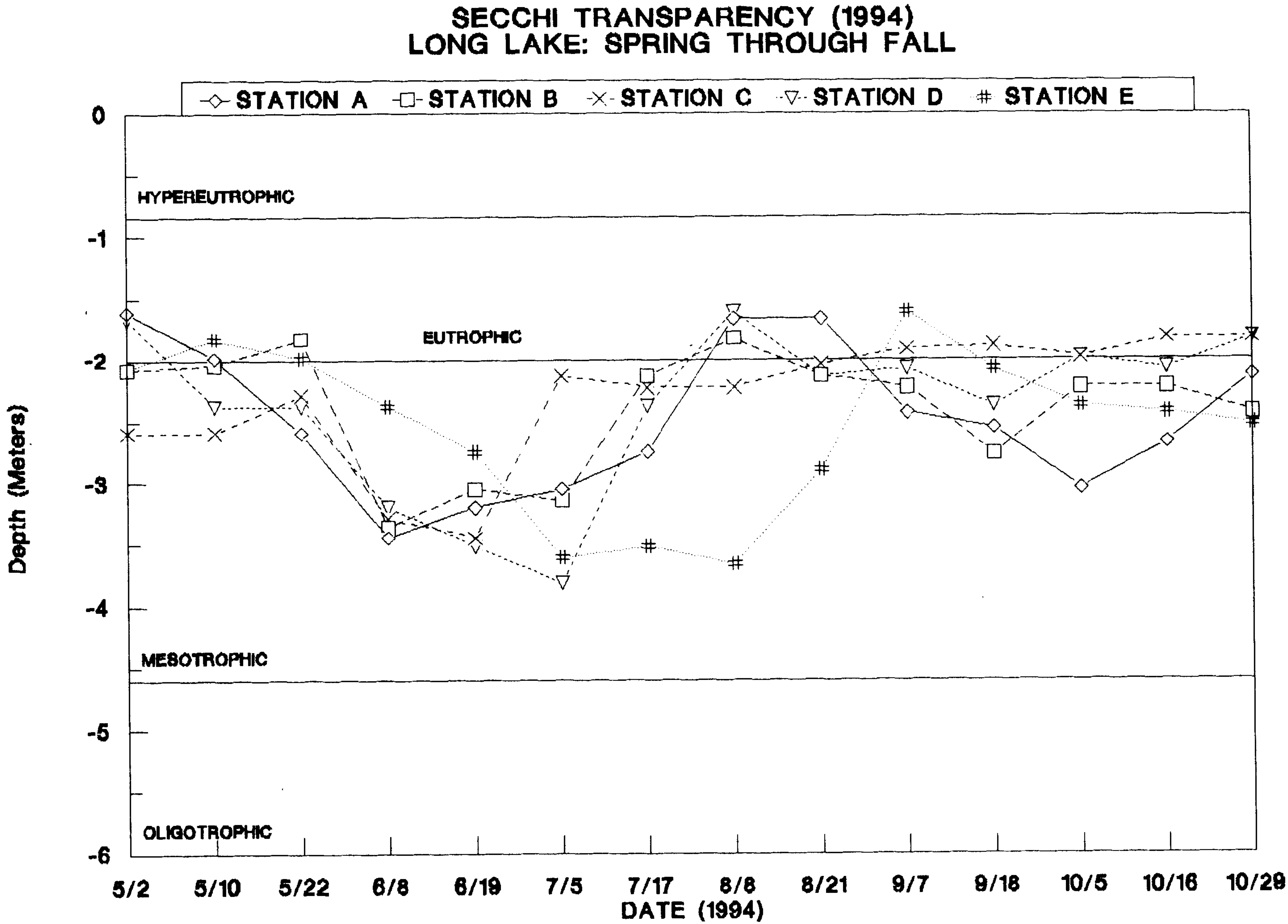

SECCHI TRANSPARENCY (1994)
LONG LAKE: SPRING THROUGH FALL
STATION A
STATION B
STATION C
STATION D
STATION E
0
-1
-2
-3
-4
-5
-6
HYPEREUTROPHIC
EUTROPHIC
MESOTROPHIC
OLIGOTROPHIC
Depth (Meters)
5/2
5/10
5/22
6/8
6/19
7/5
7/17
8/8
8/21
9/7
9/18
10/5
10/16
10/29
DATE (1994)

Figure 15

Temperature and Dissolved Oxygen Isopleths

Depth/time relationships or isopleths were used to determine the stratification (mixing) pattern at each Long Lake sample site (i.e., temperature isopleths) and to assess the loss of oxygen near the lake bottom (i.e., oxygen isopleths). Temperature isopleths indicate Long Lake became thermally stratified following spring overturn and remained stratified until the fall overturn (Figure 16). The density difference between the warm surface waters and the cold bottom waters caused the hypolimnion (bottom waters) to be "sealed-off" from the atmosphere by the epilimnion (surface waters). The oxygen in the hypolimnion (bottom waters) was not replenished by wind and wave action as occurred in the epilimnetic (surface) waters. Instead it was depleted by decomposition of organic matter. The dissolved oxygen isopleths indicated that extremely low dissolved oxygen concentrations were noted in the hypolimnion (bottom waters) at all sampling locations during the summer period (Figure 17).

Oxygen depletions in the bottom waters of Long Lake affect its fishery, and result in the release of phosphorus from its lake sediments. The lake's thermal stratification, however, "seals off" the phosphorus rich bottom waters from the epilimnion (surface waters) until the fall overturn period. Therefore, phosphorus recycled from bottom sediments does not contribute to algal growth during the summer months. Hence, epilimnetic phosphorus concentrations during the summer period appear to be due to phosphorus loading from the lake's watershed rather than an internal load.

Phytoplankton (Algae)

The phytoplankton species in Long Lake form the base of the lake's food web and directly impact the lake's fish production. Phytoplankton, also called algae, are small aquatic plants naturally present in all lakes. They derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. They provide food for several types of animals, including zooplankton, which are in turn eaten by fish. A phytoplankton population in balance with the lake's zooplankton population is ideal for fish production. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, can interfere with the recreational usage of a lake and is considered problematic.

Protection of the current water quality of Long Lake will also protect the current phytoplankton community from changes which would adversely impact the lake's ecosystem. Most of the algal species found in Long Lake during 1994 are edible by zooplankton and are considered desirable food for the aquatic animals within the lake's ecosystem. The abundance and speciation of phytoplankton were determined monthly from June through August for all Long Lake sampling locations. The data are found in Appendices A through E and the results of the analyses of these data are found in Figure 18. The lake's phytoplankton population consisted of a diverse assemblage representing green algae, blue-green algae, golden-brown algae, diatoms, cryptomonads, and dinoflagellates. The community was dominated by *Chlamydomonas globosa* (a green alga) and/or *Cryptomonas erosa* (a cryptomonad) during the early summer. During the late summer, dominance by *Lyngbya limnetica* (a blue-green alga) and *Cryptomonas erosa* (a cryptomonad) was noted. The numbers of algal cells increased throughout the summer period, thus, corroborating the chlorophyll a data. With the exception of the blue-green species, the Long Lake phytoplankton community provides food for the aquatic community and is a vital link in the lake's fishery. Protection of the existing community will protect the lake's fishery and prevent the formation of noxious surface blooms, which interfere with recreational usage of the lake.

Phosphorus load increases to Long Lake could, potentially, shift the phytoplankton community to an undesirable dominance by blue-green algae. Such a shift would have an adverse impact on the lake's ecosystem and its recreational usage. Blue-green algae are referred to as nuisance algae because they:

- are generally inedible to fish, waterfowl, and most zooplankters;
- float at the lake surface in expansive algal blooms;
- may be toxic to animals when occurring in large blooms;
- and since they are most likely to be present during the summer months, they can disrupt lake recreation.

Blue-green algal growth is often stimulated by excess phosphorus loads. The growing conditions during July and August are favorable to blue-greens, and they have a competitive advantage over the other algal species during this time. The presence of blue-green algae in Long Lake throughout the summer, and the dominance by the blue-green alga *Lyngbya limnetica* at some locations in the late summer point to the importance of judicious management to prevent phosphorus load increases to the Long Lake. Excess phosphorus loads to Long Lake could result in nuisance blue-green algal blooms. Current levels of blue-green algae are not considered

1994 LONG LAKE PHYTOPLANKTON ANALYSIS

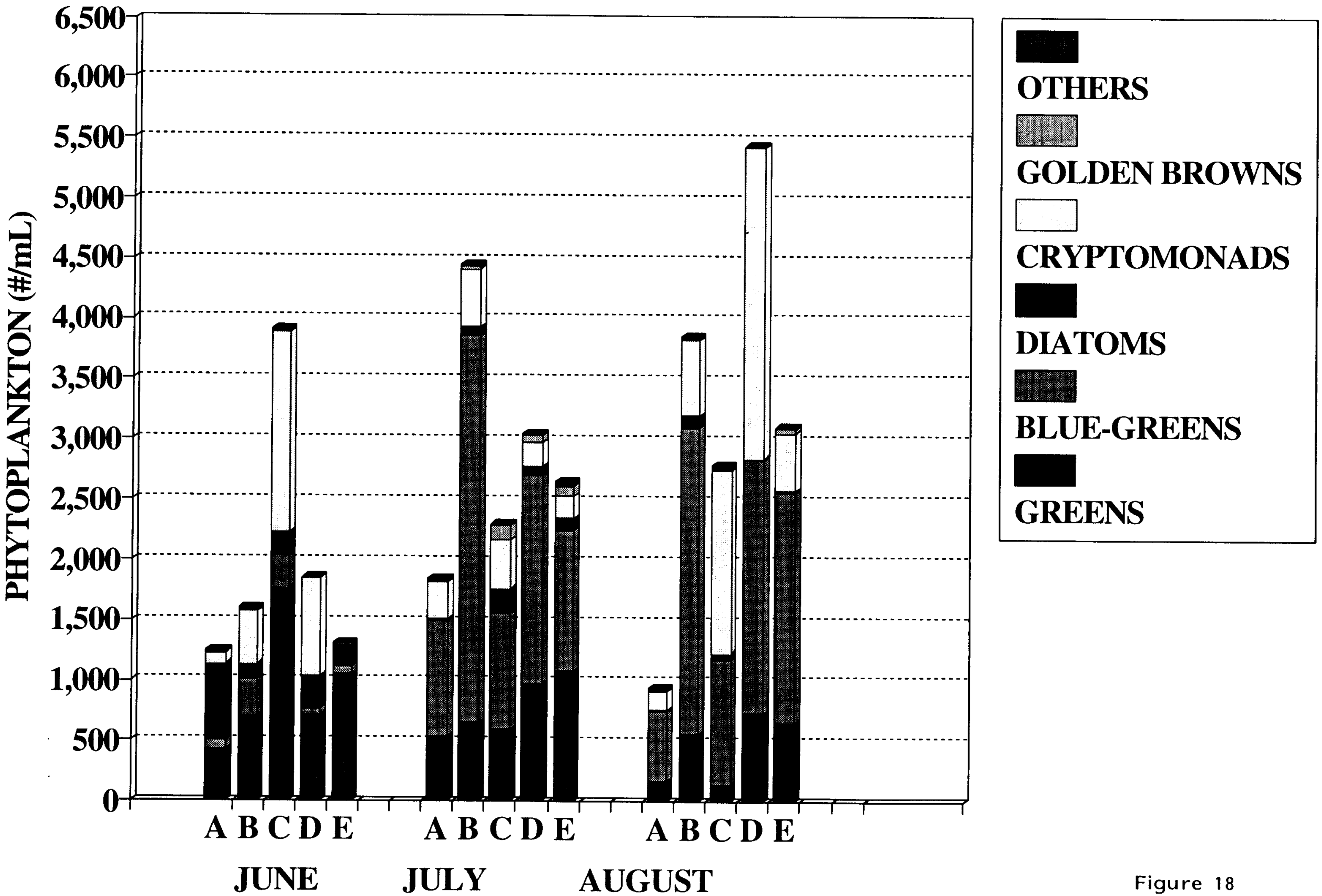


Figure 18

1994 LONG LAKE ZOOPLANKTON ANALYSIS

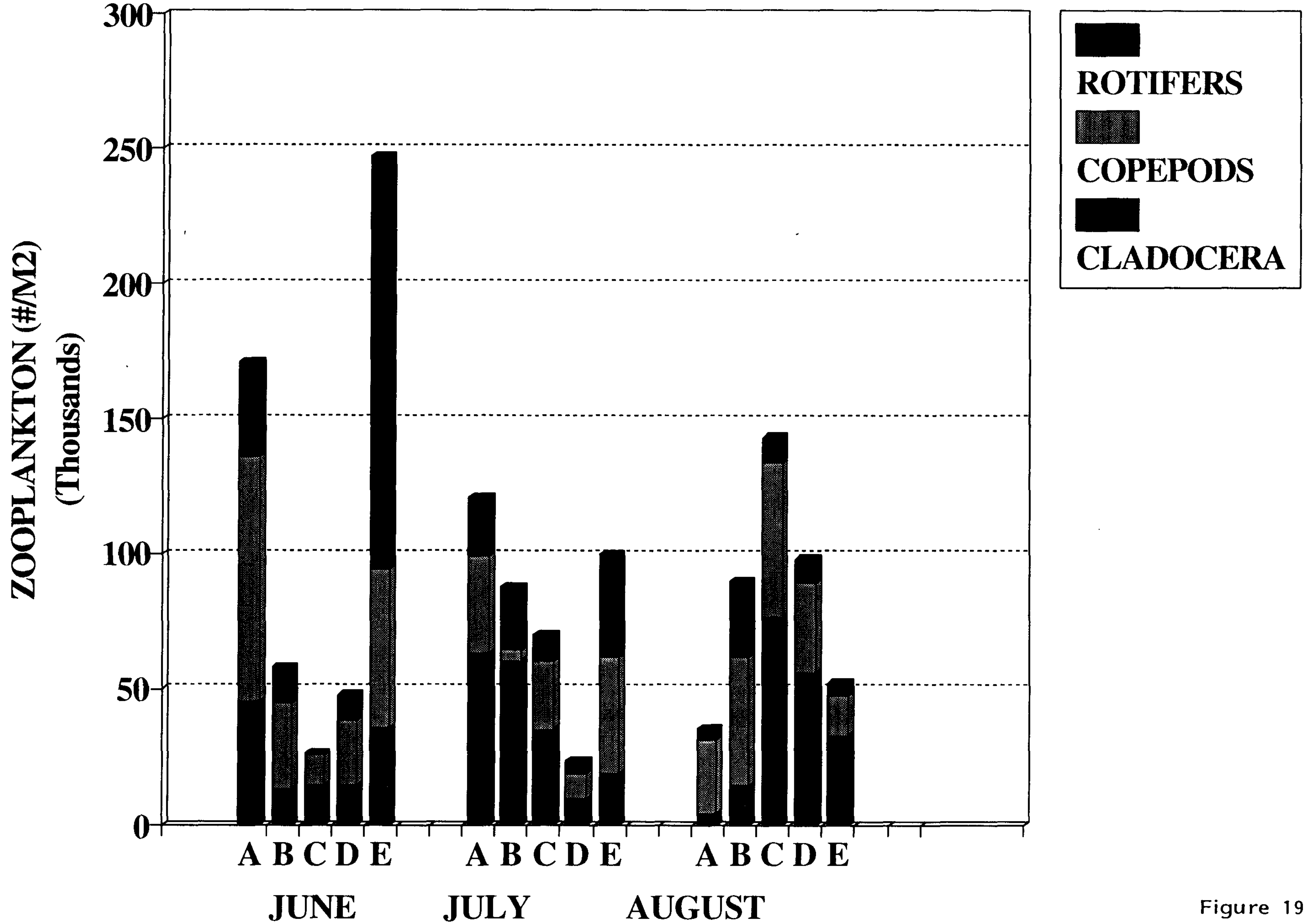


Figure 19

problematic, however. The phytoplankton data corroborate the total phosphorus, chlorophyll a, and Secchi disc data and suggest the lake currently has excellent water quality.

Zooplankton

Zooplankton are the second step in the Long Lake food web, and are considered vital to its fishery. They are microscopic aquatic animals which feed on particulate plant matter, including algae, and are in turn eaten by fish. Protection of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The abundance and speciation of zooplankton were determined monthly from June through August for all Long Lake sampling locations. The data are presented in Appendices A through E and the results of the analyses are shown in Figure 19. Three types of zooplankton were found in Long Lake-rotifers, cladocera, and copepods. Temporal and spatial fluctuations in cladocera, copepoda, and rotifer populations were noted, and there was no consistent dominance by any one group.

The zooplankton community in Long Lake provides food for the lake's fishery, but has little predatory impact on the lake's algal community. This is mainly due to the low numbers and small sizes of cladocera present in the lake. The rotifers and copepods in Long Lake graze primarily on extremely small particles of plant matter, and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae. If present in abundance, large cladocera can decrease the number of algae and improve water transparency within a lake. The abundance of large cladocera in Long Lake is dependant on their ability to escape predation by predatory fish. Planktivorous fish such as sunfish and perch feed readily on large cladocera. Escape from predation, however, is dependent upon the presence of a "refuge" within the lake. A refuge is the deepest spot in a lake away from sunlight with sufficient oxygen for the cladocera to live. During the day, cladocera will typically hide from fish in the "refuge," if one is available to them. At night when darkness makes it difficult for fish to prey upon cladocera, they rise to the lake surface to feed on algae. The low numbers and small sizes of cladocera in Long Lake suggests its refuge affords inadequate protection from predation.

Dissolved oxygen isopleths (Figure 20) provide confirming evidence that the lake's zooplankton refuge during 1994 was unable to afford protection from predatory fish. When a lake's refuge thins to a meter or less, its protection to cladocera is inadequate. The deep waters of Long Lake were anoxic (devoid of oxygen) for most of the summer of 1994. Therefore, the cladocera had little refuge from predatory fish, and were easily preyed upon.

The zooplankton data further support the need to develop a Lake Management Plan to protect the current water quality of Long Lake and to protect the lake's zooplankton community. The lake's algal population, and hence its water quality, appears to be determined by phosphorus loading from the lake's tributary watershed. Little predatory impact from the lake's zooplankton community currently occurs. Control of phosphorus loading from the lake's watershed is, therefore, essential to the preservation of the lake's current water quality. In addition, however, lake management efforts should also strive to protect the lake's zooplankton community from further reduction. Additional degradation of the lake's water quality would cause additional oxygen depletion of the lake's bottom waters. Consequently, additional thinning or complete disappearance of the lake's zooplankton refuge would occur resulting in a further reduction of their population. Preservation of the existing balance between the algal, zooplankton, and fish communities is an important aspect of the lake's management.

Macrophyte (Aquatic Weed) Survey

Aquatic plants are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. In lakes, life depends—directly or indirectly—on water plants. They are the primary producers in the aquatic food chain, converting the basic chemical nutrients in the water and soil into plant matter, which becomes food for all other aquatic life.

Within a lake, pond, or impoundment, aquatic plants grow in the area known as the littoral zone—the shallow transition zone between dry land and the open water area of the lake. The littoral zone extends from the shore to a depth of about 15 feet, depending on the depth of light penetration. Turbid or colored water, which limits light penetration, may restrict plant growth. In lakes where water clarity is low all summer, aquatic plants will not grow throughout the littoral zone, but will be restricted to the shallow areas near shore.

Other physical factors also influence the distribution of plants within a lake or pond. For example, aquatic plants generally thrive in shallow, calm water protected from heavy wind, wave, or ice action. However, if the littoral area is exposed to the frequent pounding of waves, plants may be scarce. In a windy location, the bottom may be sand, gravel, or large boulders—none of which provides a good place for plants to take root. In areas where a stream or river enters a lake, plant growth can be variable. Nutrients carried by the stream may enrich the sediments and promote plant growth; or, suspended sediments may cloud the water and inhibit growth.

Aquatic plants are grouped into four major categories:

- **Algae**—These plants have no true roots, stems, or leaves and range in size from tiny, one-celled organisms to large, multi-celled plant-like organisms, such as *Chara*. Phytoplankton (planktonic algae), which consist of free-floating microscopic plants, grow throughout both the littoral zone and the well-lit surface waters of an entire lake. Other forms of algae, including *Chara* and some stringy filamentous types (such as *Cladophora*, are common only in the littoral area.

- **Submersed**—These plants have stems and leaves that grow entirely underwater, although some may also have floating leaves. Flowers and seeds on short stems that extend above the water may also be present. Submersed plants grow from near shore to the deepest part of the littoral zone and display a wide range of plant shapes. Depending on the species, they may form a low-growing "meadow" near the lake bottom, grow with lots of open space between plant stems, or form dense stands or surface mats.

- **Floating-leaf**—These plants are often rooted in the lake bottom, but their leaves and flowers float on the water surface. Water lilies are a well-known example. Floating leaf plants typically grow in protected areas where there is little wave action.

- **Emergent**—These plants are rooted in the lake bottom, but their leaves and stems extend out of the water. Cattails, bulrushes, and other emergent plants typically grow in wetlands and along the shore, where the water is less than 4 feet deep.

Long Lake (Figures 21 to 25) contains a diverse assemblage of macrophytes. Fifteen species were noted during the 1994 survey. Diversity, rather than dominance by any one species, characterizes the lake's macrophyte community. The most frequently occurring species were *Potamogeton zosteriformis* (Flat stem pondweed) and *Ceratophyllum demersum* (Coontail). In general, macrophyte growth did not occur at depths less than 3 feet or at depths greater than 14 feet. Growth generally occurred at a moderate density. No protected species or endangered species were noted in Long Lake.

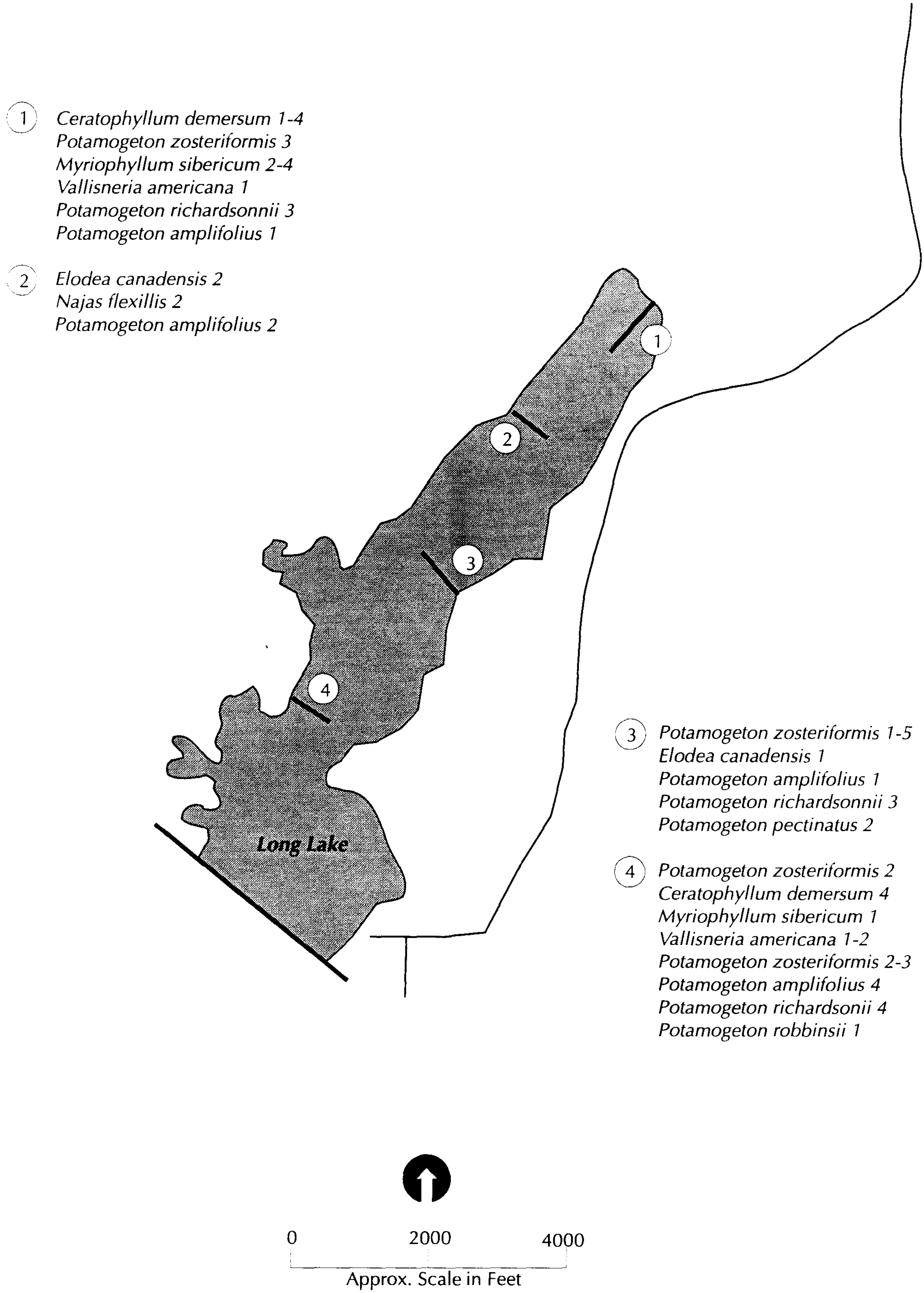


Figure 21

LONG LAKE MACROPHYTE SURVEY - SITE E
July 21 - 22, 1994

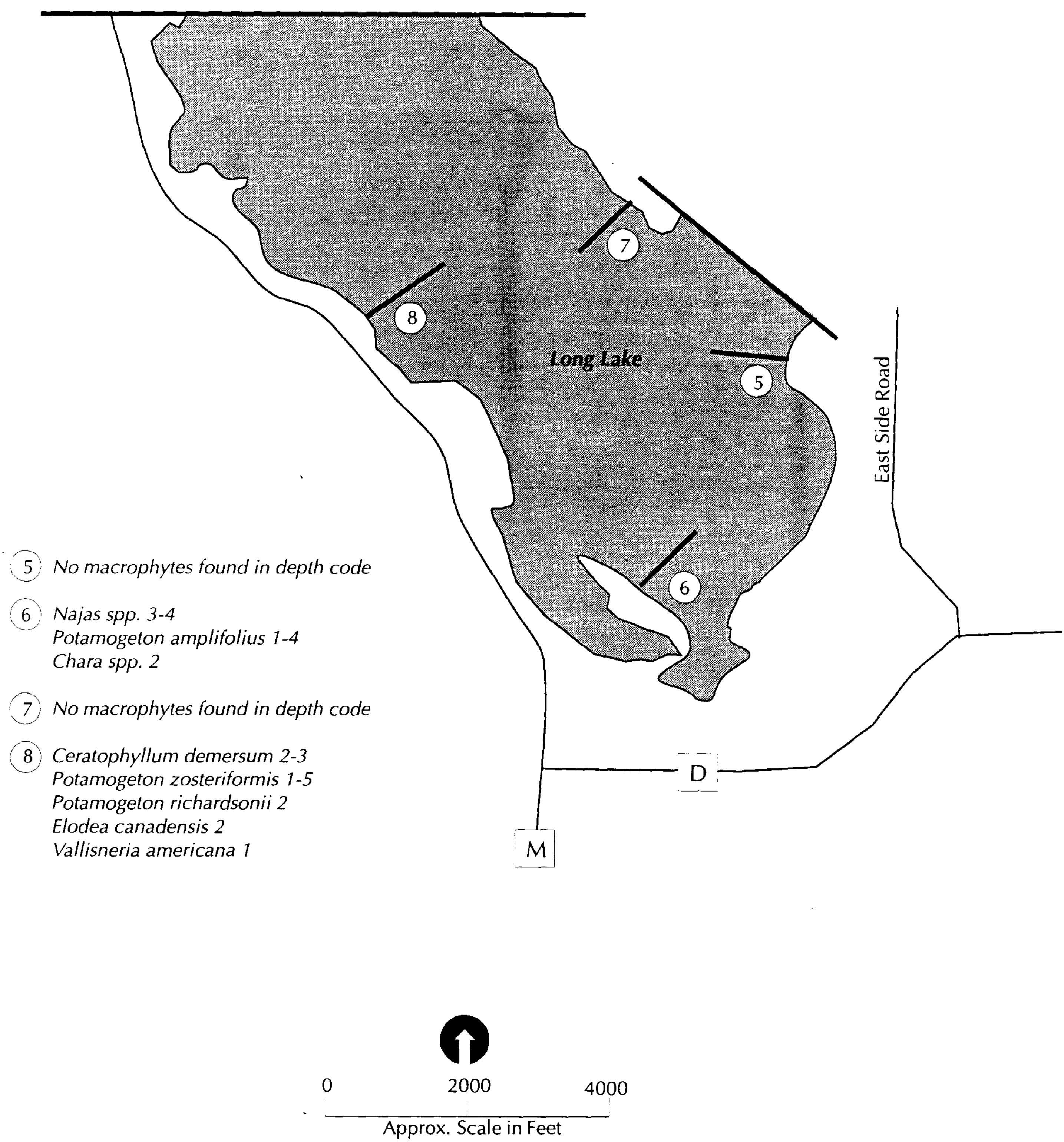
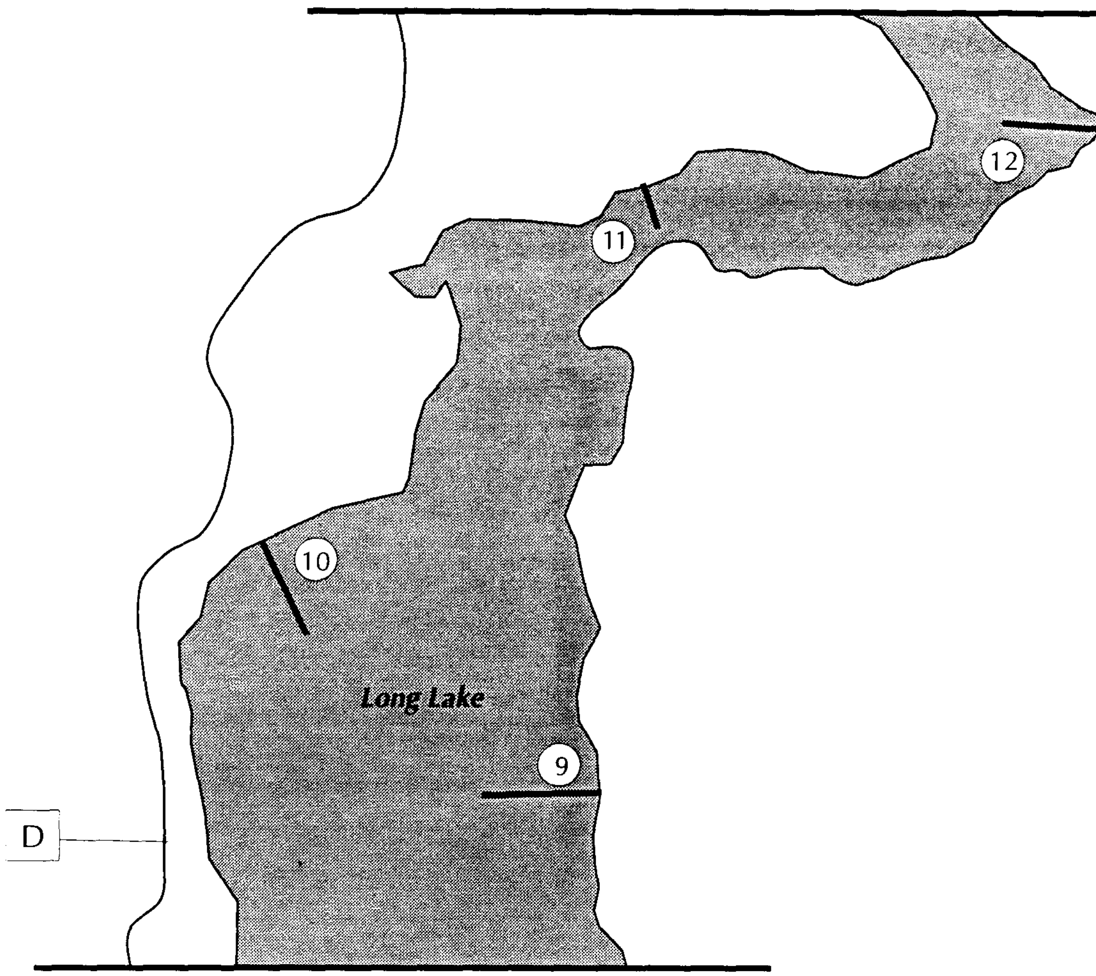


Figure 22

LONG LAKE MACROPHYTE SURVEY - SITE D
July 21 - 22, 1994



(9) *Ceratophyllum demersum 1-2*
Elodea canadensis 1
Potamogeton zosteriformis 1
Potamogeton amplifolius 4
Potamogeton pectinatus 1
Chara spp. 2
Myriophyllum sibericum 3

(10) *Potamogeton amplifolius 2-3*
Potamogeton zosteriformis 3
Ceratophyllum demersum 1
Najas spp. 1-2
Potamogeton crispus 1
Myriophyllum sibericum 1

(11) *Ceratophyllum demersum 1-2*
Chara spp. 2
Potamogeton zosteriformis 3
Elodea canadensis 2-3
Myriophyllum sibericum 2
Heteranthera dubia 1
Vallisneria americana 2
Potamogeton natans 1

(12) *Ceratophyllum demersum 4*
Potamogeton zosteriformis 2
Elodea canadensis 2-4
Myriophyllum sibericum 1
Potamogeton zosteriformis 2
Potamogeton amplifolius 1
Ceratophyllum demersum 4

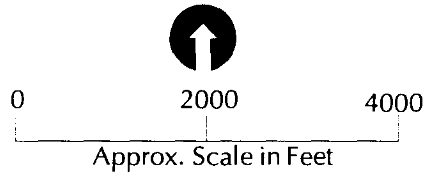
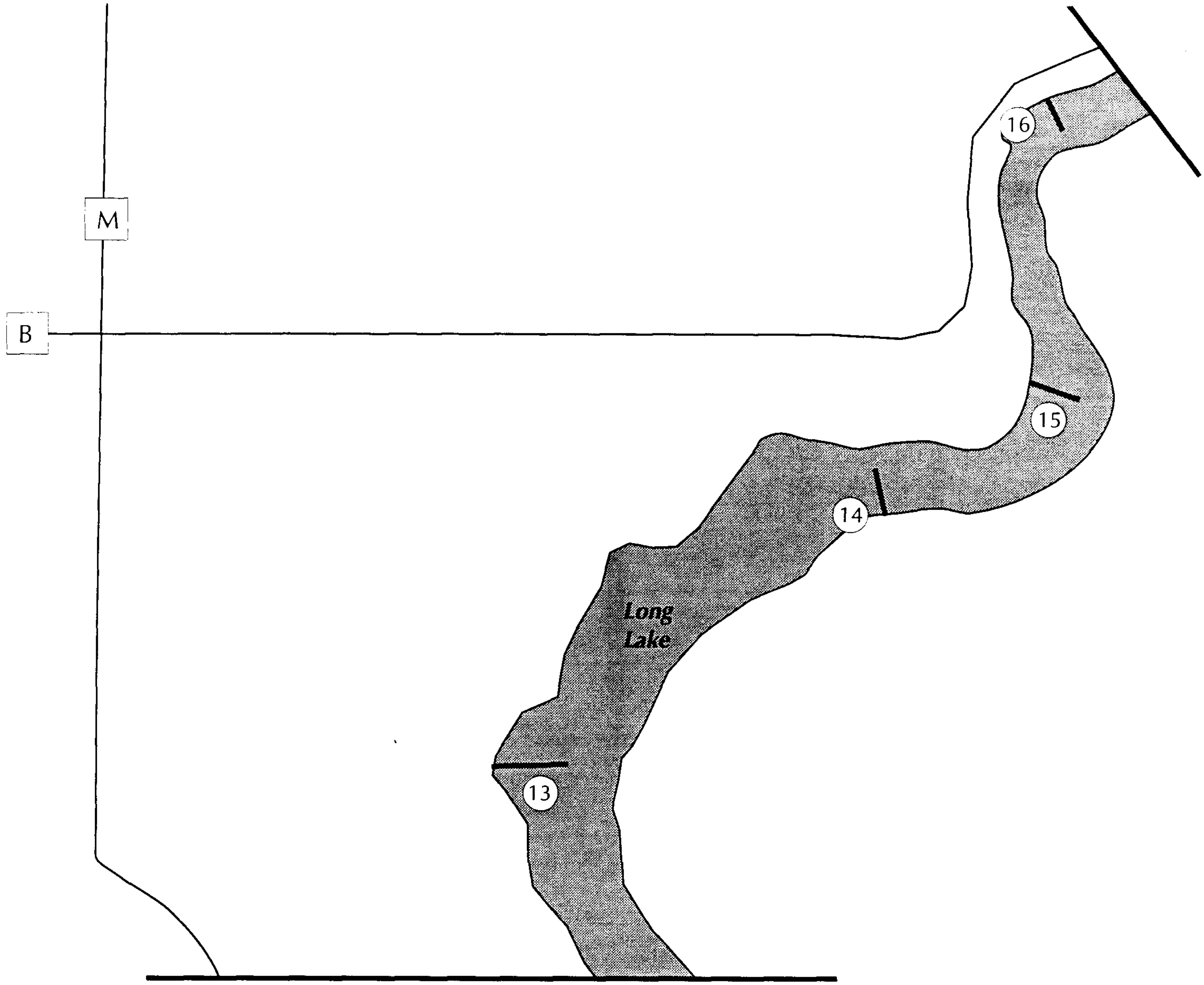


Figure 23

LONG LAKE MACROPHYTE SURVEY - SITE C
July 21 - 22, 1994



(13) *Potamogeton zosteriformis 2-5*
Vallisneria americana 2
Potamogeton richardsonii 4
Ceratophyllum demersum 1
Potamogeton richardsonii 4

(14) *Potamogeton zosteriformis 2-4*
Ceratophyllum demersum 2-4
Myriophyllum sibericum 2
Potamogeton zosteriformis 3

(15) *Najas spp. 4*
Potamogeton zosteriformis 2
Chara spp. 1
Ceratophyllum demersum 2
Najas spp. 2
Chara spp. 3
Potamogeton zosteriformis 2
Potamogeton illinoensis 4

(16) *Vallisneria americana 1*
Potamogeton zosteriformis 3-4
Najas spp. 1-2
Potamogeton robbinsii 2

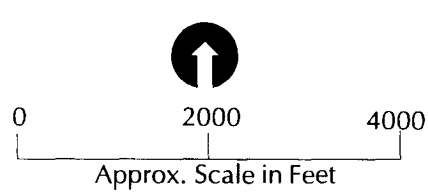
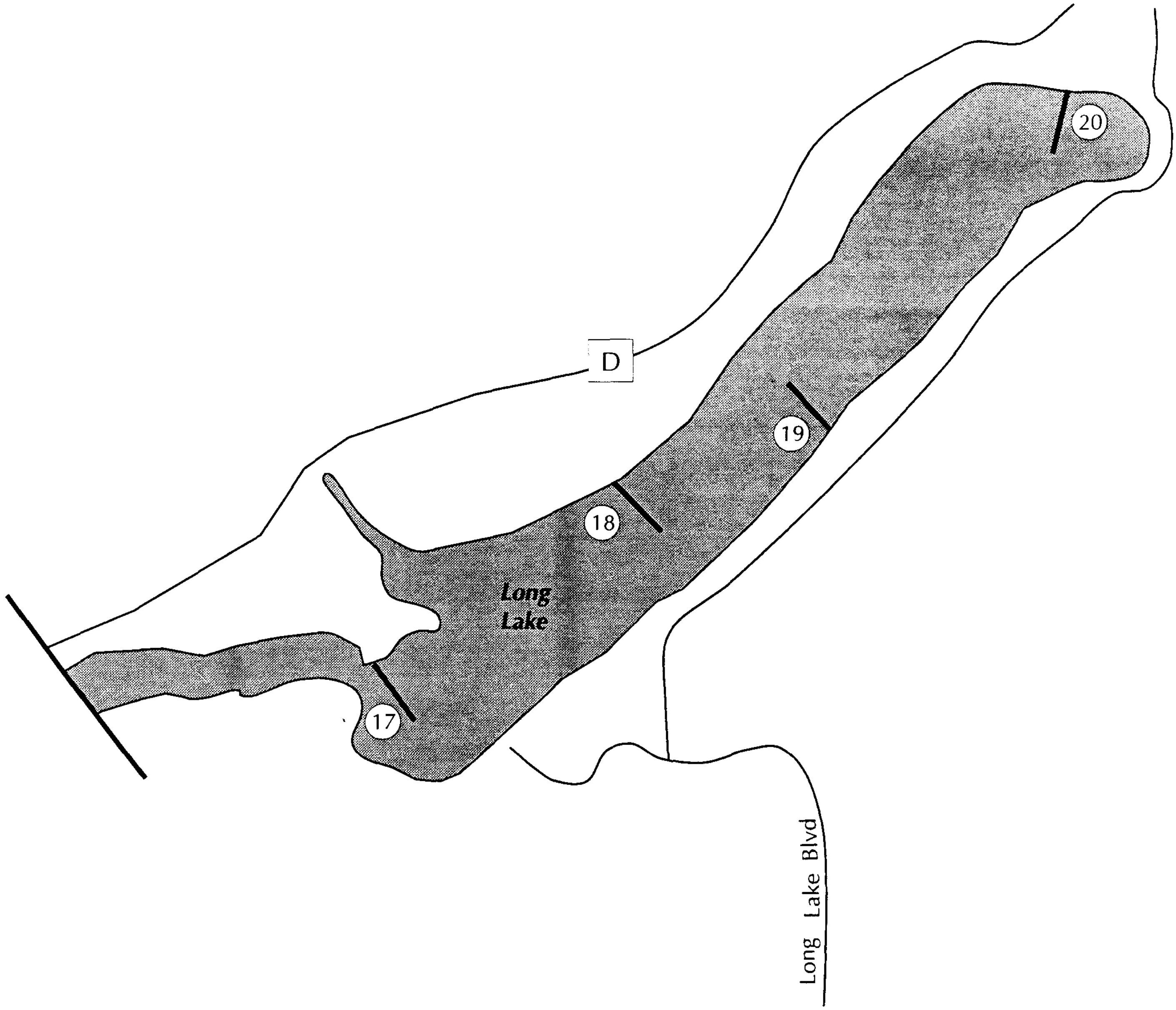


Figure 24

LONG LAKE MACROPHYTE SURVEY - SITE B
July 21 - 22, 1994



17 *Potamogeton zosteriformis 3-4*
Ceratophyllum demersum 2-3
Chara spp. 1-4
Potamogeton richardsonii 1-2
Potamogeton pectinatus 1

18 *Ceratophyllum demersum 2-3*
Potamogeton zosteriformis 1-4
Potamogeton amplifolius 2
Potamogeton richardsonii 3
Potamogeton amplifolius 2
Vallisneria americana 1

19 *Potamogeton zosteriformis 2-4*
Heteranthera dubia 2
Chara spp. 2
Potamogeton richardsonnii 2
Najas spp. 1

20 *Potamogeton zosteriformis 3*
Ceratophyllum demersum 4
Potamogeton richardsonii 1-2
Ceratophyllum demersum 4
Potamogeton pectinatus 2-4

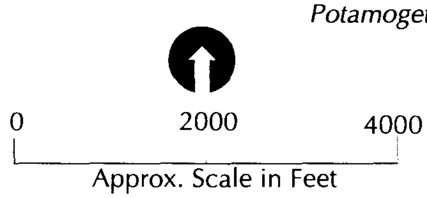


Figure 25

LONG LAKE MACROPHYTE SURVEY - SITE A
July 21 - 22, 1994

The moderate macrophyte density observed in Long Lake is consistent with its water hardness, lake type, and location. The lake is a hardwater lake. Soils in Washburn County tend to be alkaline, and area lakes generally have hard water. Hard water promotes macrophyte growth, and hard water lakes tend to have denser growths than soft water lakes (Engel, WDNR, Personal Communication). However, lakes in Washburn County typically have a moderate macrophyte density rather than the high density growths observed in southern Wisconsin lakes. From a standing crop perspective, lakes in Washburn County generally have a standing crop plant mass less than 100 grams per square meter. This differs from southern Wisconsin lakes, such as Lake Mendota, that have a standing crop plant mass ranging from 250 to 400 grams per square meter (Engel, WDNR, personal communication).

The Long Lake macrophyte community performs a number of valuable functions. Table 3 summarizes the functions performed by individual species noted in the lake. These include:

- habitat for fish, insects, and small aquatic invertebrates;
- food for waterfowl, fish, and wildlife;
- oxygen producers;
- provide spawning areas for fish, early spring;
- helps stabilize marshy borders of lakes and ponds; helps protect shorelines from wave erosion; and
- provides nesting sites for waterfowl and marsh birds.

Macrophytes in Long Lake consisted primarily of native species. Only one undesirable exotic species, *Potamogeton crispus*, was noted. It was found in only one sampling point and had a density of 1 (the lowest measurable density). This plant is, therefore, not considered problematic in Long Lake. However, its presence points to the importance of preserving existing native species within the lake. Exotic species tend to dominate plant succession in areas where native species have been eliminated. Curly leaf pondweed has a competitive advantage over native species due to its "winter annual" type growth cycle. It deposits vegetative buds, turions, on the lake bottom which grow throughout the winter period. In the spring, these growths have a competitive advantage over native species which begin their growth cycle in the spring. This species is very problematic, when allowed to reach nuisance levels. Preservation of existing native species affords the best protection against problematic growth of this species in Long Lake.

Table 3. Functions of Aquatic Plant Species Found in Long Lake.

Scientific Name	Plant Type	Plant Functions
Elodea canadensis (Canada Waterweed)	Submersed	Provides habitat for many small aquatic animals, which fish and wildlife eat.
Ceratophyllum demersum (Coontail)	Submersed	Many waterfowl species eat the shoots; it provides cover for young bluegills, perch, largemouth bass, and northern pike; supports insects that fish and ducklings eat.
Vallisneria americana (Water Celery)	Submersed	Provides shade and shelter for bluegills, young perch, and largemouth bass; choice food of waterfowl, particularly diving ducks; attracts muskrats, marsh birds, and shore birds.
Potamogeton crispus (Curleyleaf Pondweed)	Submersed	Provides some cover for fish; several waterfowl species feed on the seeds; diving ducks often eat the winter buds.
Potamogeton zosteriformis (Flatstemmed Pondweed)	Submersed	Provides some cover for bluegills, perch, northern pike, and muskellunge, though these fish prefer broadleaf pondweeds; good cover for walleye; provide food for waterfowl; support aquatic insects and many small animals that fish and ducklings eat.
Potamogeton pectinatus (Sago Pondweed)	Submersed	Provides some cover for bluegills, perch, northern pike, and muskellunge, though these fish prefer broadleaf pondweeds; good cover for walleye; provide food for waterfowl; support aquatic insects and many small animals that fish and ducklings eat.
Myriophyllum sibiricum (Northern Milfoil)	Submersed	Provides cover for fish and invertebrates; supports insects and other small animals eaten by fish; waterfowl occasionally eat the fruit and foliage.
Chara spp. (Muskgrass)	Algae	Stabilizes bottom sediments; provides food for waterfowl and cover for fish. It also supports insects and other small aquatic animals, which are important foods for trout, bluegills, smallmouth bass, and largemouth bass.
Potamogeton Richardsonii (Claspingleaf Pondweed)	Submersed	Broadleaf pondweeds provide excellent habitat for panfish, largemouth bass, mulkellunge, and northern pike; bluegills nest near these plants and eat insects and other small animals found on the leaves; walleyes use these pondweeds for cover.
Najas flexilis (Bushy Pondweed)	Submersed	Entire plants are eaten by waterfowl, especially mallards, provide cover for young largemouth bass and northern pike and small bluegills and perch.
Potmogeton amplifolius (Largeleaf Pondweed)	Submersed	Broadleaf pondweeds provide excellent habitat for panfish, largemouth bass, mulkellunge, and northern pike; bluegills nest near these plants and eat insects and other small animals found on the leaves; walleyes use these pondweeds for cover.
Potamogeton natans (Floatingleaf Pondweed)	Submersed	Broadleaf pondweeds provide excellent habitat for panfish, largemouth bass, mulkellunge, and northern pike; bluegills nest near these plants and eat insects and other small animals found on the leaves; walleyes use these pondweeds for cover.

A Guide to Aquatic Plants: Identification and Management. 1994. Minnesota Department of Natural Resources.

Historical Data Comparison

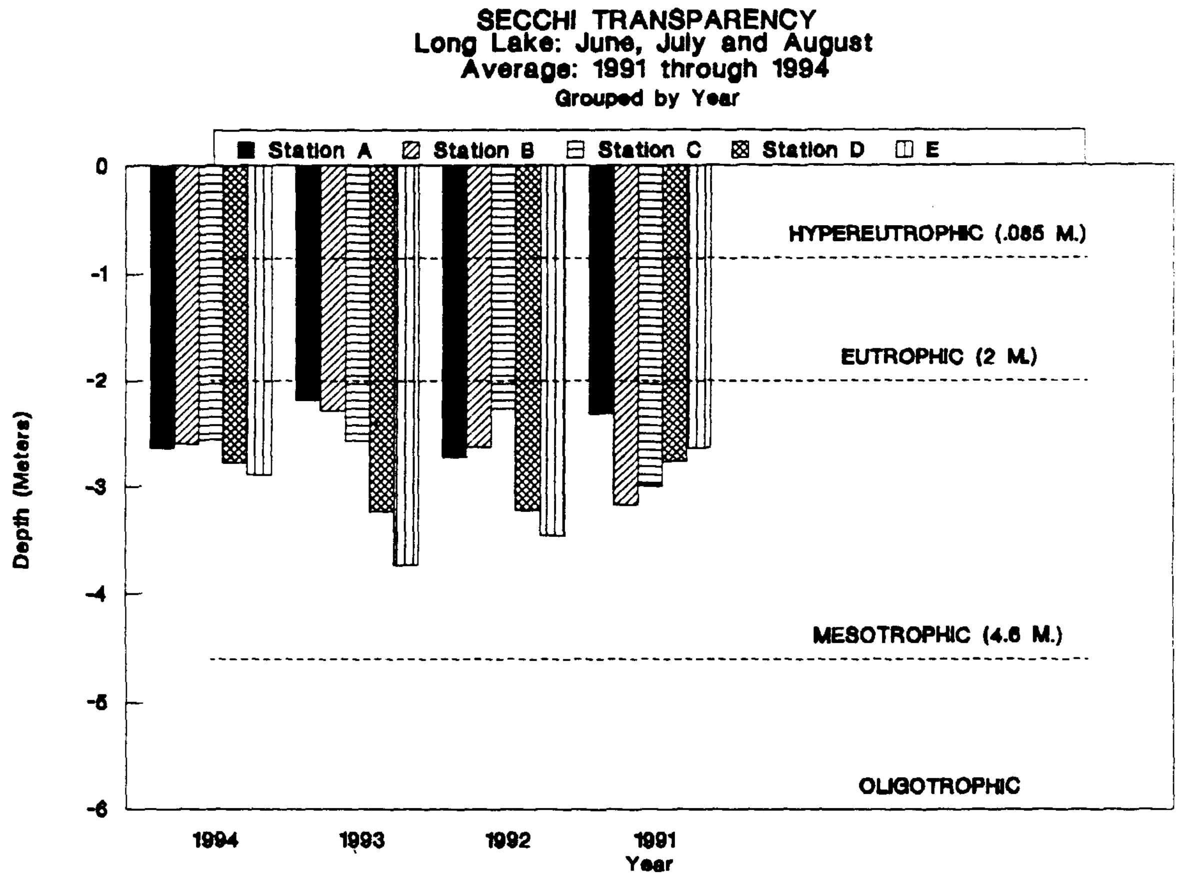
The excellent water quality noted in Long Lake during 1994 was similar to the water quality determined from data collection efforts during 1991 through 1993. The comparison of 1994 data with historical data suggests the 1994 data are relatively typical for the lake (Appendices J through V). On average, the lake has consistently exhibited excellent water transparency. As shown in Figure 26, all average summer Secchi disc measurements during the 1991 through 1994 period were within the mesotrophic category. As shown in Figures 27 through 29, however, late summer algal blooms have occasionally reduced water transparency in portions of the lake, resulting in mildly eutrophic conditions. The historical data indicate the water quality of the lake has been consistently good. However, these data, like the 1994 data, emphasize the importance of managing the lake's phosphorus load to preserve its current water quality.

1994 Watershed Lakes Water Quality Study

Data collected from lakes within the Long Lake watershed provide an indication of total phosphorus concentrations entering Long Lake from its subwatersheds. As shown in Figure 30, Mud Lake phosphorus concentrations were approximately four times higher than concentrations noted in Long Lake. Little Mud Lake and Slim Creek Flowage exhibited concentrations approximately three times and two times higher, respectively, than Long Lake concentrations. Harmon Lake and Big Devil Lake noted concentrations similar to concentrations measured in Long Lake.

Watershed Land Use Evaluation

The following watershed land-use evaluation was completed by the Natural Resource Conservation Service, Spooner Area Office. The Long Lake watershed is shown on Figure 9.



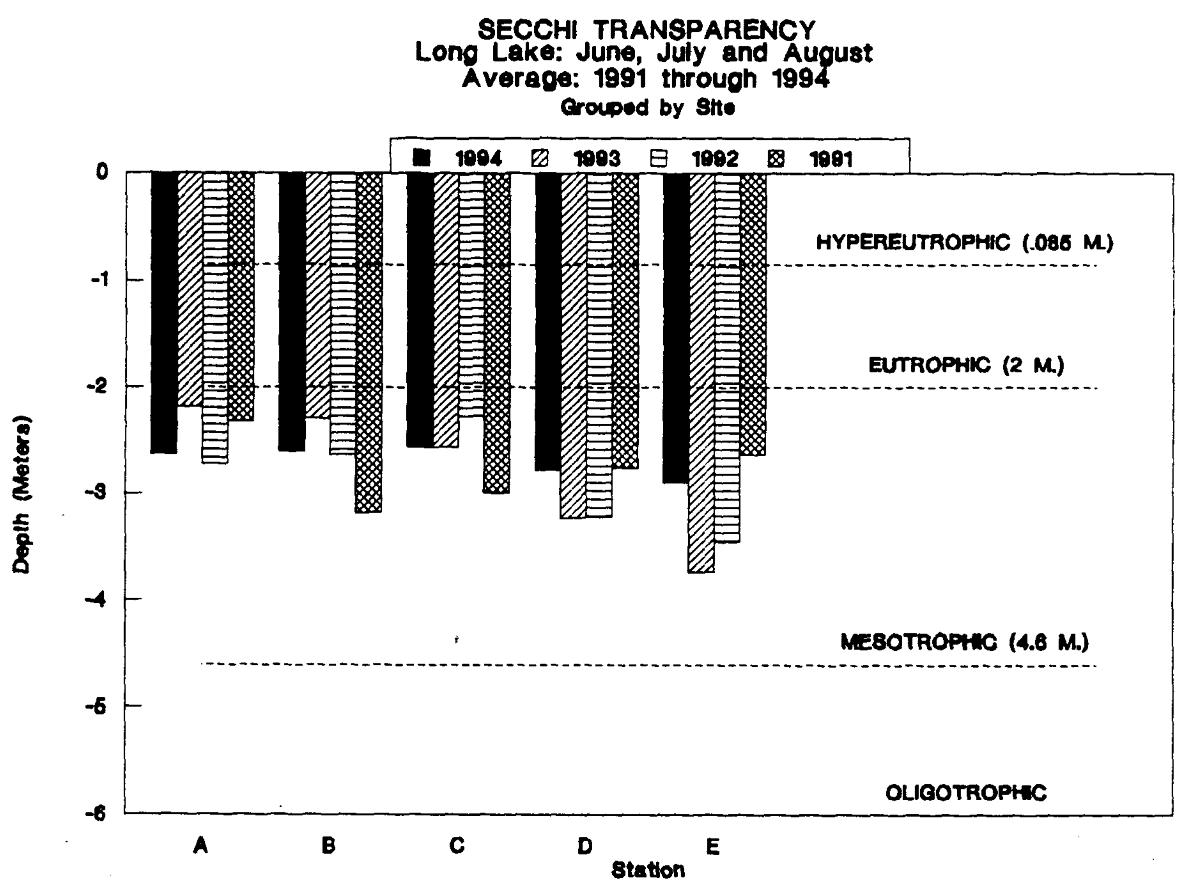


Figure 26

HISTORICAL SECCHI DISC DATA

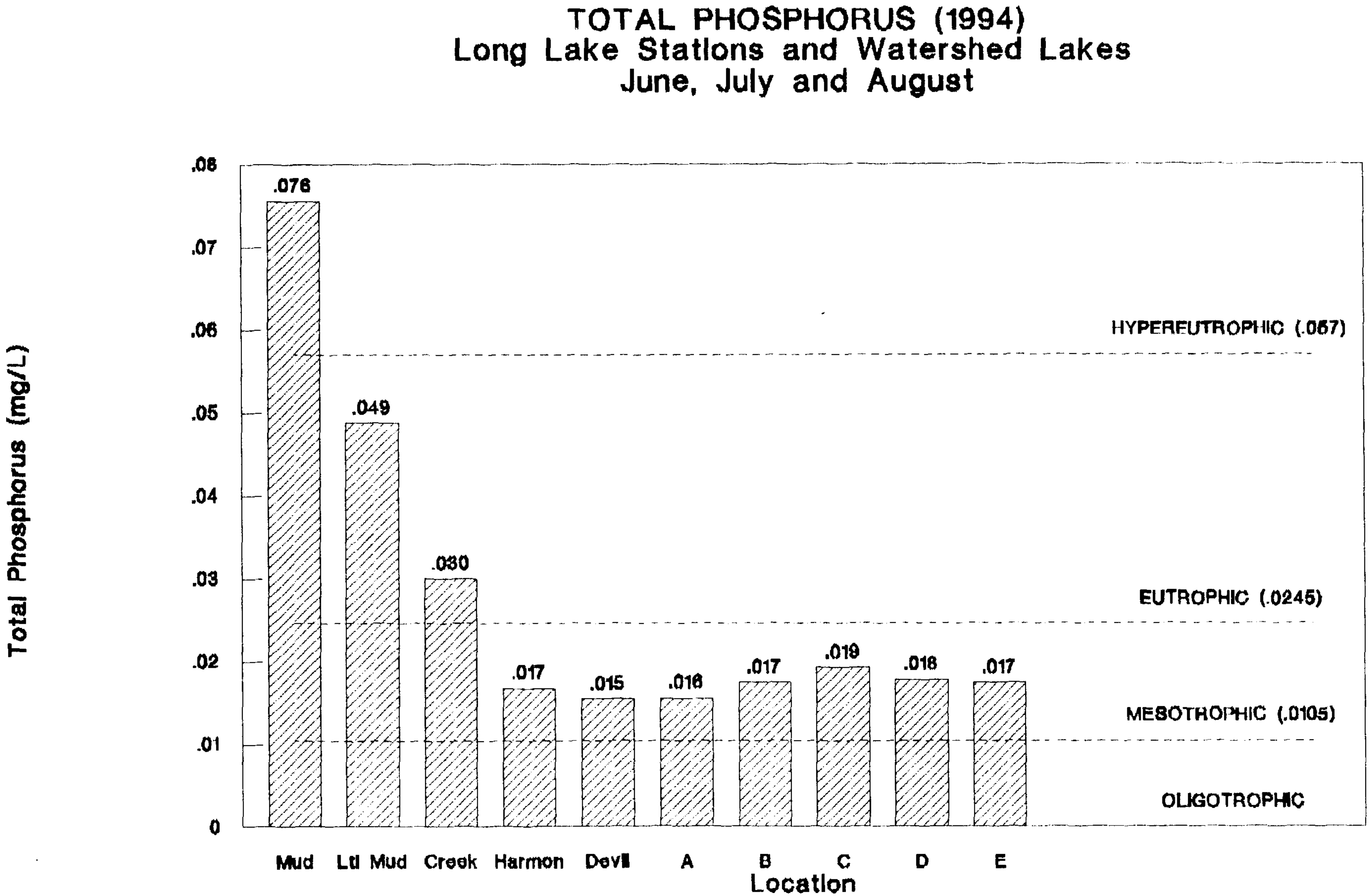

TOTAL PHOSPHORUS (1994)
Long Lake Stations and Watershed Lakes
June, July and August
Total Phosphorus (mg/L)
.08
.07
.06
.05
.04
.03
.02
.01
0
.076
.049
.030
.017
.015
.016
.017
.019
.018
.017
HYPEREUTROPHIC (.057)
EUTROPHIC (.0245)
MESOTROPHIC (.0105)
OLIGOTROPHIC
Mud
Ltl Mud
Creek
Harmon
Devil
A
B
C
D
E
Location

Figure 30

The 38,000 acre watershed tributary to Long Lake primarily consists of undeveloped forestland. Cropland comprises less than 10 percent of the watershed, approximately 2,424 acres (excluding pasture). Approximately 401.8 acres are known to be considered highly erodible land (HEL). The area contains three known dairy farms and a few livestock (beef and sheep, animal numbers unknown) farms.

The average crop rotation for the watershed appears to be 1 year corn, 1 year oats seeded to 4 years of hay or more. Therefore, soil loss average is well below the tolerable level. Spring moldboard plowing is the most common type of tillage done. A few people are trying to reduce tillage, with some even experimenting with no-till.

The soils in the Long Lake watershed vary greatly from silt loam texture to areas primarily sandy in surface texture. The majority of soil in the watershed have a sandy loam texture surface. The watershed soils are underlain primarily by acid sand and gravel, thereby promoting very good drainage. A small amount of the soil in the watershed (approximately 5 percent) is considered an organic soil comprised of peat and muck.

The woodland in the Long Lake watershed is primarily Aspen and Northern Hardwood. The Northern Hardwood cover typically consists of Red Oak, White Oak, and Paper Birch interspersed with Quaking Aspen, Basswood, White and Red Pine. In some areas Red and Sugar Maple make up the understory suggesting a change in species of Aspen in the Aspen cover type.

A fringe of development is found immediately adjacent to Long Lake consisting of approximately 600 residences and several resorts. The Tomahawk Scout reservation has preserved approximately 3,000 acres of land in its natural state, including approximately 8 miles of shoreline.

A discussion of land-usage within each subwatershed follows.

Slim Lake Basin

The Slim Lake Basin subwatershed is primarily dominated by woodland. Approximately 80.8 acres of cropland is noted, primarily under one individual's ownership. This individual has no livestock. No highly erodible land is noted in this subwatershed.

Harmon Lake Basin

The Harmon Lake Basin subwatershed is primarily dominated by woodland, with the majority of the woodland owned by the County. Approximately 176.1 acres of cropland, including 10.1 acres of highly erodible land (HEL) are in this subwatershed. The highly erodible land is in a continuous hay rotation. A portion of one dairy farm is located in this subwatershed.

Big Devil Lake Basin

Approximately 63 percent of the cropland in the Long Lake watershed are found here, as well as over half of the highly erodible land in the watershed. A total of 1,533.5 acres of cropland, including 203.1 acres of highly erodible land are located in this subwatershed. There is one dairy operation known to be present in the watershed and a few small livestock operations (beef and sheep). This area is a little more intensively farmed with snapbeans, sweet corn, and potatoes also grown in this area besides the normal corn-oats-hay rotation prevalent throughout the watershed. Approximately 150 acres of cropland are under a center pivot irrigation system. About 48 percent of the highly erodible land present in the subwatershed is enrolled in the Conservation Reserve Program (CRP).

Lower Long Lake Basin

This narrow subwatershed accounts for just 6 percent of the cropland present in the watershed (147 acres), yet 22 percent of the highly erodible land present in the watershed (88.7 acres). Most of this cropland is farmed by one individual who tends to run long hay rotations and little row crop. There is also one dairy farm present in the subwatershed.

Little Mud Lake Basin

This area is dominated primarily by woodland in private ownership. Cropland comprises 140.6 acres. There are no known livestock operations of any kind in this area and no highly erodible land.

Mud Lake Basin

This subwatershed area contains approximately 346 acres of cropland and approximately 25 percent of the highly erodible cropland in the watershed (99.9 acres). The area has one active dairy farm operation and one Conservation Reserve Program contract. The majority of land, however, is in woodland with it closely divided between public and private ownership.

Middle Long Lake Basin

This subwatershed has no cropland.

Precipitation and Lake Level Data

Precipitation and lake level data are presented in tabular and graphic format in Appendices H and I. The data will be used in the Phase II portion of the Long Lake project to develop hydrologic and phosphorus budgets. Hence, the data are presented without discussion.

An evaluation of 1994 Long Lake water quality data, together with water quality data collected during 1991 through 1993, indicates the lake has excellent water quality. However, mildly eutrophic conditions during the late summer exemplify the need for judicious management to prevent additional degradation. Further eutrophication of Long Lake may upset the current balance between the lake's phytoplankton, zooplankton, and fisheries communities, thus adversely impacting the lake's fishery. Water quality degradation may also result in additional algal blooms and a dominance by the nuisance blue-green algae. Such a change would be detrimental to the lake's recreational usage. Diligent management of the lake and its watershed, however, will preserve the current water quality and the current balance in the lake's ecosystem.

Most of the lake's watershed is currently undeveloped and consists of woodland. Uncontrolled development of the watershed would likely result in significant degradation of the lake's water quality. Development of a management plan for Long Lake and its watershed, however, affords the opportunity to evaluate different watershed development scenarios. The Phase II and Phase III portions of the Long Lake Management Plan development will:

- define the existing annual phosphorus load to Long Lake (from each of its subwatersheds and the aggregate total);
- establish a long-term water quality goal for Long Lake;
- explore development scenarios and their impacts on the water quality of Long Lake; and
- develop a management plan for Long Lake and its watershed which achieves its long-term water quality goal.

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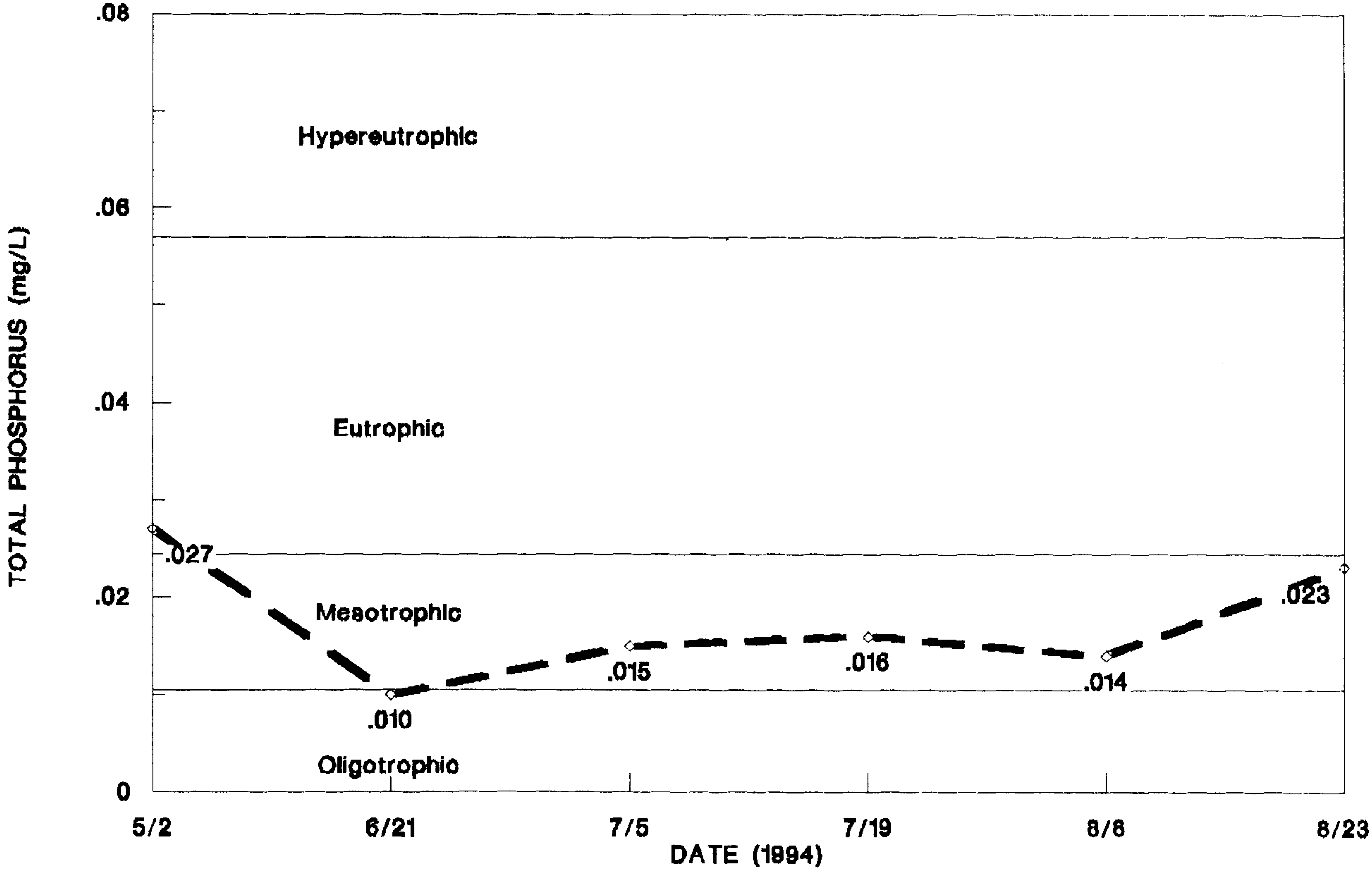
Appendix A

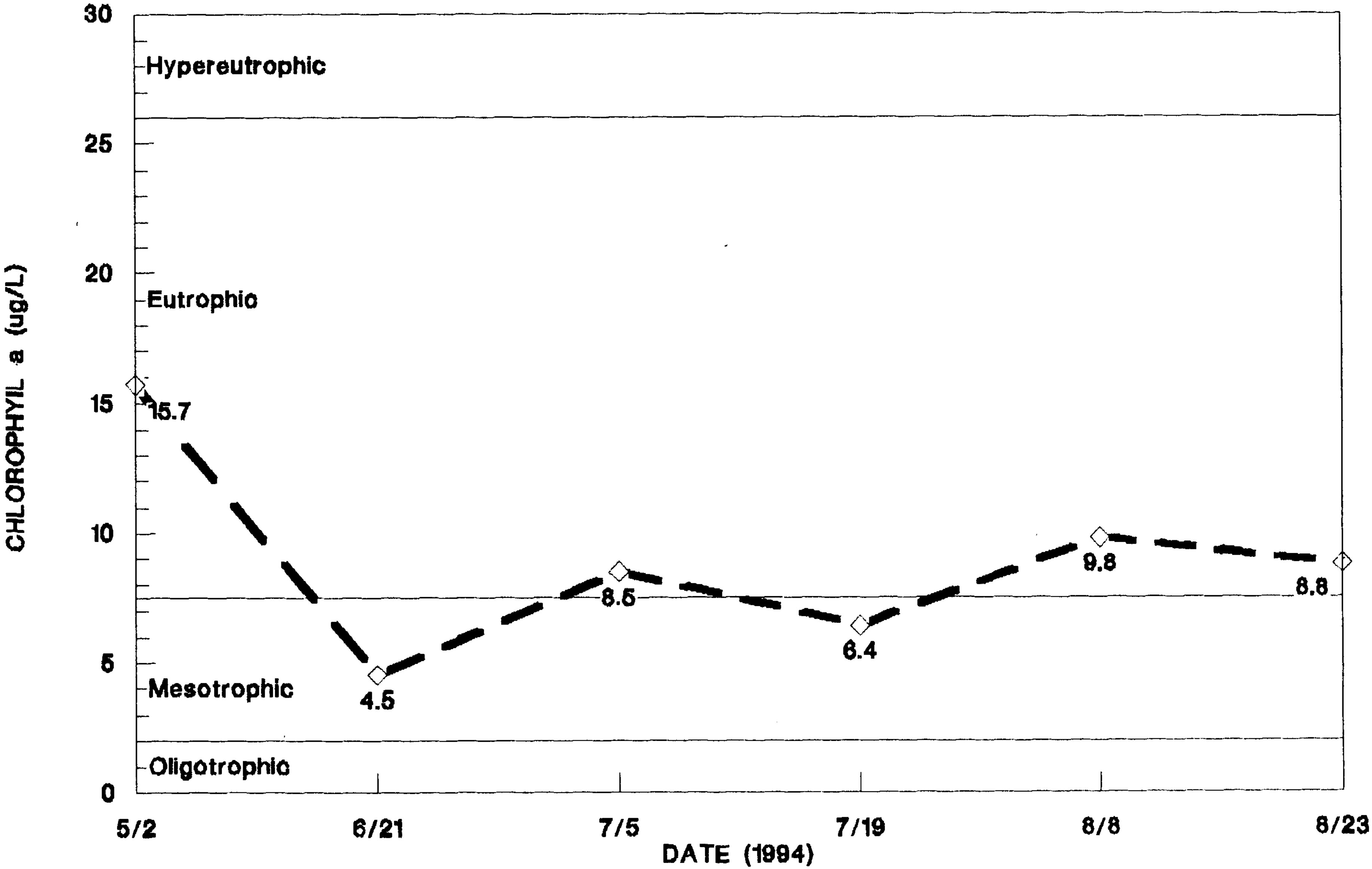
1994 Long Lake Water Quality Data—Site A

Water Chemistry
Phytoplankton
Zooplankton

TOTAL PHOSPHORUS (1994)
LONG LAKE SPRING AND SUMMER
STATION A



CHLOROPHYIL a (1994)
LONG LAKE SPRING AND SUMMER
STATION A



SECCHI TRANSPARENCY (1994)
LONG LAKE: SPRING THROUGH FALL
STATION A