Chetek Lakes Management Plan

Phase 1: Chetek Lakes Data Collection (Lake, Inflow, and Outflow Water Quality, Inflow Water Quantity, Precipitation Data, Lake Level Data, and Membership Survey)

Phase 2: Inflow Data Collection (Pokegama Creek and Moose Ear Creek Water Quantity and Quality)

Phase 3: Hydrologic and Phosphorus Budgets

May 1999

Prepared for
Chetek Lakes Protection Association

Prepared by
Barr Engineering Co.

With Assistance from:
Chetek Lakes Protection Association
Barron County Land Conservation Department
Wisconsin Department of Natural Resources

Acknowledgments

The Chetek Lakes Management Plan, Phases I, II, and III was completed with the assistance of the Chetek Lakes Protection Association. A special thanks to the following volunteers for their help during the project:

Jerry Zehner	President of Chetek Lakes Protection Association Overall Volunteer Coordinator of the Project Collection of Chetek Inflow Flow Measurements and Stream Water Quality Samples Maintenance of Flow Loggers and Automatic Samplers
Judy Reichert	Collection of Chetek Inflow Flow Measurements and Stream Water Quality Samples Maintenance of Flow Loggers and Automatic Samplers
Marlin Freyholtz	Collection of samples from Mud Lake
Ken Pfaff	Collection of samples from Mud Lake
Gary Fredrickson	Collection of samples from Prairie Lake
Chris Karpowicz	Collection of samples from Prairie Lake
George Hunter	Collection of samples from Pokegama Lake
Stella Hunter	Collection of samples from Pokegama Lake
Jack Perkins	Collection of samples from Pokegama Lake
Leo Pokryfke	Collection of samples from Tenmile Lake
Gene Ehlinger	Collection of samples from Tenmile Lake
Robert August	Collection of samples from Lake Chetek
Bob Paulson	Collection of samples from Lake Chetek
Donald Freeman	Collection of Dissolved oxygen, temperature, specific conductance, and Secchi disc measurements in Mud Lake, Prairie Lake, Pokegama Lake, Tenmile Lake, and Lake Chetek
Jim Gaspardo	Read rain gauge RG-1 (Mud Lake)
Bob Tollefson	Read rain gauge RG-2 (North Prairie)
Jeff Biesecker	Read rain gauge RG-3 (Central Prairie)
Mike Witkowski	Read rain gauge RG-4 (Upper Pokegama)
Jim Schultz	Read rain gauge RG-5 (East of Tenmile Lake)
Mike Mc Ginnis	Read rain gauge WWTP (Waste Water Treatment Plant)
Bruce Kamrath	Assist with inflow data (computer operator)
Jim Dennis	Assist with data summary (biological sciences teacher)

Thanks to Dan Ryan of the Wisconsin Department of Natural Resources for help and support throughout the project. Thank you to Dale Hanson, District Conservationist, and Tyler Gruetzmacher, Technician, of the Barron County Land Conservation Department for providing land use information for the Chetek Lakes Tributary Watershed. Thank you to Rick Cornelius of the Wisconsin Department of Natural Resources for providing fisheries information for the Chetek Lakes. Thank you to Craig Roesler and Jim Cahow of the Wisconsin Department of Natural Resources for providing macrophyte data for the Chetek Lakes.

Executive Summary

The study described by this report was initiated by the Chetek Lakes Protection Association to provide information for the development of a lake management plan. The study involved collection of data from the Chetek Lakes, its inflows, its outflow, and its watershed during 1996 through 1997. Annualized hydrologic and phosphorus budgets were then modeled for existing watershed land use conditions.

The lake water quality data showed that Chetek Lakes exhibited poor to very poor water quality. Total phosphorus, chlorophyll *a*, and Secchi disc data were generally within the eutrophic (poor water quality) during the early-summer period and the hypereutrophic (very poor water quality) during the late-summer period. Tenmile Lake was generally more nutrient-rich than the other lakes and total phosphorus and chlorophyll concentrations were in the hypereutrophic category throughout the summer period.

Water clarity is correlated with recreational use of a lake and poor water clarity results in recreational use impairment. The data indicate moderate recreational use impairment occurred during the early-summer period and severe recreational use impairment occurred during the late-summer period in all lakes. Some variation between lakes was noted relative to the date of onset of severe recreational use impairment.

The results of a survey of Chetek Lakes' riparian owners indicated the primary use of the lakes is fishing. Nearly all residents considered the lakes' current water clarity murky or cloudy, but desired a water clarity of clear. Respondents indicated that current and desired uses of the lakes are very similar, suggesting residents would make few changes in lake recreational activities if water clarity improved. However, residents indicated that use of the lake for swimming would increase if water clarity improved.

Riparian owners were surveyed to determine desired lake management goals. The most frequently selected lake management goal was improvement of lake water quality, selected by 92 percent of respondents. Based upon survey results, the following lake management goals are recommended for the Chetek Lakes:

- Improve the lakes' water quality
- Improve Fisheries

- Decrease Weed Growth
- Improve Aesthetics

The results of the hydrologic budgets for the five basins of the Chetek Lakes indicate tributary inflows and upstream lake basins are the primary sources of water for the basins.

The results of the overall lake phosphorus budget analysis estimated that the total phosphorus load into the Chetek Lakes is approximately 40,715 pounds per year, based on 1996-1997 data. Approximately 84 percent results from watershed runoff, including 56 percent from monitored inflowing streams. Macrophyte senescence within Mud Lake represents the second highest phosphorus load to the lakes, approximately 8 percent of the total annual load. An estimated 5 percent of the total projected load results from internal loading from sediments. Atmospheric deposition and septic systems comprise the remaining 3 percent of the annual load. The total load to the Chetek Lakes is less than the sum of the loads to the five individual basins. The discrepancy occurs because the loads to the individual lake basins include phosphorus loaded to downstream basins from upstream basins (i.e., phosphorus moving through the lake system), while the total load to the lake system excludes the phosphorus load moving through the system from basin to basin.

Based on modeling results, the individual budgets for each of the lake's five basins suggest:

- **Mud Lake**—estimated annual phosphorus load of 10,172 pounds, a loading rate of 4.1 pounds per acre-foot. Phosphorus sources include macrophyte senescence (30 percent), Pokegama Creek (56 percent), the lake's direct watershed (11 percent), atmospheric deposition (less than 1 percent), septic systems (less than 1 percent), and internal loading from sediments (less than 2 percent). Approximately 88 percent of the phosphorus load entering Mud Lake flows to downstream basins (30 percent to Prairie and 58 percent to Pokegama).

- **Prairie Lake**—estimated annual phosphorus load of 11,147 pounds, a loading rate of 0.8 pounds per acre-foot. Phosphorus sources include cropland within the lake's direct watershed (44 percent), outflow from Mud Lake (27 percent), flow from Rice Creek (17 percent), remaining land uses in the lake's direct watershed (6 percent), septic systems (less than 3 percent) and atmospheric deposition (2 percent). Approximately 55 percent of phosphorus entering Prairie Lake flows to Lake Chetek.

- **Pokegama Lake**—estimated annual phosphorus load of 8,611 pounds, a loading rate of 1.6 pounds per acre-foot. Phosphorus sources include Mud Lake outflow (69 percent), the lake's direct watershed (17 percent), internal loading from sediments (11 percent), septic systems (1 percent) and atmospheric deposition (1 percent). Approximately 69 percent of the phosphorus entering Pokegama Lake flows to Lake Chetek.

- **Tenmile Lake**—estimated annual phosphorus load of 10,357 pounds, a loading rate of 4.4 pounds per acre-foot. Phosphorus sources include Tenmile Creek (88 percent), Short Creek (8 percent), the lake's direct watershed (less than 2 percent), septic systems (less than 1 percent), atmospheric deposition (less than 1 percent), and internal loading from sediments (1 percent). Approximately 91 percent of the phosphorus entering Tenmile Lake flows to Lake Chetek.

- **Lake Chetek**— estimated annual phosphorus load of 30,922 pounds, a loading rate of 3.1 pounds per acre-foot. Phosphorus sources include upstream lake basins (70 percent of the annual load), Moose Ear Creek (22 percent), the lake's direct watershed (6 percent), septic systems (less than 1 percent), atmospheric deposition (less than 1 percent), and internal sediment loading (1 percent). Approximately 71 percent of phosphorus entering Lake Chetek flows out the Chetek River.

Completion of a Lake Management Plan for the Chetek Lakes is recommended to improve their water quality. Prior to completion of the management plan, the following project is recommended to confirm or fine-tune estimates presented in this report:

- Mud Lake curlyleaf pondweed study to determine coverage, density, and phosphorus content

- Study of flow between Mud Lake and Prairie Lake

- Analysis of the Chetek Lakes' system using the Bathtub model to fine-tune estimates of flow and phosphorus loading between basins

The following management plan development project is recommended:

1. Establish a long-term water quality goal for each lake basin

2. Determine potential watershed management practices in the Chetek Lakes' watershed

3. Determine potential in-lake management practices (e.g., curlyleaf pondweed management in Mud Lake)

4. Model the estimated water quality benefits from implementation of watershed and in-lake management practices identified in numbers 2 and 3

5. Determine whether implementation of watershed and/or in-lake management practices will result in goal achievement

6. Develop a management plan for Chetek Lakes and its watershed

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

Located in Barron County, Wisconsin, five lakes comprise the impoundment known as Chetek Lakes: Mud Lake, Prairie Lake, Pokegama Lake, Tenmile Lake, and Lake Chetek. The five lakes comprise a surface area of 3,800 acres. The impoundment is relatively shallow, noting a maximum depth of 22 feet. Chetek Lakes are considered a great fishery and a significant water resource by the Chetek Lakes Protection Association, the Wisconsin Department of Natural Resources (WDNR), and area residents. However, the lakes note frequent problematic algal blooms during the summer months.

The Chetek Lakes Protection Association initiated the following Chetek Lakes Planning Grant Project to investigate the lakes' current condition, and develop a lake management plan.

1.1 Comprehensive Lake Management Plan

The ultimate goal of the Chetek Lakes Protection Association is to complete a comprehensive lake management plan. Plan completion involves several steps, including:

- Collection of data (i.e., lake and tributary water quality, precipitation, lake level, watershed land use, and recreational user expectations/desires).
- Preparation of hydrologic and phosphorus budgets for existing watershed land use conditions.
- Preparation of the comprehensive lake management plan.

The project discussed in this report includes the first two steps to the lake management plan (i.e., collection of data and preparation of hydrologic and phosphorus budgets).

1.2 Report Coverage

This report discusses the methodology, results, and conclusions from a three-phase project that included data collection and hydrologic and phosphorus budget completion. The report will answer the following two questions that apply to properly managing lakes:

1. What is the general condition of the lake?
2. Are there problems evident in the water quality?

To answer the first question, this report begins with descriptions of the watershed, the lake, methods of data collection and analysis. The results of water quality monitoring are then summarized in tables, figures, and accompanying descriptions.

To answer the second question, water quality data are analyzed and compared to established water quality standards for lakes.

A third and final question will be answered in the intended lake management plan development project.

1. What are the most effective solutions to the lake's water quality problems?

Hydrologic and phosphorus budgets were prepared in preparation for the lake management plan development project, and are discussed in this report.

A background information section is also included in the report. Section 2.0 covers general concepts in lake water quality.

2.0 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
- Watershed

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

2.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake naturally becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fill the lake's basin. Over a period of many years, the lake successively becomes a pond, a marsh and, ultimately, a terrestrial site. This process of eutrophication is natural and 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).

2.2 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 60 µg/L total phosphorus.

4. ***Hypereutrophic* – [64 ≤ TSI]** Extremely productive lakes which 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 60 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.

2.3 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, the 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.

2.4 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.

2.5 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 mid-summer, 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.

2.6 Watershed

The land area that drains to the lake is called a watershed. The watershed may be small, as is the case of small seepage lakes. Seepage lakes have no stream inlet or outlet and, consequently, their watersheds include the land draining directly to the lake. A lake's watershed may be large, as in drainage lakes such as Chetek Lakes. Drainage lakes have both stream inlets and outlets and, consequently, their watersheds include the land draining to the streams in addition to 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 entire 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.

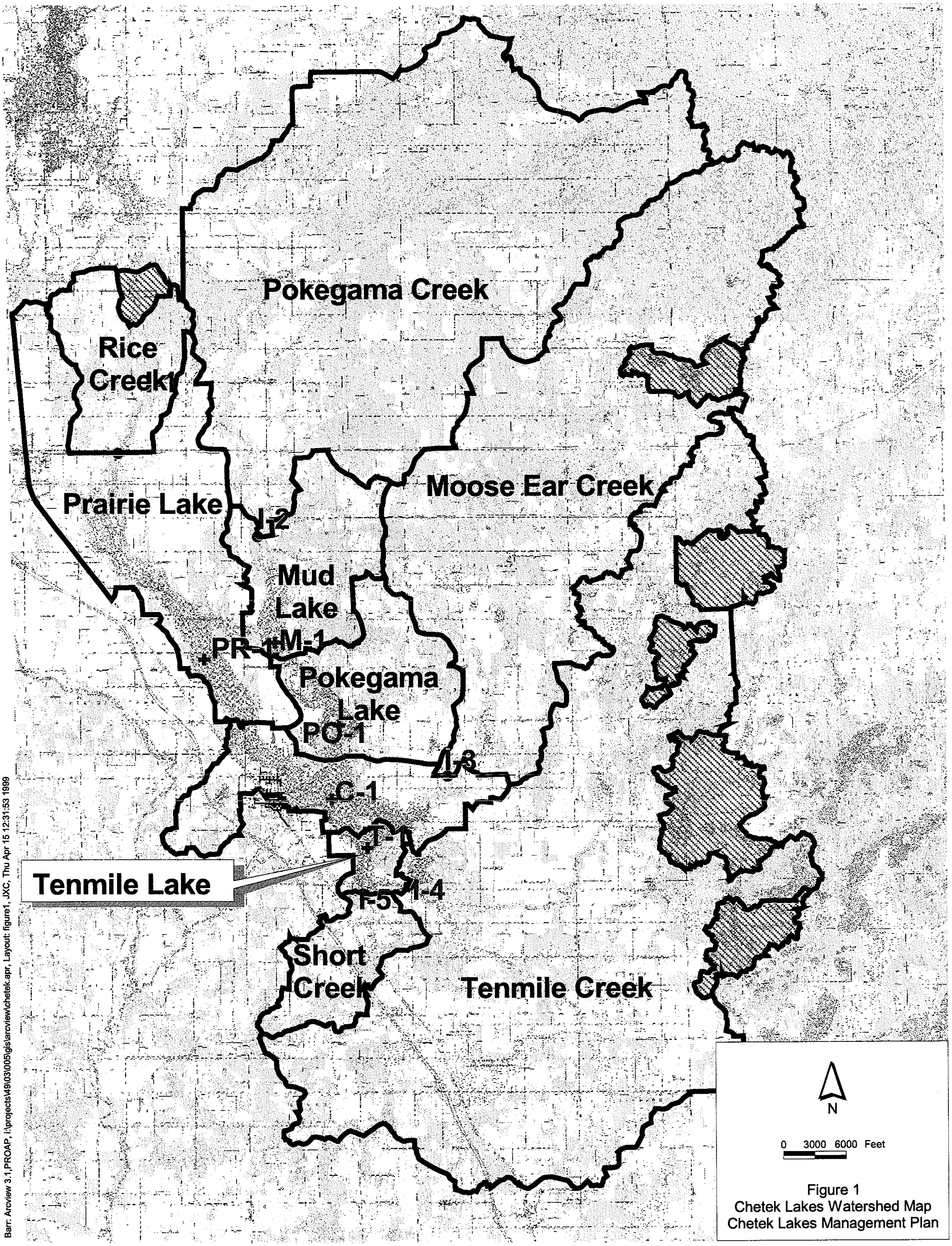
3.0 Basin Characteristics

Chetek Lakes, in Barron County, Wisconsin, covers an area of approximately 3,800 acres. The lake consists of five basins (Figure 1) and each basin is considered a separate lake. However, because the basins are joined together, the lake is perceived as a single basin. Table 1 summarizes basin characteristics of the Chetek Lakes (Thorson, 1997).

Table 1 Chetek Lakes Basin Characteristics

Basin	Surface Area (Acres)	Mean Depth (Feet)	Max Depth (Feet)	Volume (acre-ft.)	Shoreline Length (Miles)
Mud (Ojaski)	577	4.3	15	2,460	5.2
Prairie	1,534	9.1	16	14,035	21.4
Pokegama	506	10.5	19	5,322	10.0
Chetek	770	13.0	22	9,991	7.1
Tenmile	376	6.3	12	2,369	6.4

Chetek Lakes are soft-water drainage lakes flowing into the Chetek River. The lakes note an excellent fishery and are heavily fished. Primary fish species are largemouth bass, bluegill, and crappies. Additional sport fish present in the lakes include northern pike, smallmouth bass, walleye, pumpkinseed, rock bass, and perch. Other fish species in the lakes include red horse, sucker, and bullheads.



Pokegama Creek
Rice Creek1
Prairie Lake
Moose Ear Creek
I-2
Mud Lake
PR-1
M-1
Pokegama Lake
PO-1
I-3
C-1
T-1
Tenmile Lake
I-5
I-4
Short Creek
Tenmile Creek
N
0 3000 6000 Feet
Figure 1
Chetek Lakes Watershed Map
Chetek Lakes Management Plan
Barr: Arcview 3.1,PROAP, I:\projects\49\03\005\gis\arcview\chetek.apr, Layout: figure1, JXC, Thu Apr 15 12:31:53 1999

4.0 Methods

4.1 Lake Water Quality Data Collection

In 1996, a representative lake sampling station was selected for each of the five basins. Sampling stations were located in the deepest portion of each basin (Figure 2). Water samples were collected once during May, twice per month during June through August, and once during September. Temperature, dissolved oxygen, specific conductance, and Secchi disc were measured twice per month during May through October and once during February of 1997. A total of seven water quality parameters were measured at the Chetek Lakes' sampling stations. Tables 2 through 6 list the water quality parameters, and specify when and at what depths samples or measurements were collected in each basin. Dissolved oxygen, temperature, specific conductance and Secchi disc transparency were measured in the field; whereas, water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen, and chlorophyll *a*. A survey of macrophyte coverage was completed by the WDNR in August of 1997.

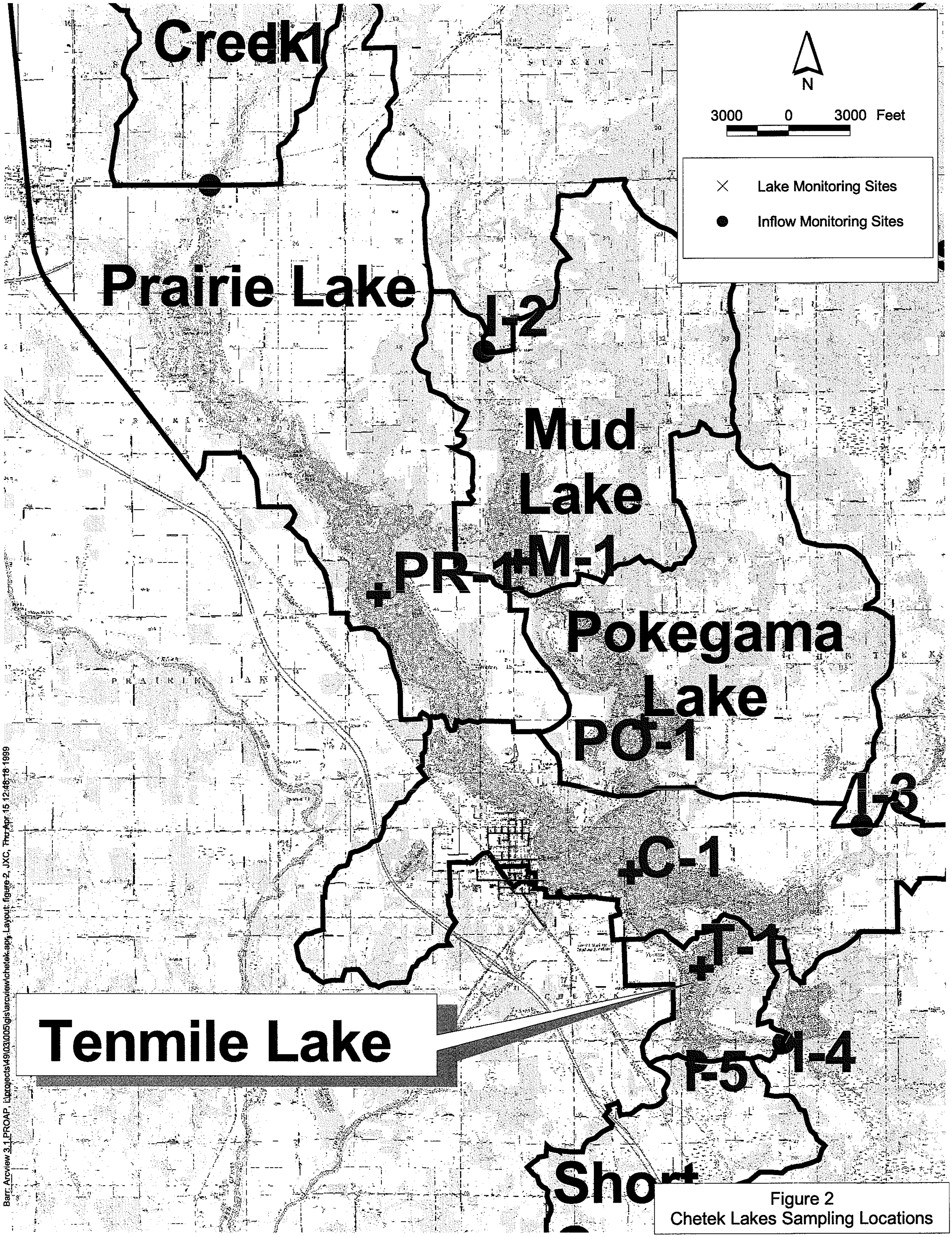


Figure 2
Chetek Lakes Sampling Locations

Table 2 1996 Mud Lake Water Quality Parameters

Parameters	Depth (meters)	5/7	5/21	6/3	6/18	7/10	7/23	8/6	8/19	9/4	9/18	10/3	10/16	2/11/97
Dissolved Oxygen	Surface to bottom profile	X	X		X	X	X	X	X	X	X	X	X	X
Temperature	Surface to bottom profile	X	X		X	X	X	X	X	X	X	X	X	X
Specific Conductance	Surface to bottom profile	X	X		X	X	X	X	X	X	X	X	X	X
Chlorophyll a	0-2	X			X	X	X	X	X	X				
Secchi Disc	—	X	X		X	X	X	X	X	X	X	X	X	
Total Phosphorus	Surface to bottom profile	X		X	X	X	X	X	X	X				
Soluble Reactive Phosphorus	0-2	X		X	X	X	X	X	X	X				
Total Kjeldahl Nitrogen	0-2	X		X	X		X	X	X	X				
Nitrate + Nitrite Nitrogen	0-2	X		X	X									
Lab Specific Conductance	0-2								X					
Alkalinity	0-2								X					
pH	0-2								X					

11

Table 3 1996 Prairie Lake Water Quality Parameters

Parameters	Depth (meters)	5/20	6/3	6/19	7/10	7/23	8/6	8/19	9/5	9/18	10/3	10/16	2/11/97
Dissolved Oxygen	Surface to bottom profile	x	x	x	x	x	x	x	x	x	x	x	x
Temperature	Surface to bottom profile	x	x	x	x	x	x	x	x	x	x	x	x
Specific Conductance	Surface to bottom profile	x	x	x	x	x	x	x	x	x	x	x	x
Chlorophyll a	0-2		x	x	x	x	x	x	x				
Secchi Disc	—	x	x	x	x	x	x	x	x	x	x	x	
Total Phosphorus	Surface to bottom profile		x	x	x	x	x	x	x				
Soluble Reactive Phosphorus	0-2		x	x	x	x	x	x	x				
Total Kjeldahl Nitrogen	0-2		x	x	x	x	x	x	x				
Nitrate + Nitrite Nitrogen	0-2		x	x									
Lab Specific Conductance	0-2							x					
Alkalinity	0-2							x					
pH	0-2							x					

12

Table 4 1996 Pokegama Water Quality Parameters

Parameters	Depth (meters)	5/6	5/20	6/3	6/18	7/10	7/23	8/6	8/19	9/4	9/18	10/16	2/11/97
Dissolved Oxygen	Surface to bottom profile	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	Surface to bottom profile	X	X	X	X	X	X	X	X	X	X	X	X
Specific Conductance	Surface to bottom profile	X	X	X	X	X	X	X	X	X	X	X	X
Chlorophyll a	0-2	X			X	X	X	X	X	X			
Secchi Disc	—	X	X	X	X	X	X	X	X	X	X	X	
Total Phosphorus	Surface to bottom profile	X			X	X	X	X	X	X			
Soluble Reactive Phosphorus	0-2	X			X	X	X	X	X	X			
Total Kjeldahl Nitrogen	0-2	X			X	X	X	X	X	X			
Nitrate + Nitrite Nitrogen	0-2	X											
Lab Specific Conductance	0-2	X							X				
Alkalinity	0-2	X							X				
pH	0-2	X							X				

Table 5 1996 Tenmile Lake Water Quality Parameters

Parameters	Depth (meters)	5/7	5/20	6/3	6/17	7/10	7/23	8/6	8/19	9/4	9/18	10/3	10/16	2/11/97
Dissolved Oxygen	Surface to bottom profile	x	x	x		x	x	x	x	x	x	x	x	x
Temperature	Surface to bottom profile	x	x			x	x	x	x	x	x	x	x	x
Specific Conductance	Surface to bottom profile	x	x	x		x	x	x	x	x	x	x	x	x
Chlorophyll a	0-2	x		x	x	x	x	x	x	x				
Secchi Disc	—	x	x	x		x	x	x	x	x	x	x	x	
Total Phosphorus	Surface to bottom profile	x		x	x	x	x	x	x	x				
Soluble Reactive Phosphorus	0-2	x		x	x	x	x	x	x	x				
Total Kjeldahl Nitrogen	0-2	x		x	x	x	x	x	x	x				
Nitrate + Nitrite Nitrogen	0-2	x		x	x	x		x						
Lab Specific Conductance	0-2													
Alkalinity	0-2													
pH	0-2													

14

Table 6 1996 Lake Chetek Water Quality Parameters

Parameters	Depth (meters)	5/6	5/20	6/3	6/18	7/10	7/23	8/6	8/20	9/5	9/18	10/3	10/16	2/11/97
Dissolved Oxygen	Surface to bottom profile	x	x	x	x	x	x	x	x	x	x	x	x	x
Temperature	Surface to bottom profile	x	x	x	x	x	x	x	x	x	x	x	x	x
Specific Conductance	Surface to bottom profile	x			x	x	x	x	x	x	x	x	x	x
Chlorophyll a	0-2	x		x	x	x	x	x	x	x				
Secchi Disc	—	x	x	x	x	x	x	x	x	x	x	x	x	
Total Phosphorus	Surface to bottom profile	x		x	x	x	x	x	x	x				
Soluble Reactive Phosphorus	0-2	x		x	x	x	x	x	x	x				
Total Kjeldahl Nitrogen	0-2	x		x	x	x	x	x	x	x				
Nitrate + Nitrite Nitrogen	0-2	x		x	x									
Lab Specific Conductance	0-2	x							x					
Alkalinity	0-2	x							x					
pH	0-2	x							x					

4.2 Inflow/Outflow Monitoring Methods

The tributary monitoring program included the collection of samples during baseflow, rainstorms, and snowmelt. Grab samples were collected from five inflow locations and from the lake's outflow (see Figure 2) during each lake sample event to determine baseflow concentrations. Inflow locations included I-1 (i.e., Rice Creek), I-2 (i.e., Pokegama Creek), I-3 (i.e., Moose Ear Creek), I-4 (i.e., Tenmile Creek), and I-5 (i.e., Short Creek). Grab samples were collected from I-1, I-4, and I-5 during two spring, two summer, and two fall rainstorms during 1996 to monitor stormwater runoff. Automatic samplers were used to collect runoff samples from I-2 and I-3 during two spring, two summer, and two fall rainstorms during 1996. Snowmelt samples were collected from five inflow stations on a daily basis (i.e., one grab sample per day) during the period March 10 through April 15, 1997. Samples collected during the March 10 through March 26 period were composited on a flow weighted basis; samples collected during March 27 through April 15 were composited on a flow weighted basis. Consequently, a total of two composite snowmelt samples were analyzed. All baseflow, snowmelt and rainstorm samples were analyzed for total phosphorus by the State Laboratory of Hygiene.

The "Floating Object" method of discharge measurement was generally used to measure discharge at inflow stations I-1, I-4, and I-5 during each sample event. Following is a description of the "Floating Object" method:

1. A stretch of stream about 100 feet long with fairly even gradient and flow was selected. The average width and depth of the stream were determined.

2. The time in seconds required for an orange to traverse the length of the flow station was measured. The process was repeated five times and an average of the five trials was taken.

3. Discharge was computed in the following manner:

$$Q=\frac{(WxDxL)\ a}{T}$$

Where: "Q" = rate of flow in cubic feet per second (cfs)
"W" = average width of the stream in feet
"D" = average depth in feet

"a" = a constant for stream bottom type where a = 0.8 if stream bottom is rough and strewn with rocks, rubble and coarse gravel and a = 0.9 if strewn bottom is smooth, mud, sand, or bedrock

"L" = length of the stream over which speed of floating orange was measured

"T" = time in seconds required for the orange to traverse the measured distance

All sampling and discharged measurements were completed by Chetek Lakes Protection Association volunteers, trained by Barr Engineering Co. professionals. During the early-May training session, discharge was measured with a Marsh McBirney discharge meter, in addition to the floating orange method, to compare the two methods of measurement.

On several occasions during the monitoring period, volunteers inadvertently failed to record one or more pieces of information regarding discharge measurement (e.g., stream depth). Consequently, it was not possible to estimate discharge on several occasions during the monitoring period.

During early-May of 1996, flow logger/automatic sampling units were installed at tributary inflow locations I-2 (i.e., Pokegama Creek) and I-3 (Moose Ear Creek). The equipment was used to collect more complete information regarding the volume of water entering Chetek Lakes from two inflowing streams and the phosphorus concentrations of the streams during runoff events. Measurements and sample collection occurred during the May through November period of 1996. Equipment was installed by a Barr Engineering Company professional with assistance from a Chetek Lakes' volunteer.

Following equipment installation, Chetek Lakes' volunteers maintained and operated the equipment. Equipment maintenance occurred approximately every two weeks and consisted of: (1) battery replacement, (2) examination of equipment and verification that it was functioning properly, (3) downloading data from the flow logger to a portable field computer unit, and (4) sending the electronic data to Barr to be filed on its computer network.

As discussed previously, stormwater runoff sample collection occurred during two spring, two summer, and two fall rainstorms. On each sampling occasion, up to 24 bottles were filled by each automatic sampler at prescribed intervals throughout each runoff event. Samples were collected by Chetek Lakes' volunteers. At the time of sample collection, data were downloaded from each flow logger. Samples and flow data from the runoff event were shipped to Barr Engineering Company via an overnight carrier. The samples collected at each location were then flow-composited by Barr Engineering Co. The flow data were used to determine the flow-compositing volumes from each of the sample bottles. One flow composited sample from each location was submitted to the State Laboratory of Hygiene for total phosphorus analysis. After each runoff event, Barr staff cleaned all sample bottles and returned them to a Chetek volunteer. Clean sample bottles were installed in each sampler.

4.3 Evaluation of the Tributary Watershed

The Chetek Lakes watershed was divided into ten subwatersheds which include the tributary streams and their watersheds, as well as the remaining areas draining directly to each of the lake basins (see Figure 1). Land uses within each subwatershed were determined by the Barron County Land Conservation Department. The City of Chetek provided an aerial photo and storm sewer information for the City. Table 7 shows the contributing watershed areas (i.e., runoff from this land area enters the Chetek Lakes) and land uses for each of the ten subwatersheds. Figure 3 shows each subwatershed as a percentage of the total watershed.

Approximately 7,056 acres within the Chetek lakes watershed is considered non-contributing. This means that surface runoff from this land area does not enter the Chetek Lakes. Non-contributing areas by subwatershed include:

- 1,003 acres in the Moose Ear Creek subwatershed
- 444 acres in the Rice Creek subwatershed
- 5,609 acres in the Tenmile Creek subwatershed

Non-contributing areas are depicted on Figure 1 as hatched areas (i.e., watershed areas with diagonal lines).

Table 7 Contributing Watershed Areas and Land Uses for the Chetek Lakes' Subwatersheds

Watershed Name	Commercial/ Industrial	Farm	Forested	Other	Residential	Water	Total
Lake Chetek	59.52	1,236.65	713.46	944.38	495.43	1,322.25	**4,771.69**
Moose Ear Creek	0	7,594.00	12,021.29	4,507.32	52.09	210.32	**24,385.02**
Mud Lake	0	872.27	2,098.33	1,213.67	48.37	387.69	**4,620.33**
Pokegama Creek	0	6,146.83	16,856.92	7,061.89	1,228.96	269.67	**31,564.27**
Pokegama Lake	0	1,317.78	1,569.53	1,263.85	132.18	589.37	**4,872.71**
Prairie Lake	19.33	5,386.89	2,193.65	1,708.38	349.91	1,436.66	**11,094.82**
Rice Creek	0	548.63	1,296.83	840.22	0.79	43.95	**2,730.42**
Short Creek	0	699.79	927.83	736.20	1.06	292.83	**2,657.71**
Tenmile Lake	0	90.94	279.36	220.90	70.17	352.99	**1,014.36**
Tenmile Creek	0	12,397.58	12,322.55	5,930.23	29.84	5,419.74	**36,099.94**
Total	**78.85**	**36,291.36**	**50,279.75**	**24,427.04**	**2,408.80**	**10,325.47**	**123,811.27**

Chetek Lakes Subwatersheds Percent of Total

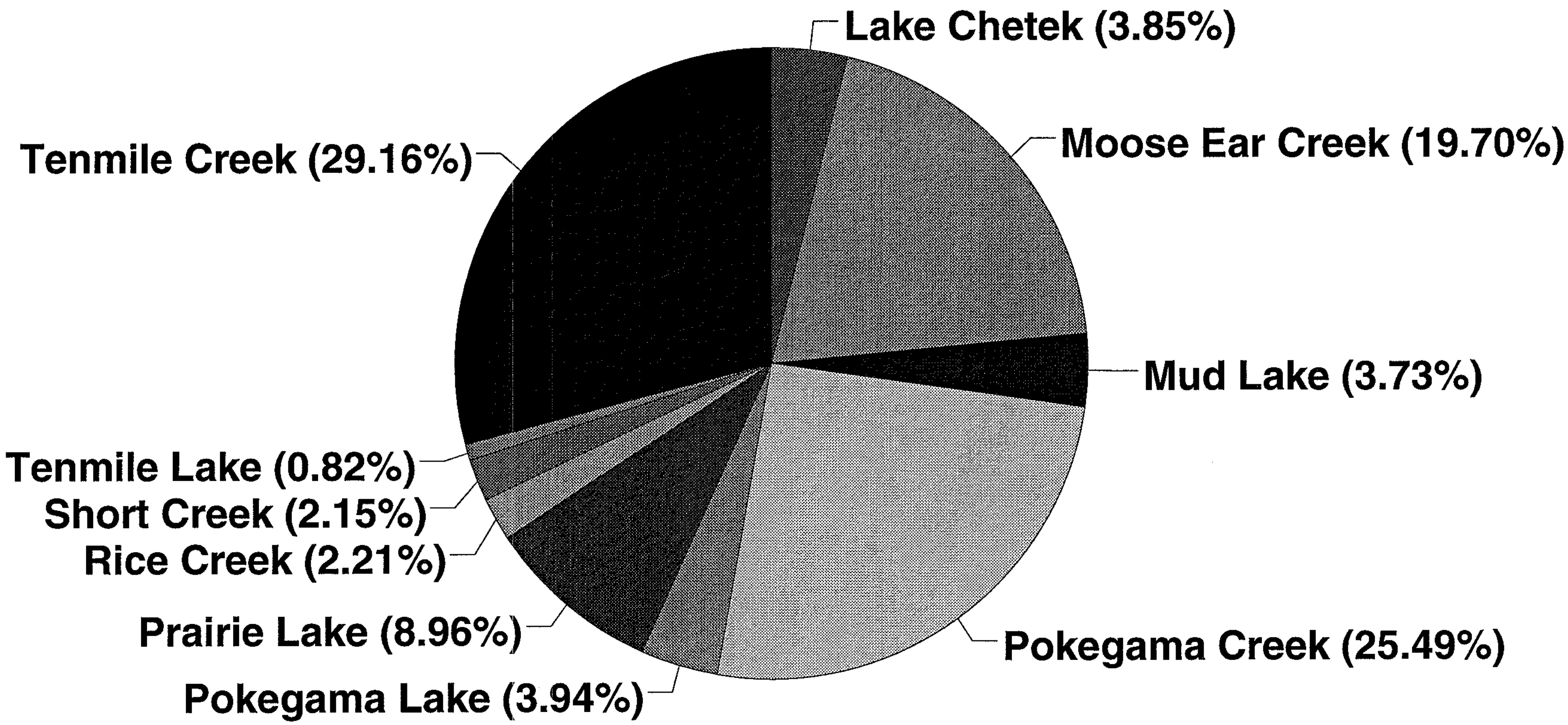


Figure 3

P:\49\03\005\report\subwater.wb2:Subwatershed%

4.4 Hydrologic Budget Determination

Seven rain gages within Chetek Lakes' watershed were read daily by volunteers to determine daily precipitation amounts. Measurements from North Ojaski (RG1), North End Prairie Lake (RG2), Central Prairie (RG3), Upper Pokegama (RG4), and East of Ten Mile Lake (RG5) were made between April and October 1996. Measurements from the Waste Water Treatment Plant (WWTP) and the Dam were made between October 1995 and March 1997. Daily high, low, and average air temperatures were measured at the Dam during the period October 1995 through March 1997.

Evaporation from the lake water surface area and surface runoff from the lake's direct watershed areas, during the study period, were 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. Wind speeds and humidity used for input in the Meyer Watershed Model were taken from 1996 data from the Minneapolis/St. Paul International Airport National Weather Service station. Average daily temperature readings and average daily and total monthly precipitation from the study area were used as input for predicting surface runoff in the model.

A staff gage at the Dam was read on a daily basis during the period October 1995 through March 1997. The staff gage readings were converted to mean sea level (M.S.L.) elevations and used to determine the change in lake storage.

A hydrologic (water) budget for Chetek Lakes, based on the 1995–96 water year (October 1, 1995 through September 30, 1996), was determined by measuring or estimating the important components of the budget. The important components of the budget include:

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

Due to the limited scope of the project, the net groundwater flow could not be estimated and was assumed to be negligible compared to the remaining budget components. Total lake outflow for the study period was determined by solving the water balance equation as presented below:

$$OF = P + RO - EVAP +/- S$$

Where:

OF	=	Lake Outflow
EVAP	=	Evaporation from the Lake's Surface
P	=	Direct Precipitation on the Lake's Surface
RO	=	Watershed Runoff
S	=	Change in Lake Storage

A relationship was developed between the continuous monitoring data from Moose Ear Creek and the corresponding available daily monitoring data from the three tributary sites that did not have continuous monitoring. This relationship was used to estimate the average daily flow rates at the three tributary sites that did not have continuous monitoring data.

4.5 Phosphorus Budget and Lake Water Quality Mass Balance Model

Numerous researchers have demonstrated the relationship between phosphorus loads, water loads and lake basin characteristics to the observed in-lake total phosphorus concentration. The relationship was used to verify the annual phosphorus load into Chetek Lakes based on average surface phosphorus concentrations, the lake's hydrologic budget, and lake basin characteristics. The relationship has many forms. The equation used for Chetek Lakes was adapted from one developed by Dillon and Rigler (1974), modified by Nurnberg (1984) and has the form of:

$$P = \frac{L_A (1 - R_P)}{Q_S} + \frac{L_I}{Q_S}$$

Where:

- P = is the mean phosphorus concentration
- L_A = amount of phosphorus added per unit surface area of lake from all sources except from the internal load of the lake
- R_P = the coefficient which describes the total amount of phosphorus retained by the sediments each year
- Q_S = the outflow of the lake divided by its surface area
- L_I = mass of phosphorus added to the lake from internal loading

For Chetek Lakes, all variables of the equation were measured or could be estimated based on data collected during the study. This equation was added to the Wisconsin Lake Model Spreadsheet

(WILMS) (Panuska and Wilson, 1994) and compared with the other predictive lake water quality equations already present in WILMS.

The overall Chetek Lakes phosphorus budget was determined using the tributary water quality data and corresponding watershed runoff volumes to determine phosphorus export coefficients for each of the subwatershed areas that drain the five main tributary streams. These data were combined with the export rates for each of the phosphorus input sources (or land uses) within the direct subwatersheds to estimate the total loads to each of the lake's basins. The phosphorus budget for Chetek Lakes was determined by measuring or estimating the important components of the budget. The important components of the budget include:

- Watershed Surface Runoff from Forested, Farm, Residential, Commercial/Industrial, Water, and Other Land Uses
- Internal Loading
- Atmospheric Wet and Dry Deposition on the Lake Surface
- Septic System Loading
- Monitored Tributaries
- Macrophyte Senescence

The watershed surface runoff component was estimated using an annual phosphorus export coefficient for each land use type within the direct subwatersheds. An annual phosphorus export coefficient of 0.08 kg/ha/yr was used for the forested portions of the subwatersheds. This value closely corresponds with the most likely default coefficient in the WILMS model (Panuska and Wilson, 1994), and that observed by Singer and Rust (1975). The cropland phosphorus export coefficient, used in this analysis, was either 0.86 or 1.16 kg/ha/yr. This choice of coefficients is based on the relative amounts of row crops and non-row crops within the typical crop rotations for each watershed and agrees well with that observed by others (Burwell et al., 1975; Alberts et al., 1978). The residential phosphorus export coefficient of 0.58 kg/ha/yr corresponds with other published data (Landon, 1977; Bannerman et al., 1983). Harms et al. (1974) obtained a phosphorus export coefficient of 0.22 kg/ha/yr, which corresponds well with the 0.25 kg/ha/yr used for the pasture/CRP land use within the subwatersheds. An annual phosphorus export coefficient of 0.10 kg/ha/yr. was used for wetland landuses within each subwatershed. This agrees with the most likely default coefficient in the WILMS model (Panuska and Lilly, 1995 and Corsi et al., 1997). The commercial/industrial export coefficient of 1.49 kg/ha/yr., used in this analysis, agrees well with Bannerman et al. (1983).

Internal loading (L_I in the above equation) was estimated for each of the lake basins using the total phosphorus data from the lake's water column. The summer internal load, for each basin, is the product of the fraction of hypolimnetic phosphorus released to the surface waters, the sediment phosphorus release rate, the fraction of the lake basin surface area experiencing anoxia, and the duration of hypolimnetic anoxia. The 1996 dissolved oxygen profiles of each basin were used to estimate the duration of anoxia (D.O. <0.5 mg/L). The fraction of each lake basin's total surface area experiencing anoxia was based on the depths of the observed summer anoxia and the morphometry of each basin. The average sediment total phosphorus release rate (typically in the range of 15–17 mg/m^2/day) was estimated using the total phosphorus data from each lake basin's water column and the relationship developed by Nurnberg (1986). Finally, the fraction of hypolimnetic total phosphorus released to the surface waters was estimated to facilitate the calibration of the lake mass balance model. For the calibrated model, this fraction ranged from 0.6 to 1.0 for each of the shallower lake basins (Pokegama, Tenmile and Mud Lakes). This release fraction agrees with that observed by Nurnberg and Peters (1984). The deeper lake basins (Chetek and Prairie Lakes) had release fractions less than 0.1 for the calibrated models. This agrees with the release fractions observed by Einsele (1936).

An atmospheric wet and dry deposition rate of 0.25 kg/ha/yr, which agrees well with the most likely export coefficient in the WILMS model (Panuska and Wilson, 1994) and others (Richardson and Merva, 1976; Eisenreich et al., 1977), was applied to the surface area of Chetek Lakes. The watershed runoff component from the tributary subwatersheds was estimated using measured inflow concentrations and measured runoff from each of the monitored watersheds.

Phosphorus export rate 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. The equation used for Chetek Lakes estimated the septic system load as follows:

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

Where:

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

The number of dwellings per lake was determined from information presented in *The Lakes of Barron County* (Thorson 1997). Permanent and seasonal dwellings were estimated based upon

The number of dwellings per lake was determined from information presented in *The Lakes of Barron County* (Thorson 1997). Permanent and seasonal dwellings were estimated based upon limited local information (Zehner, Personal Communication, 1998). The most likely soil retention coefficients of 90 and 40 were chosen for properly and improperly functioning systems, respectively. 10 percent of the septic systems were assumed to be improperly functioning, yielding a weighted soil retention coefficient of 85. Each permanent and seasonal dwelling unit was assumed to have four residents on average. The seasonal dwelling units were assumed to have been occupied 120 days per year.

Phosphorus loading from macrophyte senescence was estimated to be negligible for all portions of Chetek Lakes except Mud Lake. A dense growth of curlyleaf pondweed is found throughout Mud Lake. Curlyleaf pondweed dies off in late-June resulting in macrophyte senescence. Phosphorus loading from macrophyte senescence was estimated for Mud Lake. This source of phosphorus loading was estimated based on the total phosphorus content of the plant material (on a dry-weight basis), the plant growth density and the areal coverage of the plants within the lake basin. The areal coverage for Mud Lake was estimated to 303 acres, based on the lake basin area at the 10-foot depth. The estimated plant growth density was 28 grams of curyleaf pondweed (dry-weight basis) per $0.1m^2$ of lake surface area. This density is slightly higher than that observed at Big Lake (Barr, 1999). The curlyleaf pondweed total phosphorus content was assumed to be 0.4 percent, on a dry-weight basis. This value is slightly higher than the phosphorus content observed by Engel (Engel, 1985; and Personal Communication, 1999).

4.6 Chetek Lakes Survey

The Chetek Lakes Protection Association completed a membership survey during 1996. The survey was sent to a total of 190 property owners on Chetek Lakes. A total of 132 property owners completed and returned the survey, which is a 69 percent return rate. Survey questions solicited information regarding lake usage, water quality perceptions, and lake management desires of riparian owners.

5.0 Results and Discussion

5.1 Compiled Data

Water quality data acquired by the 1996 monitoring program are compiled in Appendices A through I. Appendices A through E present the tabulated in-lake water quality data for the five lake basins. Selected water quality parameters from Appendices A through E are analyzed and summarized in the discussion below. Appendix F contains the tabulated inflow/outflow measurements of total phosphorus. From these results, the flux of phosphorus from the watershed was calculated and used to calibrate the phosphorus mass balance model. Lake level data used to determine changes in lake volume are shown in Appendix G. Appendix H contains the precipitation data collected by Chetek Lakes Protection Association volunteers, the Waste Water Treatment Plant operator, and the Dam operator. Appendix I presents the results of an aquatic plant survey completed by the WDNR during August of 1997. Appendix J presents the Chetek Lakes' hydrologic and phosphorus budgets. Appendix K presents the results of a survey of Chetek Lakes Protection Association members.

5.2 Seasonal Patterns in 1996 Water Quality Conditions

An evaluation of 1996 Chetek Lakes water quality data was completed to evaluate the extent of present water quality degradation. The evaluation was based upon a standardized lake rating system. The rating system uses the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency measurements to assign the lake to a water quality category that best describes its water quality. Water quality categories include oligotrophic (i.e., excellent water quality), mesotrophic (i.e., good water quality), eutrophic (i.e., poor water quality), and hypereutrophic (i.e., very poor water quality).

5.2.1 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 Chetek Lakes, June through August N:P ratios for lake sampling locations were evaluated. Based on the data presented in Table 8, algal growth in Tenmile Lake appeared to be nitrogen-limited throughout the 1996 summer period. This means that the lake had excess phosphorus relative to the lake's nitrogen concentration. Algal growth in Prairie, Mud, Pokegama, and Chetek lakes appeared to be phosphorus-limited during the early-summer and nitrogen-limited during the late-summer period. This means that the lake had excess nitrogen relative to the lake's phosphorus concentration during the early-summer. However, by late-summer, the reverse situation occurred. Summer average N:P ratios indicate all lakes, on average, were phosphorus-limited except Tenmile Lake.

Table 8 **1996 Chetek Lakes Surface Water June Through August N:P Ratios**

Lake	N:P Ratios						
	06/03	06/17-06/19	07/10	07/23	08/06	08/19-08/20	Summer Average
Mud	13	18	--	11	12	10	13
Prairie	17	18	11	18	10	7	14
Pokegama	--	16	11	13	12	12	13
Tenmile	11	6	8	10	8	10	9
Chetek	16	22	13	13	12	10	14

Several blue-green algal species (e.g., *Aphanizomenon, Anabaena, Microcystis*) are able to produce the nitrogen they need for growth through nitrogen fixation. Nitrogen fixing species are able to out-compete other algal species when nitrogen is the lake's limiting nutrient. Their growth is stimulated by excess phosphorus. The excess phosphorus in Chetek Lakes provides the ideal habitat for nitrogen-fixing blue-green algal growth. If nitrogen fixing blue-green species are dominant in Chetek lakes, then phosphorus is the nutrient that limits algal growth.

Total phosphorus data collected from Chetek Lakes during 1996 were generally within the hypereutrophic (i.e., very poor water quality) category during the spring, eutrophic (i.e., poor water quality) category during the early-summer period, and hypereutrophic (i.e., very poor water quality) category during the late-summer period (Figures 4 through 8). Tenmile Lake was generally more nutrient-rich than the other lakes and noted phosphorus concentrations within the hypereutrophic category throughout the monitoring period. The following ranges in phosphorus concentrations were observed in the five lakes:

- Mud Lake—0.051 to 0.139 mg/L
- Prairie Lake—0.037 0.164 mg/L
- Pokegama Lake—0.051 to 0.134 mg/L
- Tenmile Lake—0.070 to 0.113 mg/L
- Chetek Lake—0.045 to 0.100 mg/L

All lakes noted an increase in phosphorus during the mid-June through mid-July period. However, Mud Lake noted a much higher increase in phosphorus during this period than the other lakes. In Mud Lake, a dense growth of curly leaf pondweed died off in late-June and the data indicate that senescence added a large pulse of phosphorus to the lake. During the period June 18 through July 10 of 1996, the lake's 0- to 2-meter phosphorus concentration nearly tripled. Phosphorus-rich Mud Lake waters flowing into Pokegama Lake during the mid-June to mid-July period contributed towards the observed 75 percent increase in Pokegama Lake's 0- to 2-meter phosphorus concentration. Prairie, Tenmile, and Chetek lakes observed 0- to 2-meter phosphorus concentration increases of approximately 50 percent during this period.

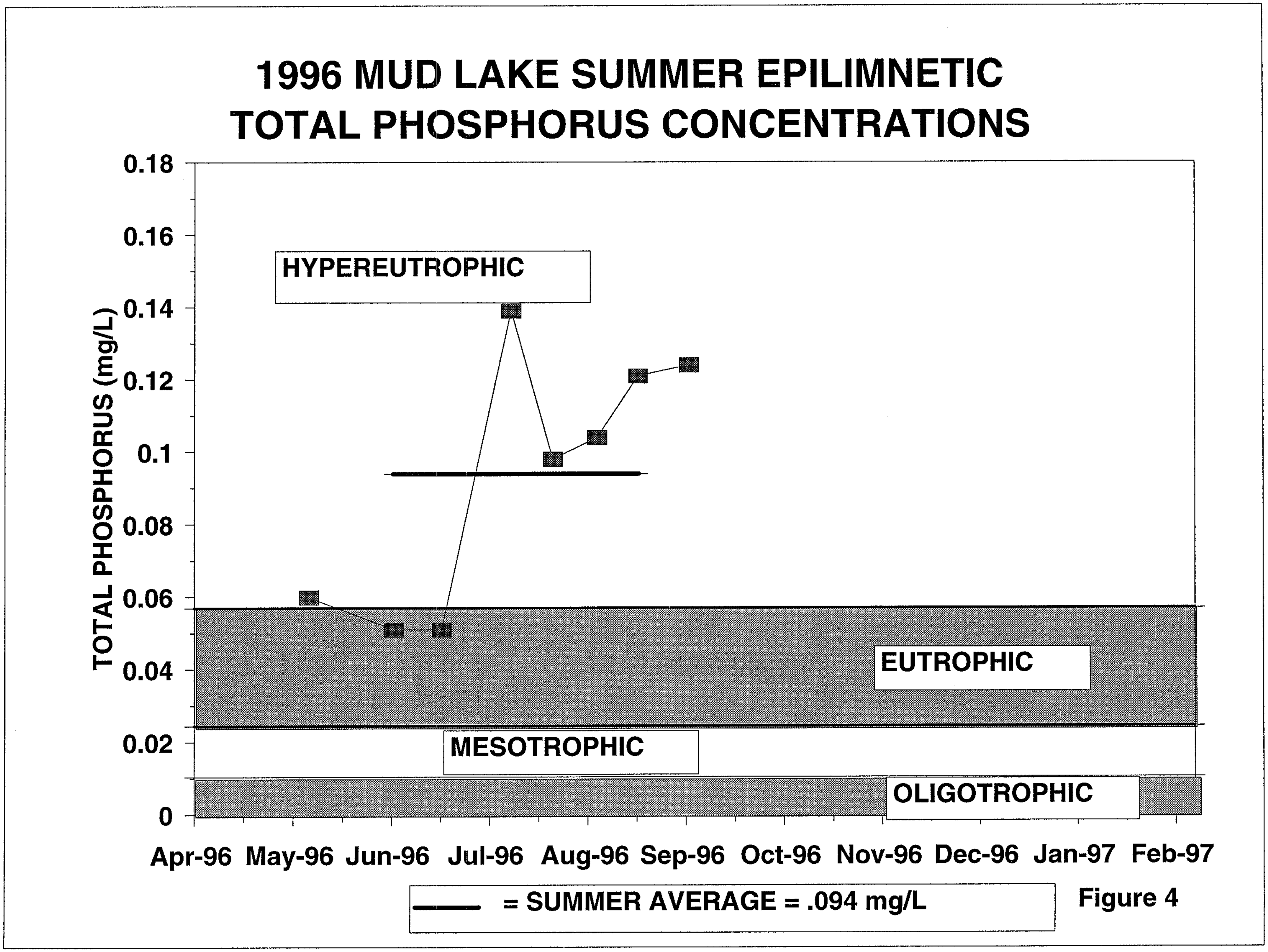


Figure 4

P:\49\03\005\qpw\tpgraph.wb2:Tenmiletpgr

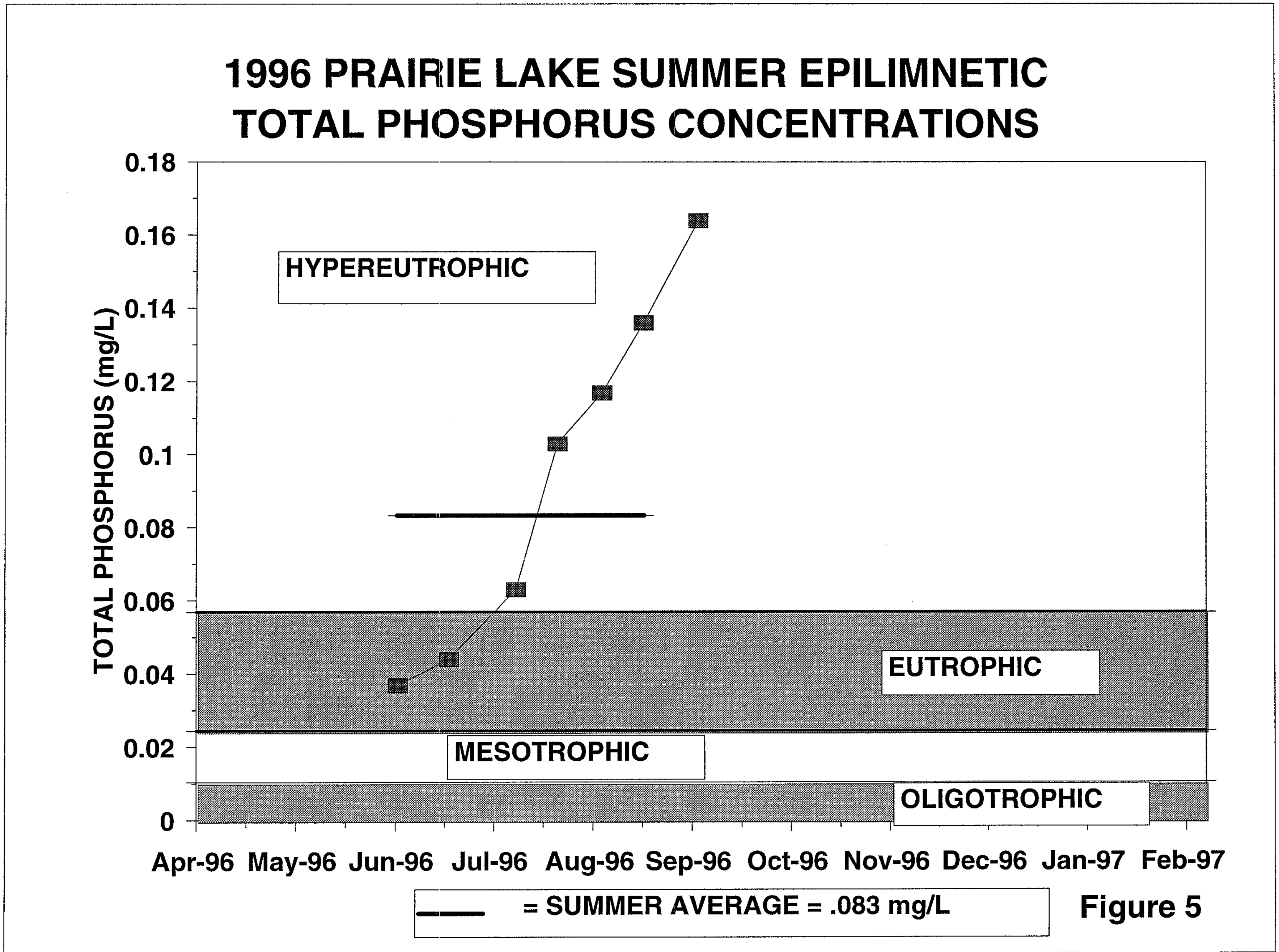


Figure 5

P:\49\03\005\qpw\tpgraph.wb2:Tenmiletpgr

1996 POKEGAMA LAKE SUMMER EPILIMNETIC TOTAL PHOSPHORUS CONCENTRATIONS

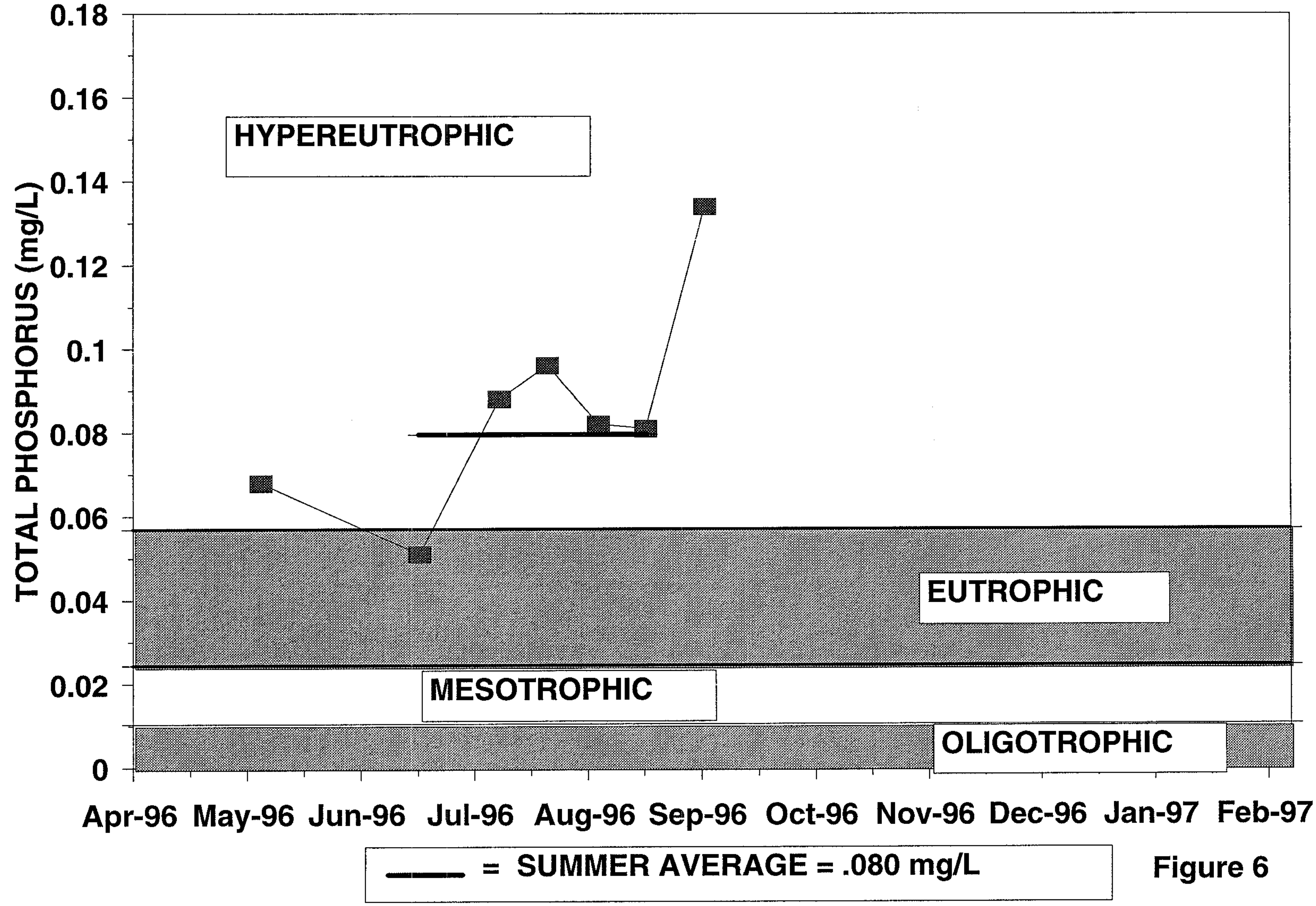
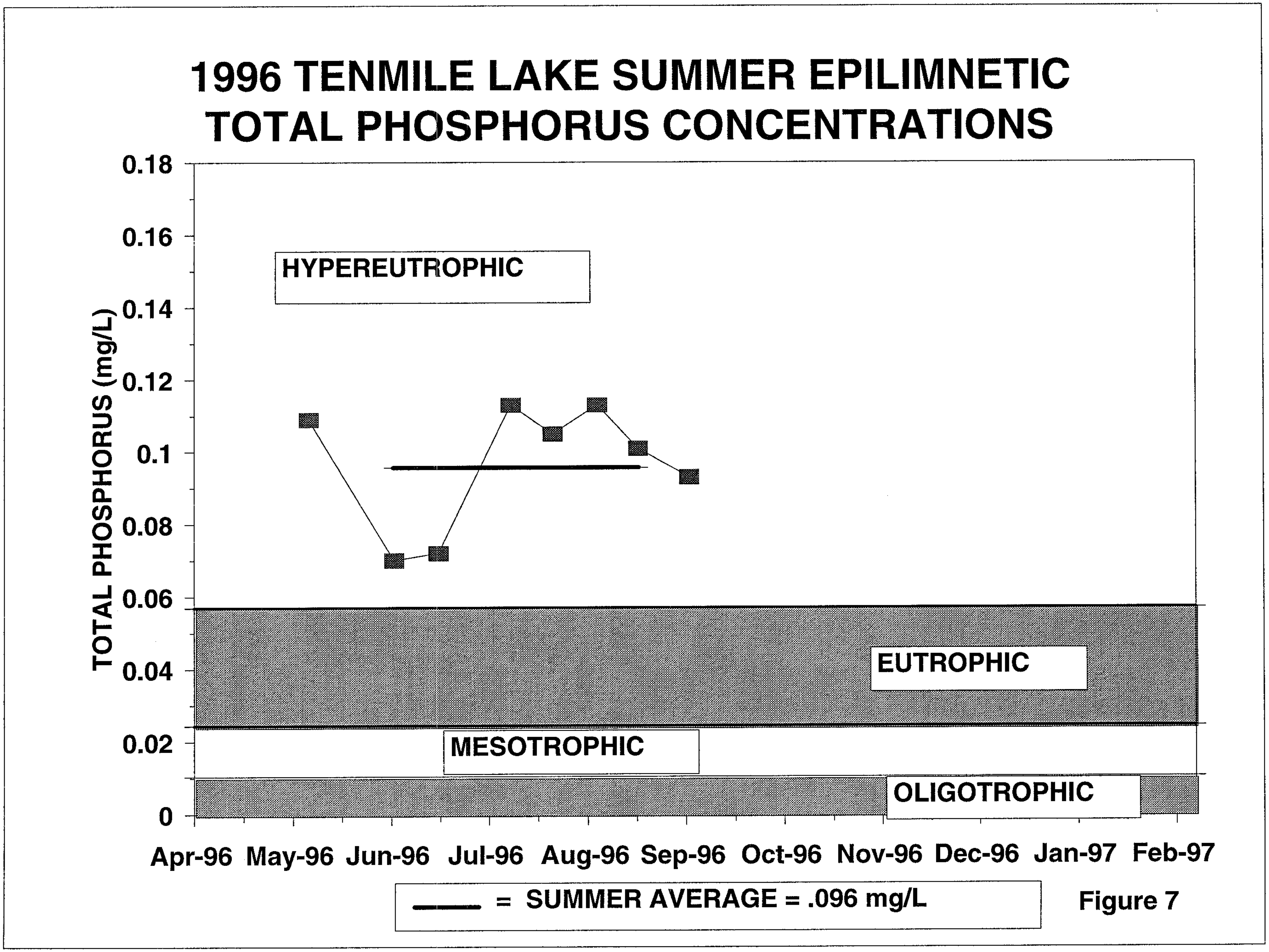


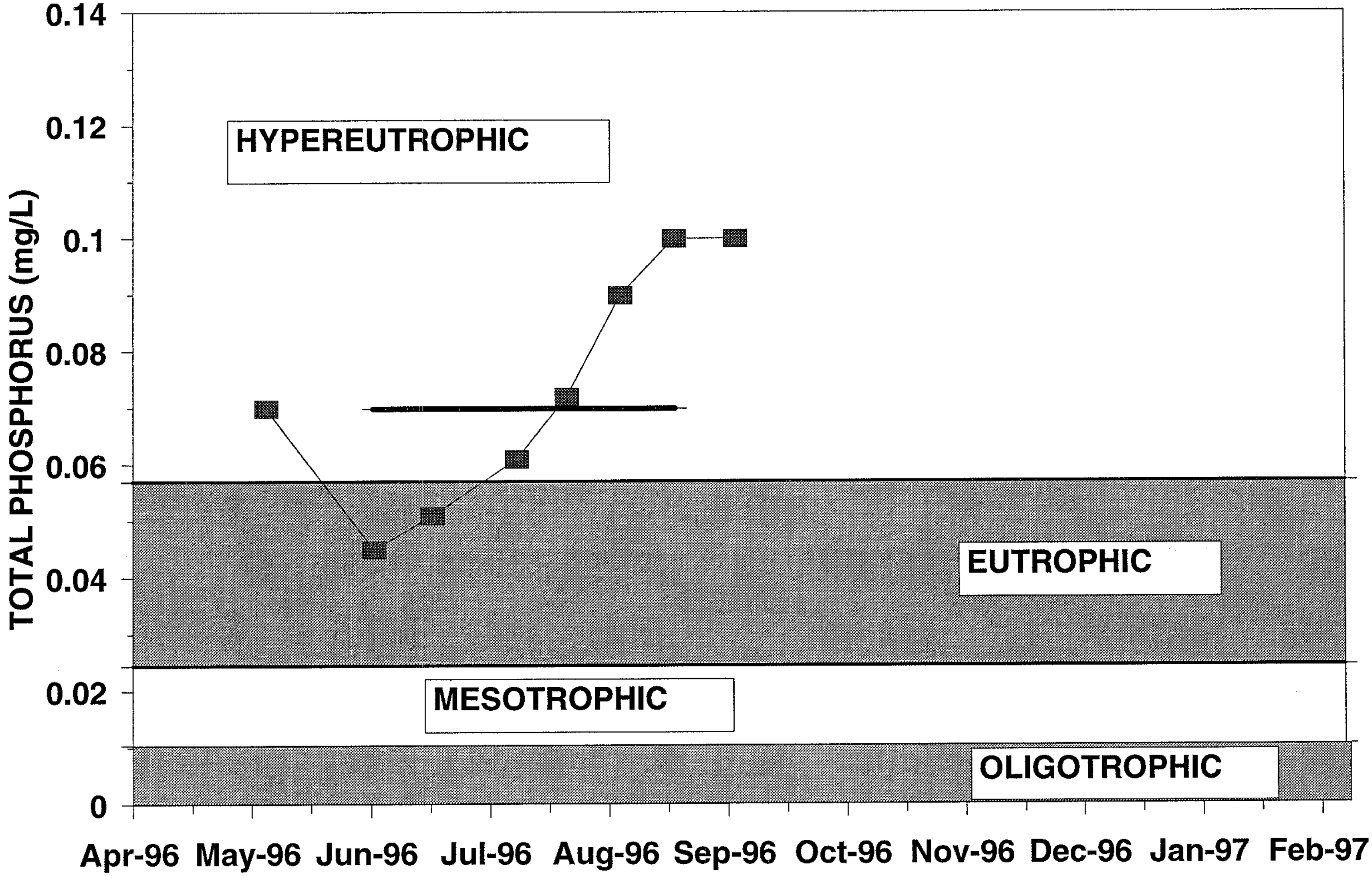
Figure 6

P:\49\03\005\qpw\tpgraph.wb2:Pokegamatpgr



P:\49\03\005\qpw\tpgraph.wb2:Tenmiletpgr

1996 LAKE CHETEK SUMMER EPILIMNETIC TOTAL PHOSPHORUS CONCENTRATIONS



—— = SUMMER AVERAGE = .070 mg/L

Figure 8

5.2.2 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 1996 Chetek Lakes chlorophyll *a* data indicate that all basins experienced severe algal blooms throughout the summer period. Chlorophyll *a* data were generally within the eutrophic (i.e., poor water quality) category during the early-summer period and hypereutrophic (i.e., very poor water quality) during the late-summer period (See Figures 9 through 13). Tenmile Lake observed poorer water quality than the other basins and chlorophyll *a* concentrations were in the hypereutrophic (i.e., very poor water quality) category throughout the summer period. The seasonal pattern of chlorophyll *a* concentrations was similar to phosphorus concentrations in the basins, confirming that the lake's algal growth is directly related to phosphorus levels.

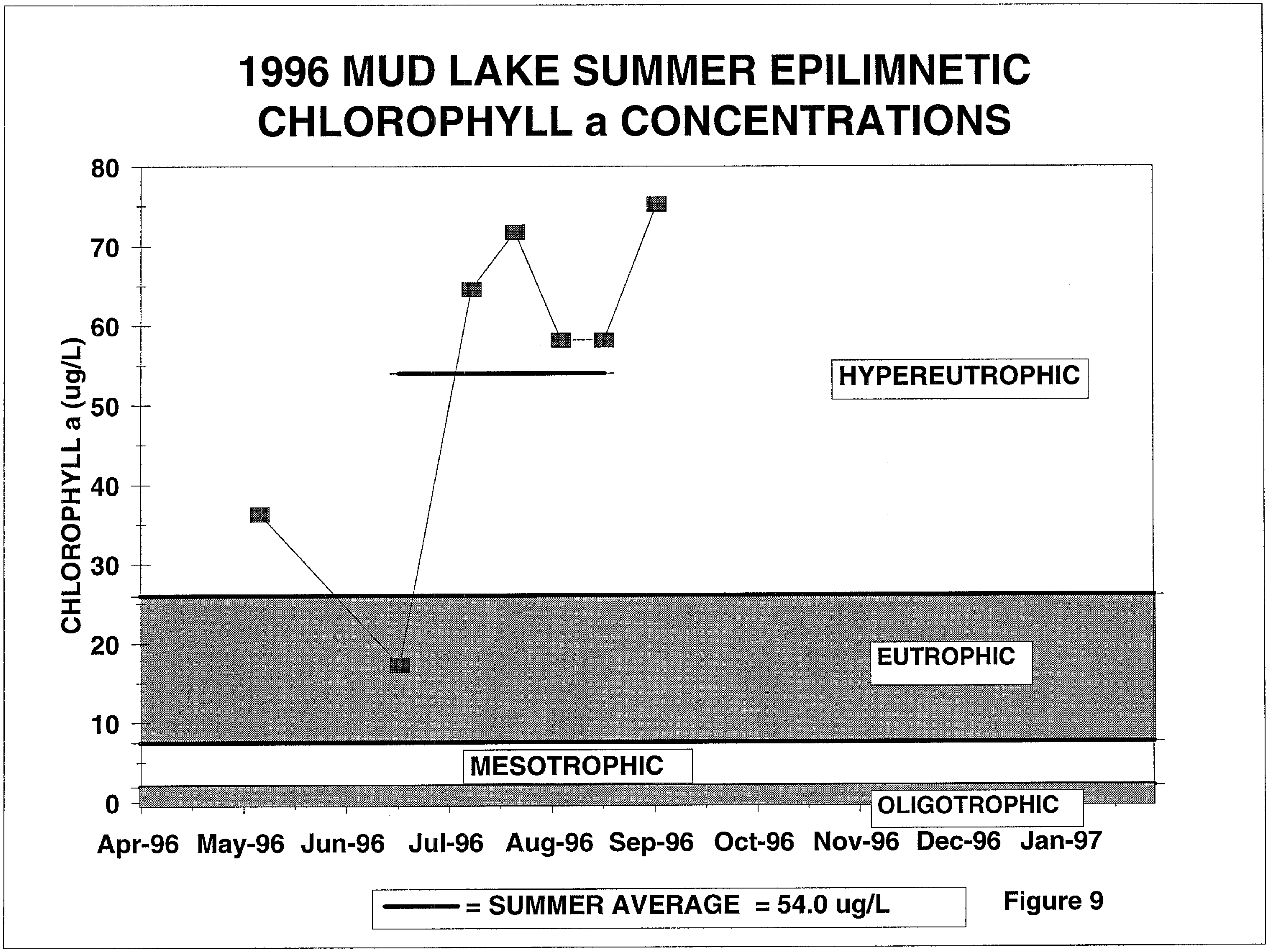


Figure 9

P:\49\03\005\qpw\chlorogr.wb2:Tenmilechloro

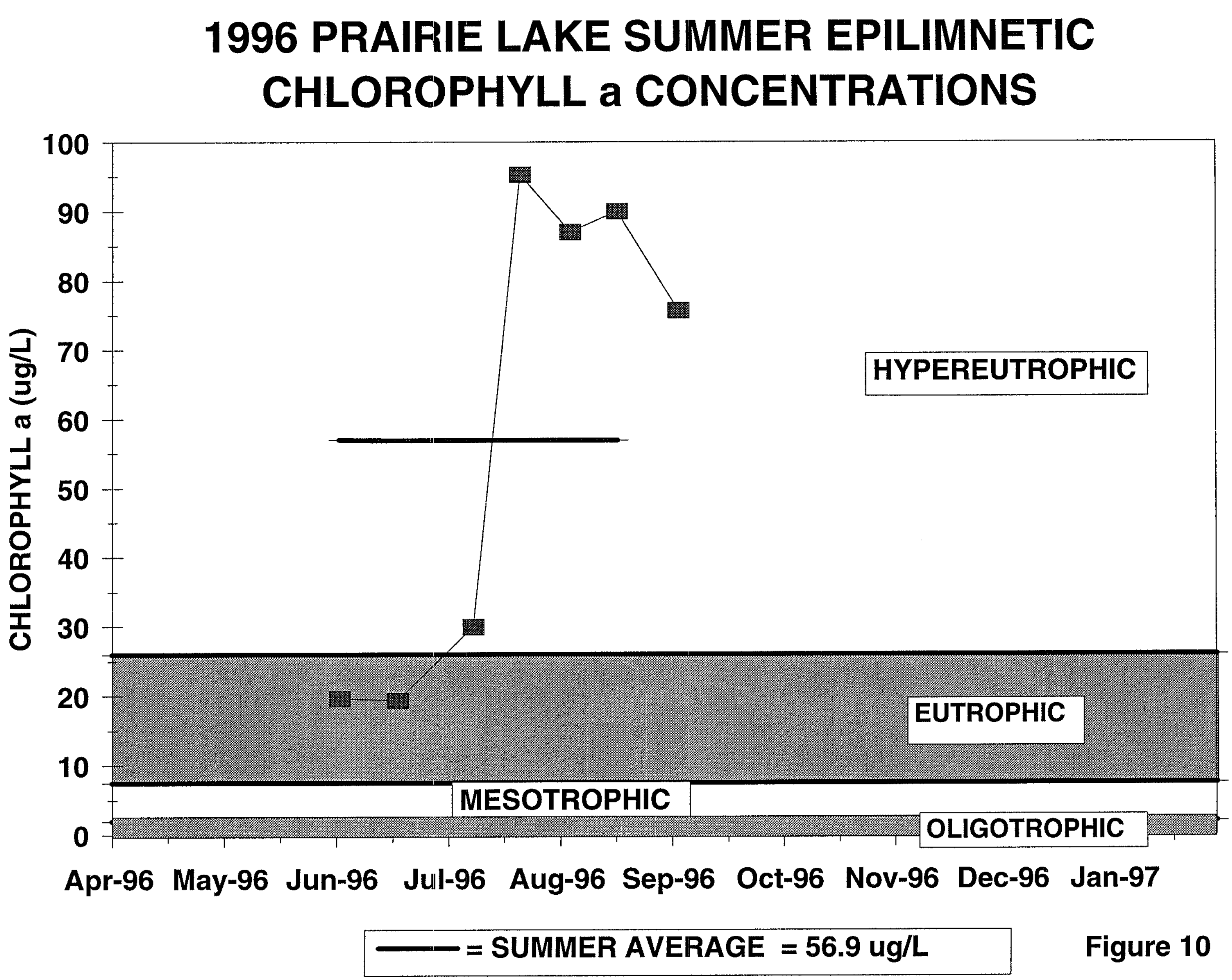

1996 PRAIRIE LAKE SUMMER EPILIMNETIC
CHLOROPHYLL a CONCENTRATIONS
CHLOROPHYLL a (ug/L)
100
90
80
70
60
50
40
30
20
10
0
HYPEREUTROPHIC
EUTROPHIC
MESOTROPHIC
OLIGOTROPHIC
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97
= SUMMER AVERAGE = 56.9 ug/L

Figure 10

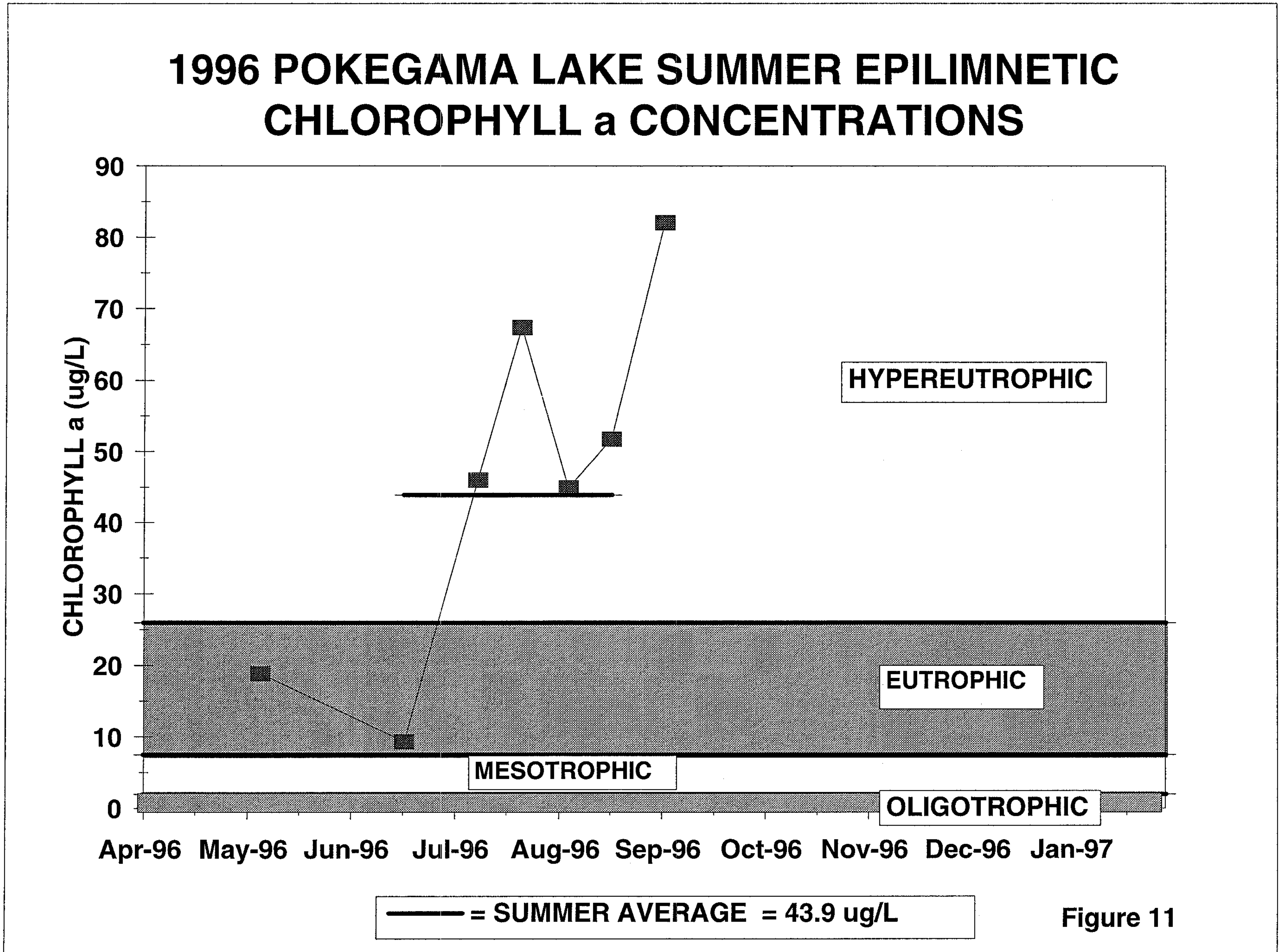


Figure 11

P:\49\03\005\qpw\chlorogr.wb2:Pokegamachloro

1996 TENMILE LAKE SUMMER EPILIMNETIC CHLOROPHYLL a CONCENTRATIONS

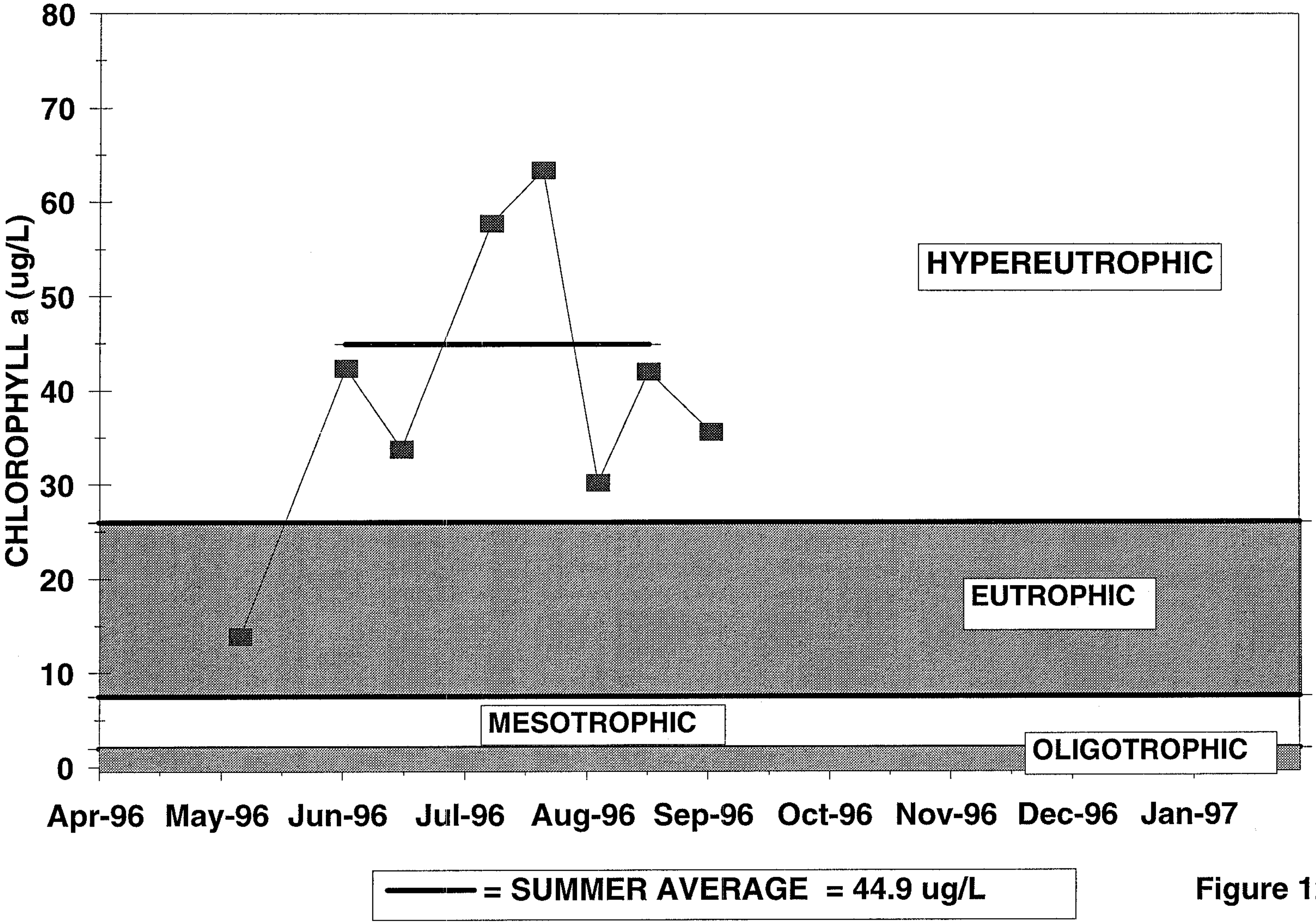


Figure 12

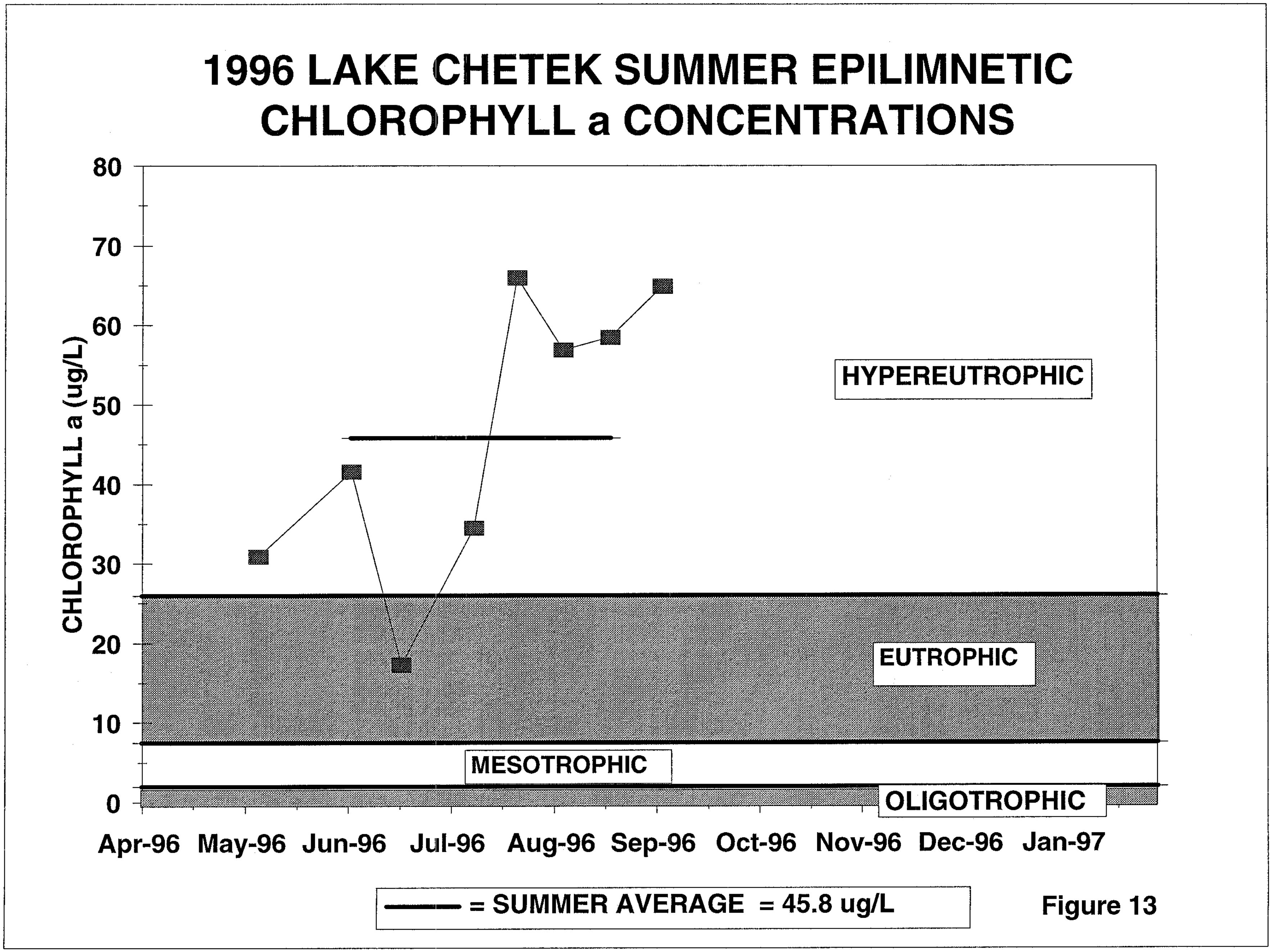


Figure 13

P:\49\03\005\qpw\chlorogr.wb2:Tenmilechloro

5.2.3 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 (Osgood, 1989) revealed the following relationship between a lake's recreational use impairment and Secchi disc transparencies:

- *Moderate to severe use-impairment occurs at Secchi disc transparencies less than 1 meter (3.3 feet).*
- *Moderate impairment occurs at Secchi disc transparencies of 1 to 2 meters.*
- *Minimal impairment occurs at Secchi disc transparencies of 2 to 4 meters.*
- *No impairment occurs at Secchi disc transparencies greater than 4 meters*

Secchi disc measurements in Chetek Lakes generally mirrored phosphorus and chlorophyll *a* concentrations. Mud Lake, Prairie Lake, and Pokegama Lake observed Secchi disc measurements in the eutrophic (i.e., poor water quality) category during June and observed measurements in the hypereutrophic (i.e., very poor water quality) category during July through September (See Figures 14 through 16). Chetek Lake observed measurements in the eutrophic (i.e., poor water quality) category during June through July and measurements in the hypereutrophic (i.e., very poor water quality) category during August through September (See Figure 17). Tenmile Lake observed measurements in the eutrophic (i.e., poor water quality) category during June through early-August and measurements in the hypereutrophic (i.e., very poor water quality) category during late-August through September (See Figure 18).

The Secchi disc measurements indicate that Lake Chetek and Tenmile Lake observed better water clarity than the other lakes during the late- summer period despite having similar or greater quantities of chlorophyll *a* (i.e., a measure of the quantity of algae in the water). The differences in water clarity are believed caused by differences in algal species rather than differences in water quality. Differences in algal sizes and shapes result in differences in the way that light scatters when it shines through the water. Light scattering differences result in differences in water clarity. Hence, a different mix of algae in two basins can result in water clarity differences even if the basins have the same quantity or mass of algae. A comparison of water clarity measurements in the five basins on each sampling date indicates the water clarity measurements at Lake Chetek and Tenmile Lake were from 2 inches to 13 inches higher than the water clarity measurements observed at the other three basins during the June through September period.

Water clarity is correlated with recreational-use of a lake and poor water clarity results in recreational-use impairment. Secchi disc measurements indicate moderate recreational-use impairment occurred during June in Mud, Prairie, and Pokegama lakes; the data indicate severe recreational-use impairment occurred during July through September in these lakes. Secchi disc measurements indicate moderate recreational-use impairment occurred in Lake Chetek during June through July; the data indicate severe recreational-use impairment occurred in the lake during August through September. Secchi disc measurements in Tenmile Lake indicate severe recreational-use impairment occurred during June, moderate recreational use impairment occurred during July, and severe recreational-use impairment occurred during August through September.

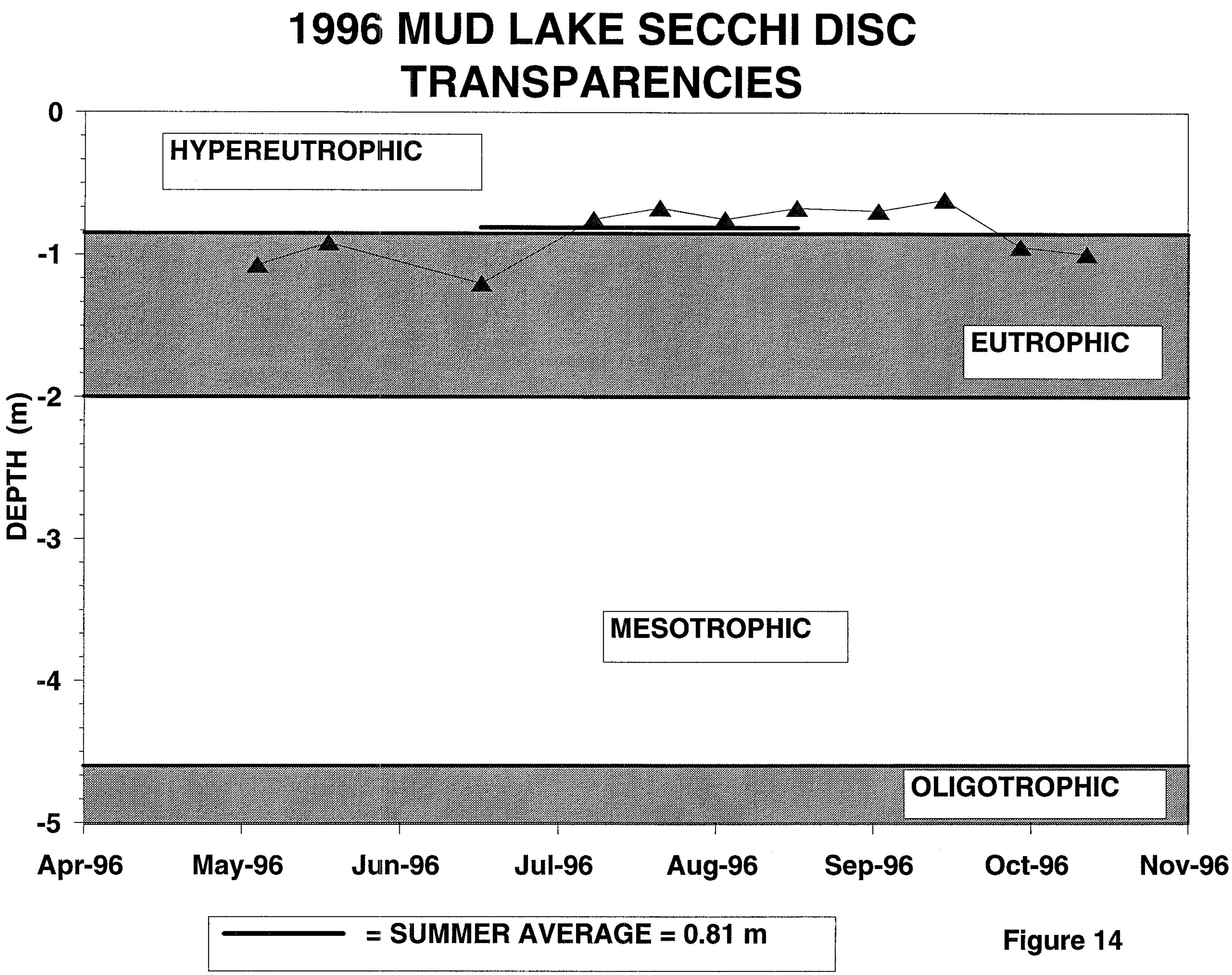


Figure 14

P:\49\03\005\qpw\secgraph.wb2:Prairiesecchi

1996 PRAIRIE LAKE SECCHI DISC TRANSPARENCIES

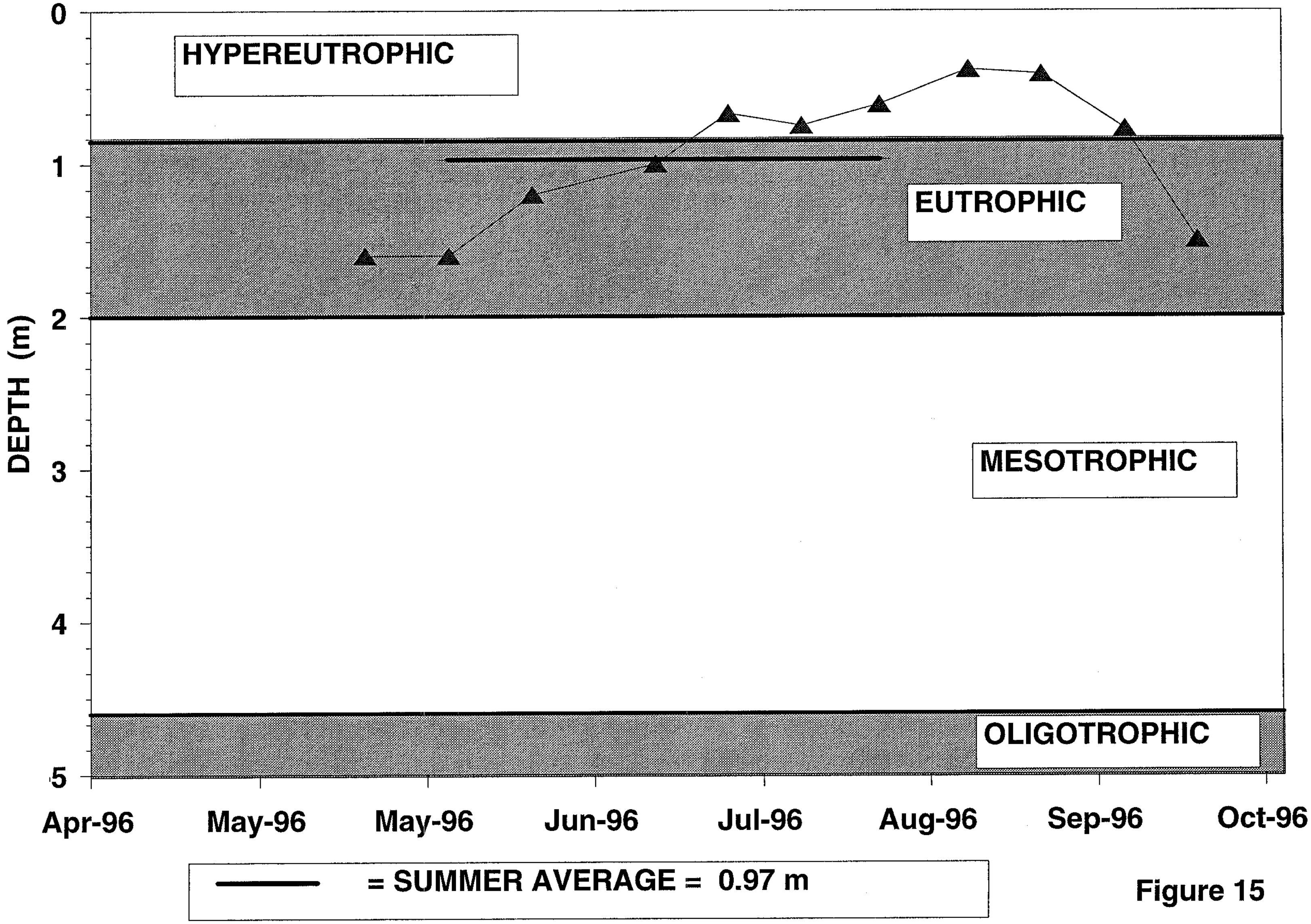
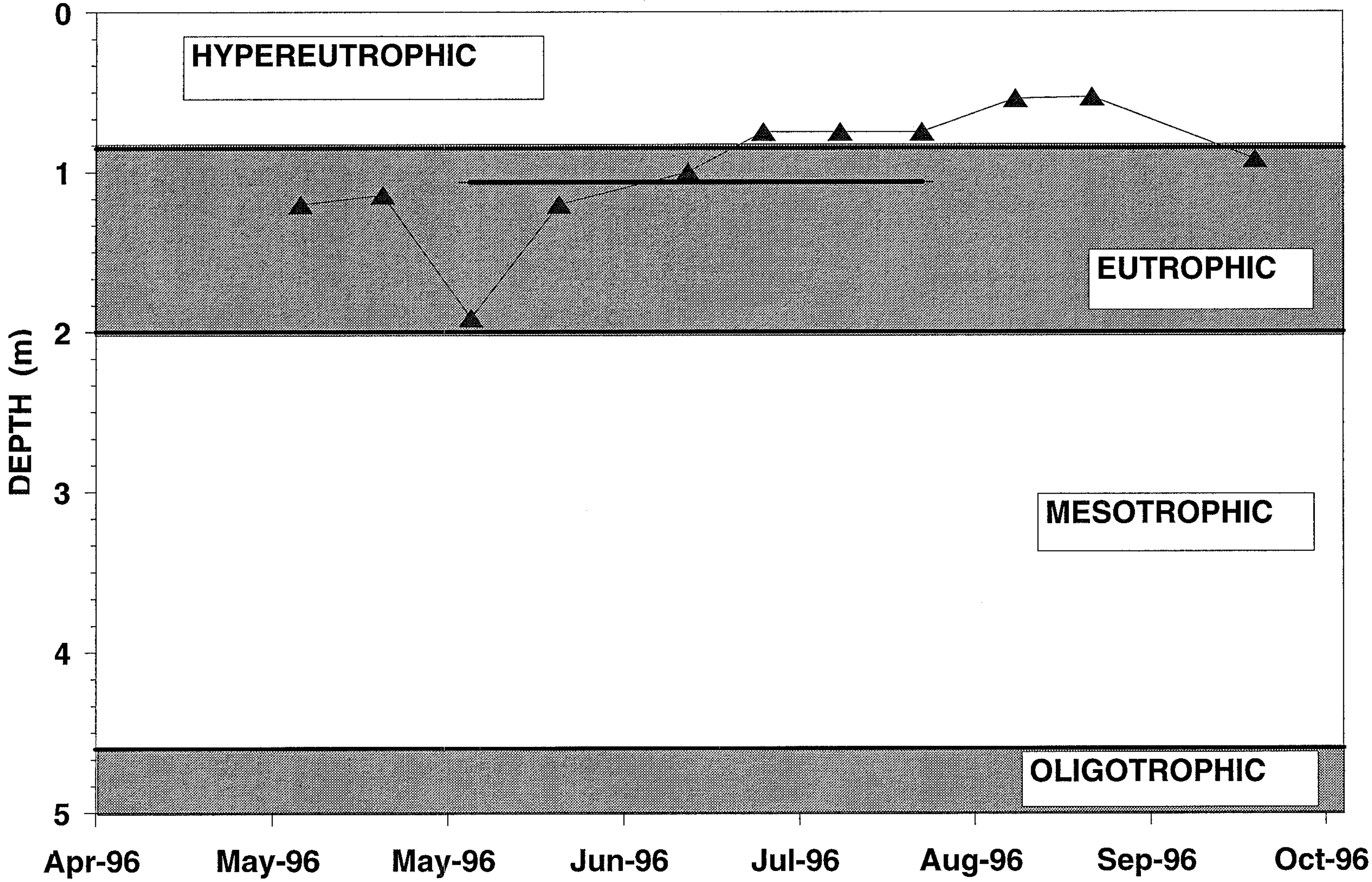


Figure 15

P:\49\03\005\qpw\secgraph.wb2:Prairiesecchi

1996 POKEGAMA LAKE SECCHI DISC TRANSPARENCIES



—— = SUMMER AVERAGE = 1.06 m

Figure 16

P:\49\03\005\qpw\secgraph.wb2:Mudsecchi

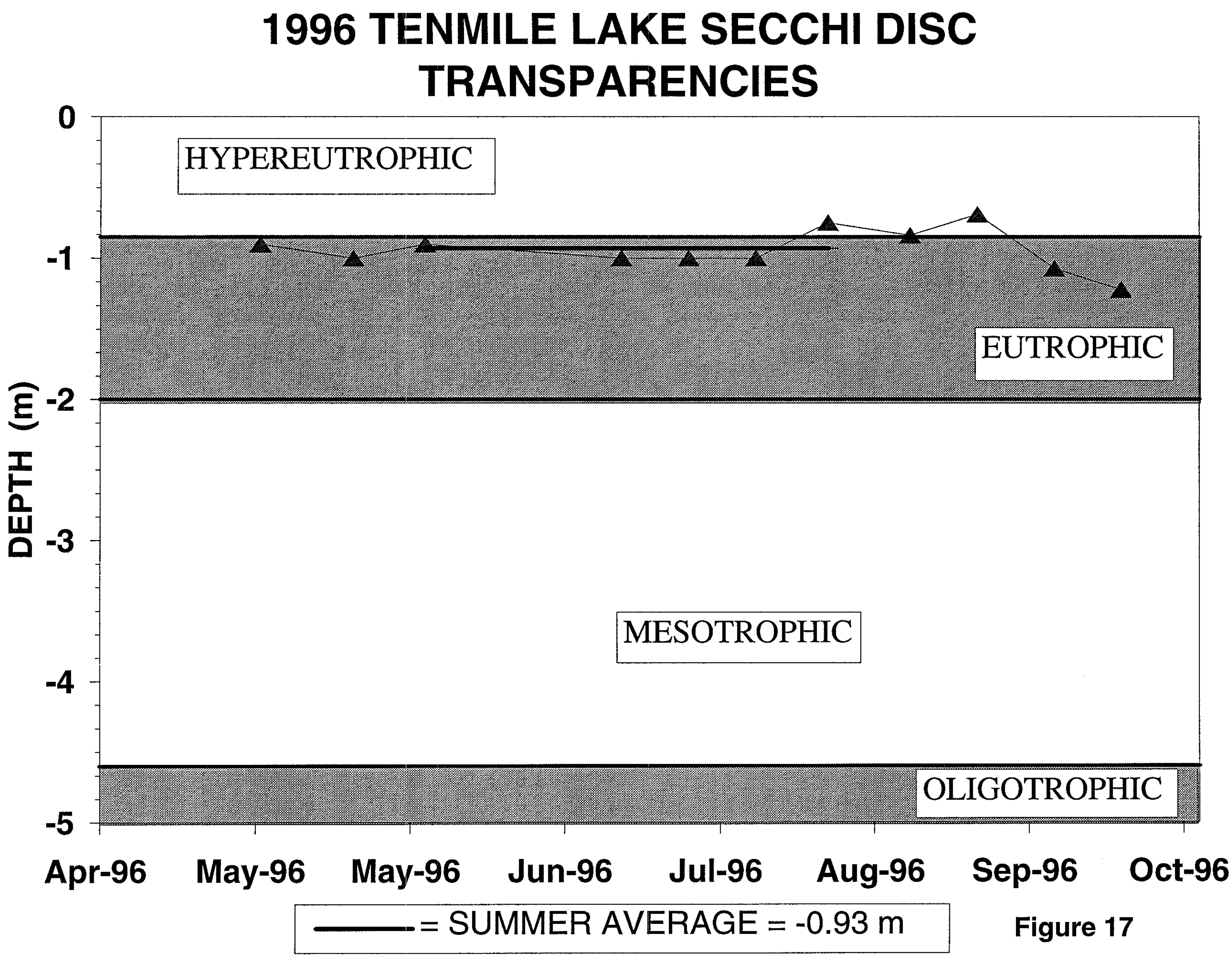


Figure 17

P:\49\03\005\qpw\secgraph.wb2:Prairiesecchi

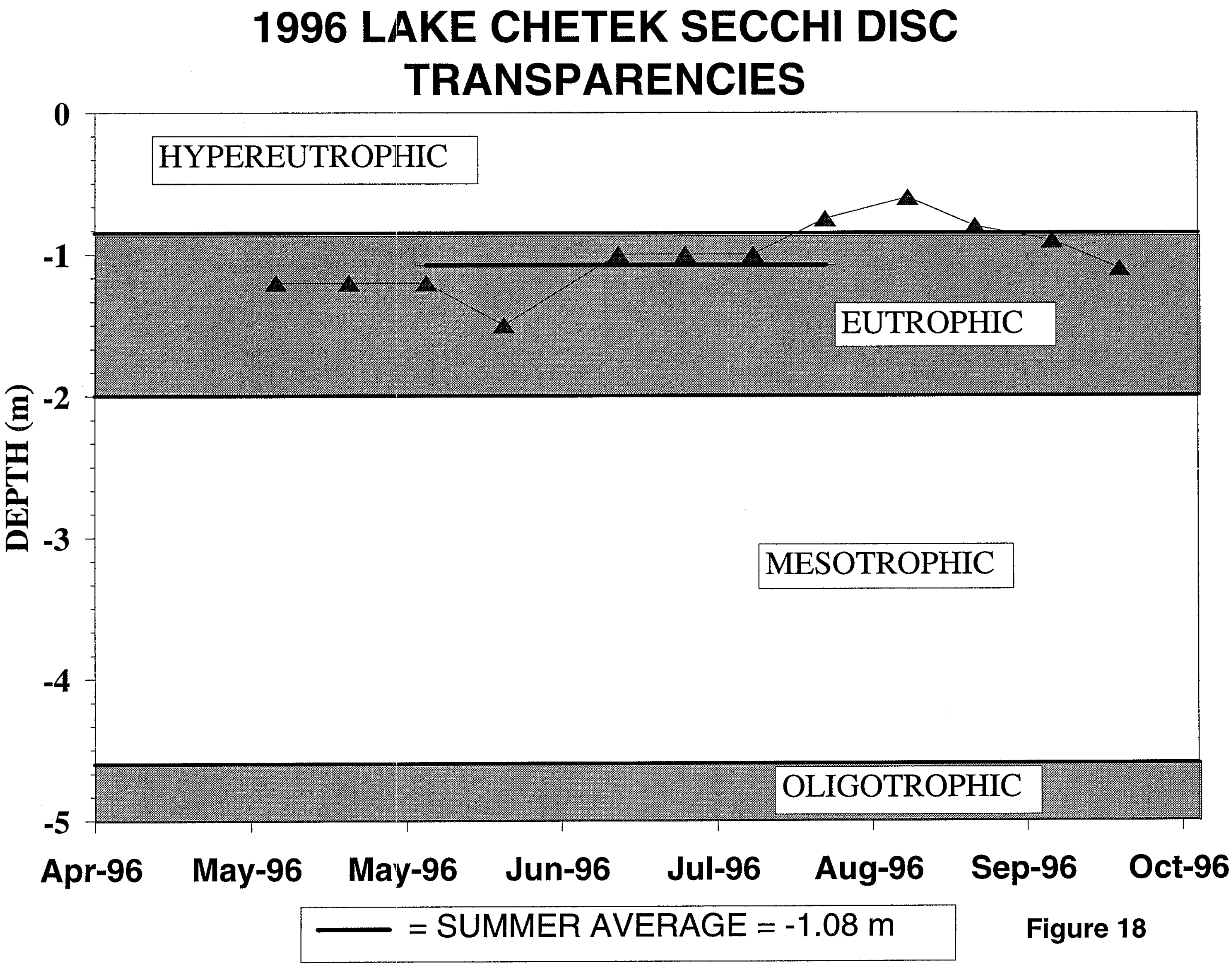


Figure 18

P:\49\03\005\qpw\secgraph.wb2:Prairiesecchi

5.2.4 Temperature, Dissolved Oxygen, Specific Conductance, and 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, total phosphorus, and specific conductance were prepared for the five basins. The temperature isopleth diagrams (Figures 19 through 23) indicate all basins observed weak stratification during the summer period and were completely mixed during the spring and fall periods.

The dissolved oxygen isopleth (Figures 24 through 28) diagrams show dissolved oxygen concentrations near the lake bottom were near zero during July at Mud, Pokegama, and Chetek lakes and were near zero at all basins during August. Oxygen depletion occurs in the bottom waters when algal cells and other organic matter on the lakes' bottom decompose. Consequently, as the quantity of algal cells in the lakes increases, the rate of decomposition at the lakes' bottom also increases. During the summer period, highest quantities of algal cells were observed during August when lowest oxygen concentrations in the lakes' bottom waters were observed. Oxygen depletion of the bottom waters reduces the available habitat for organisms (e.g., fish and zooplankton). A dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish. Table 9 shows the portions of each lake containing oxygen concentrations of 5 mg/L or larger during the sampling period.

The period of oxygen depletion in the hypolimnion matches the period of apparent internal phosphorus loading, shown in the total phosphorus isopleth diagrams (Figures 29 through 33). The importance of the internal phosphorus load to the lake's annual load is discussed later in Section 5.8 "Phosphorus Budget and Lake Water Quality Mass Balance Model." The specific conductance isopleth diagrams (Figures 34 through 38) provide confirming evidence of apparent internal phosphorus loading. Specific conductance provides a general measurement of dissolved solids, including phosphorus. Increased levels of dissolved solids in the anoxic (i.e., void of oxygen) bottom waters suggests internal phosphorus loading may be occurring.

During the winter months, ice cover prevents the introduction of oxygen to the lakes via wind mixing. Streams flowing into the lakes, however, supply oxygen whenever flow occurs. As shown in Table 9, depletion of oxygen throughout the winter period reduced the quantity of oxygen in the lakes. Depletion results from decomposition at the lakes' bottom and from respiration by fish and other animals living in the lake. Tenmile Lake observed the highest oxygen levels during the winter period and Prairie Lake observed the lowest oxygen levels during this period. During the winter period (i.e., February measurement), Tenmile lake was the only basin to observe oxygen levels greater than 5 mg/L from the lake's surface to its bottom. Mud, Pokegama, and Chetek lakes observed oxygen measurements greater than 5 mg/L from the lakes' surface to the six foot depth. Prairie Lake observed oxygen levels greater than 5 mg/L from the lake's surface to the three foot depth. Winter aeration in Prairie Lake prevents winterkill.

Table 9 **Summary of Lake Depths Containing at Least 5 mg/L Oxygen**

Lake	Maximum Depth (Feet)	Range of Lake Depths Containing at Least 5 mg/L Oxygen (Feet)			
		Spring Period (May)	Summer Period (June-August)	Fall Period (September-October	Winter Period (February)
Mud	15	Surface to Bottom	Minimum -- 0-6; Maximum - 0-10	Minimum -- 0-6; Maximum - 0-13	0-6
Prairie	16	0-13	Minimum -- 0-10; Maximum - 0-13	Minimum -- 0-10; Maximum - 0-13	0-3
Pokegama	19	Minimum -- 0-13; Maximum - Surface to Bottom	Minimum -- 0-6; Maximum - Surface to Bottom	Minimum -- 0-6; Maximum - 0-16	0-6
Tenmile	12	Minimum -- 0-6 Maximum - Surface to Bottom	Minimum -- 0-3; Maximum - Surface to Bottom	Minimum -- 0-6; Maximum - Surface to Bottom	Surface to Bottom
Chetek	22	Surface to Bottom	Minimum -- 0-13; Maximum - 0-16	Minimum -- 0-13; Maximum - 0-16	0-6

1996 Mud Lake Time-Depth Diagram of Temperature Isopleths (degrees C)

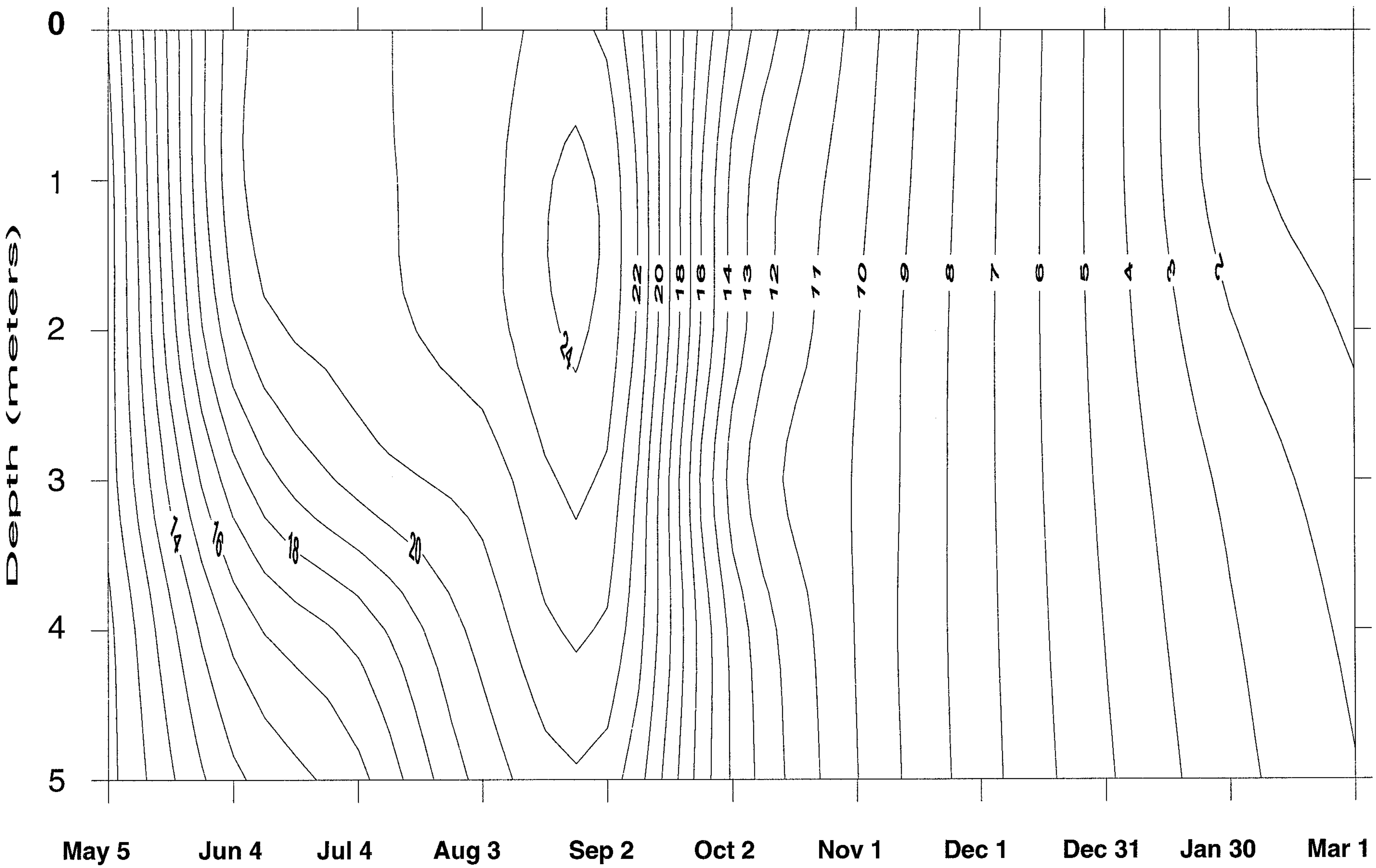


Figure 19

1996 Prairie Lake Time-Depth Diagram of Temperature Isopleths (degrees C)

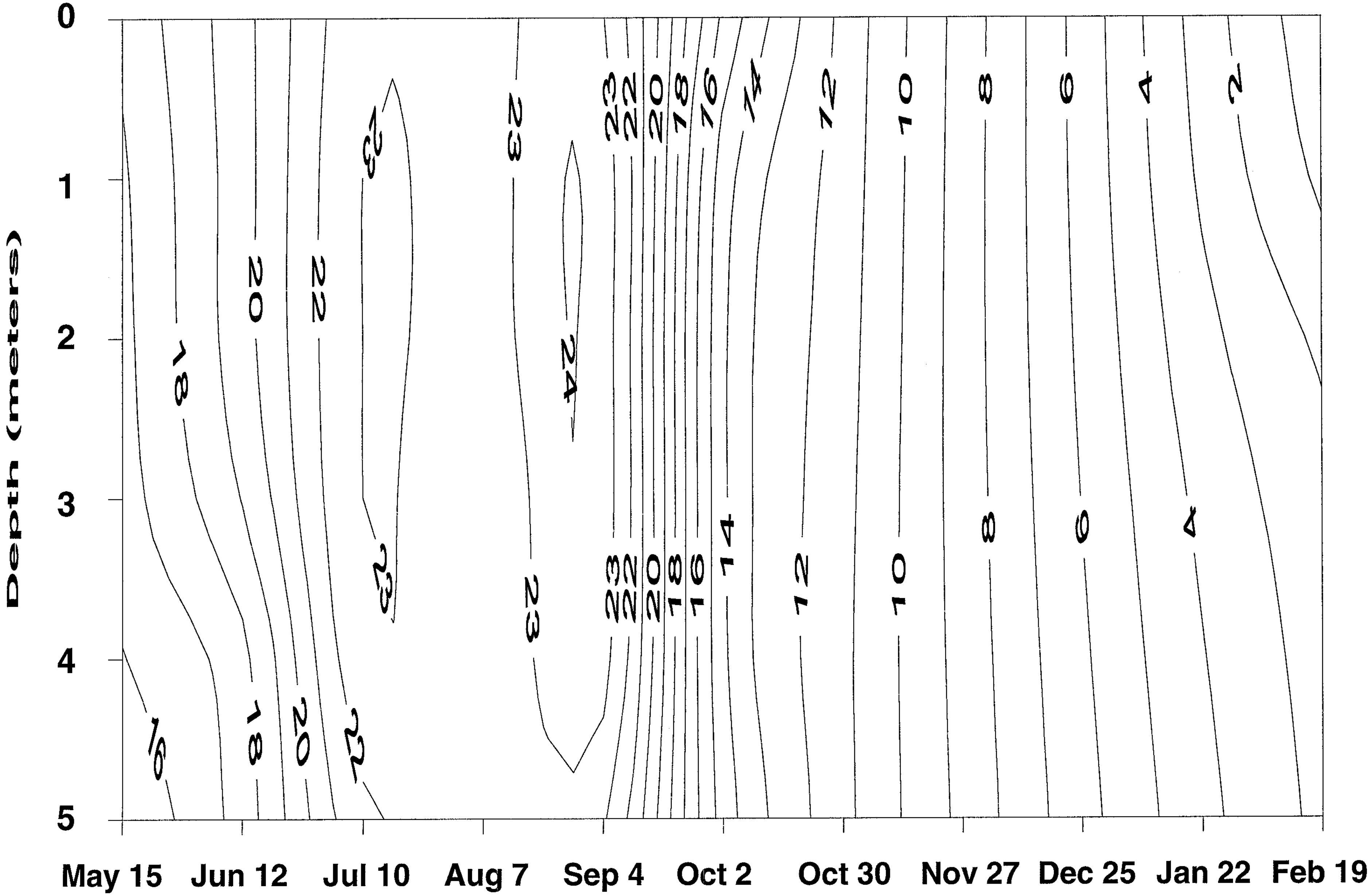


Figure 20

51

1996 Pokegama Lake Time-Depth Diagram of Temperature Isopleths (degrees C)

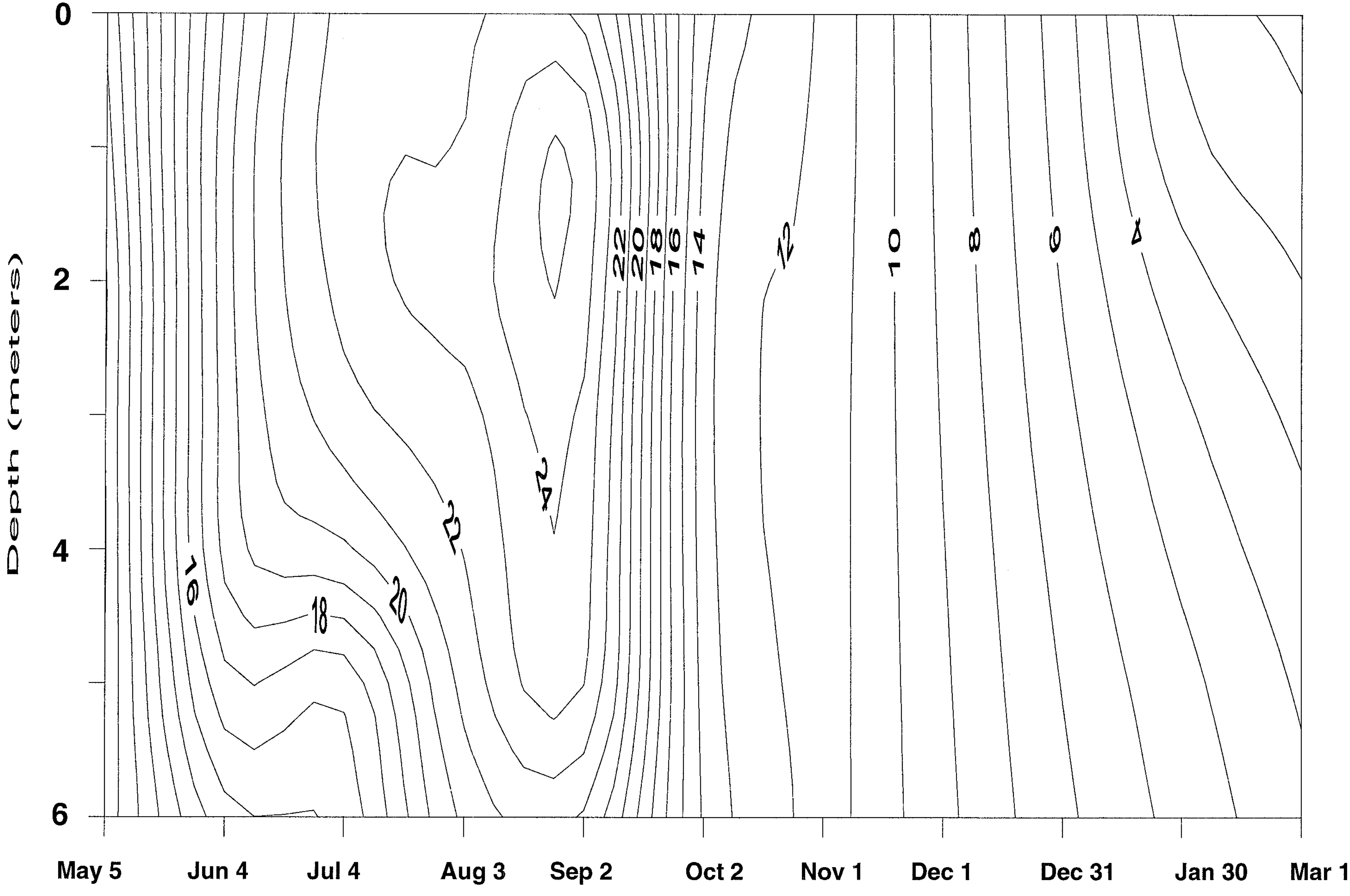


Figure 21

1996 Tenmile Lake Time-Depth Diagram of Temperature Isopleths (degrees C)

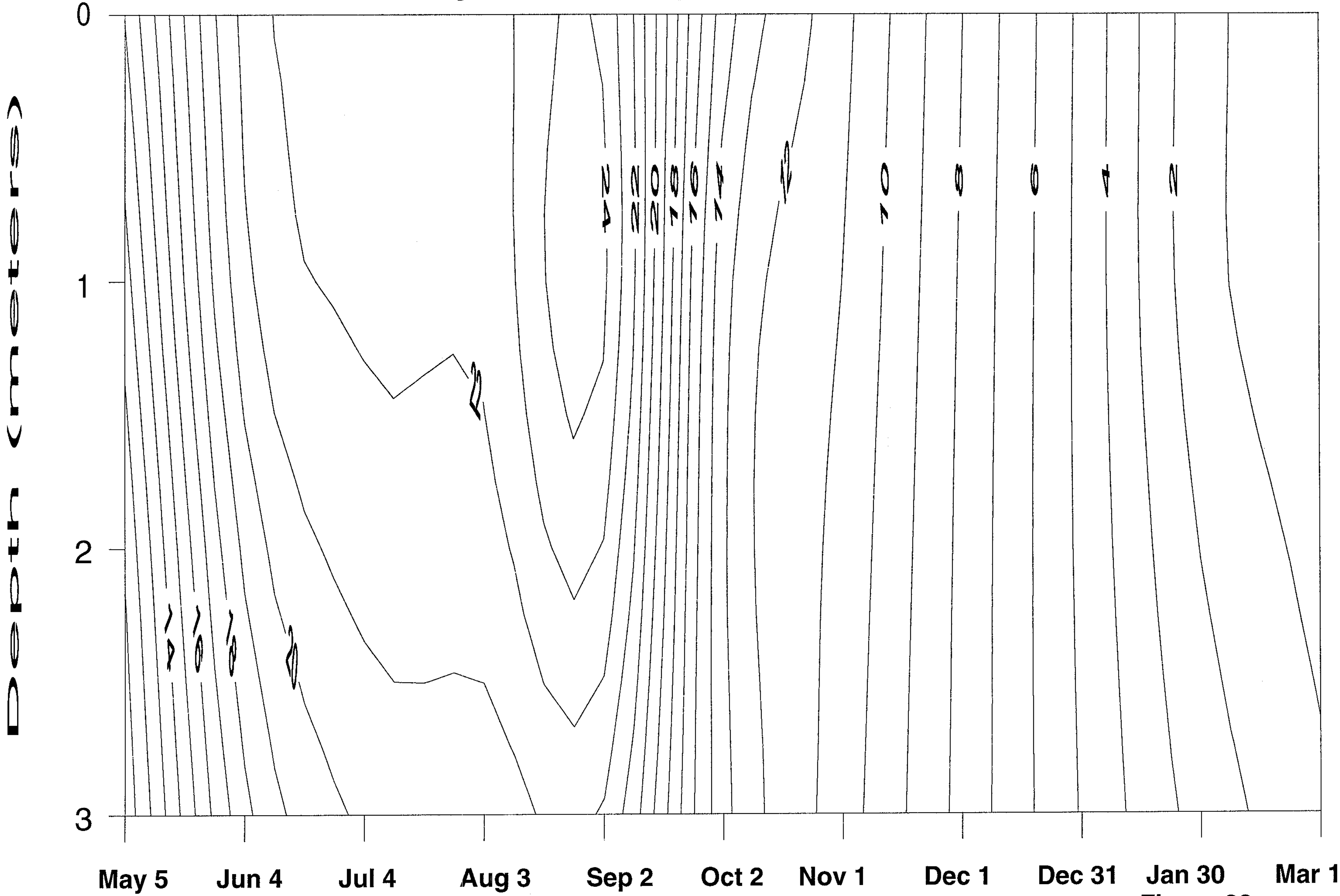


Figure 22

1996 Lake Chetek Time-Depth Diagram of Temperature Isopleths (degrees C)

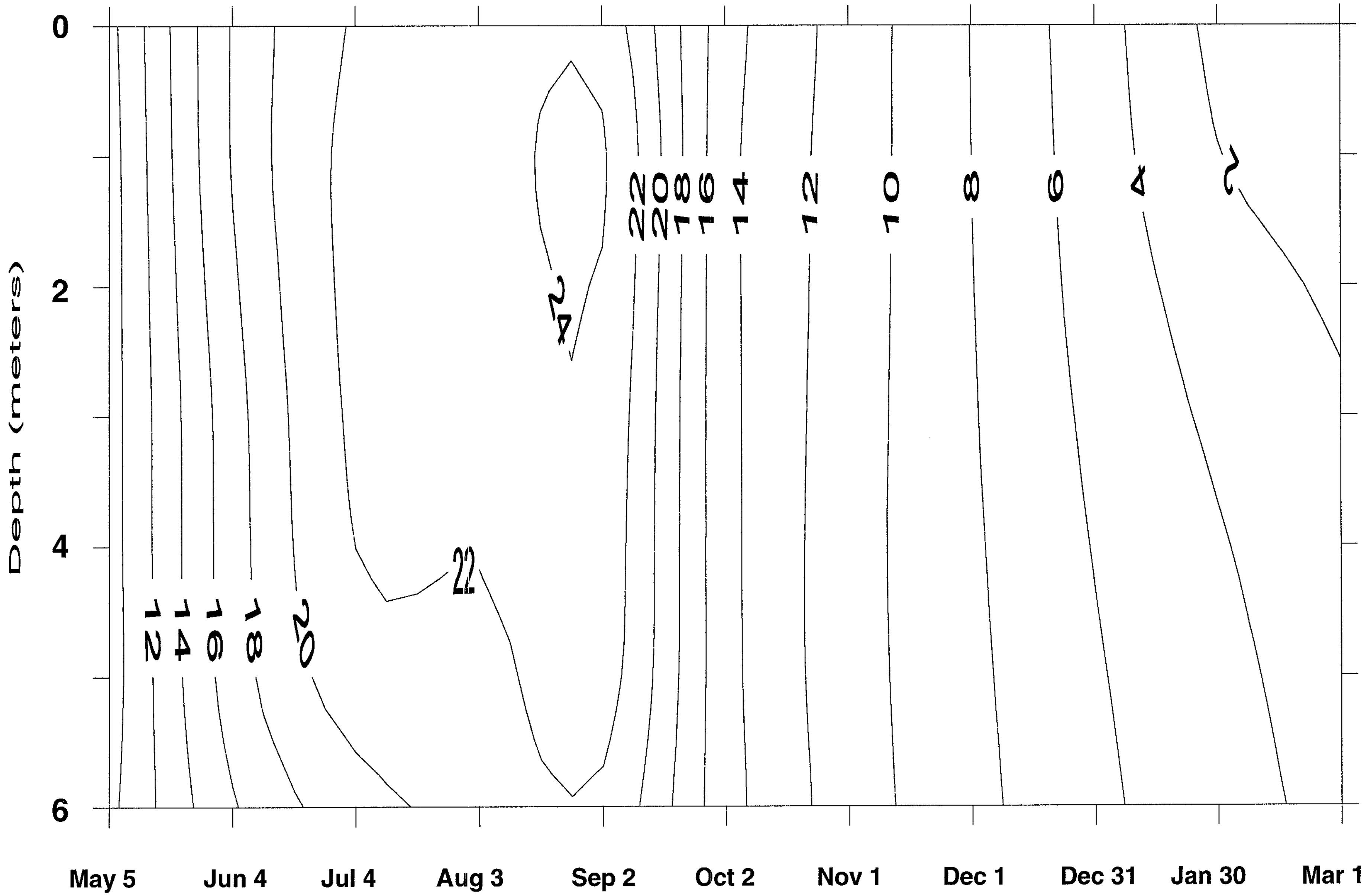


Figure 23

1996 Mud Lake Time-Depth Diagram of Dissolved Oxygen Isopleths (mg/L)

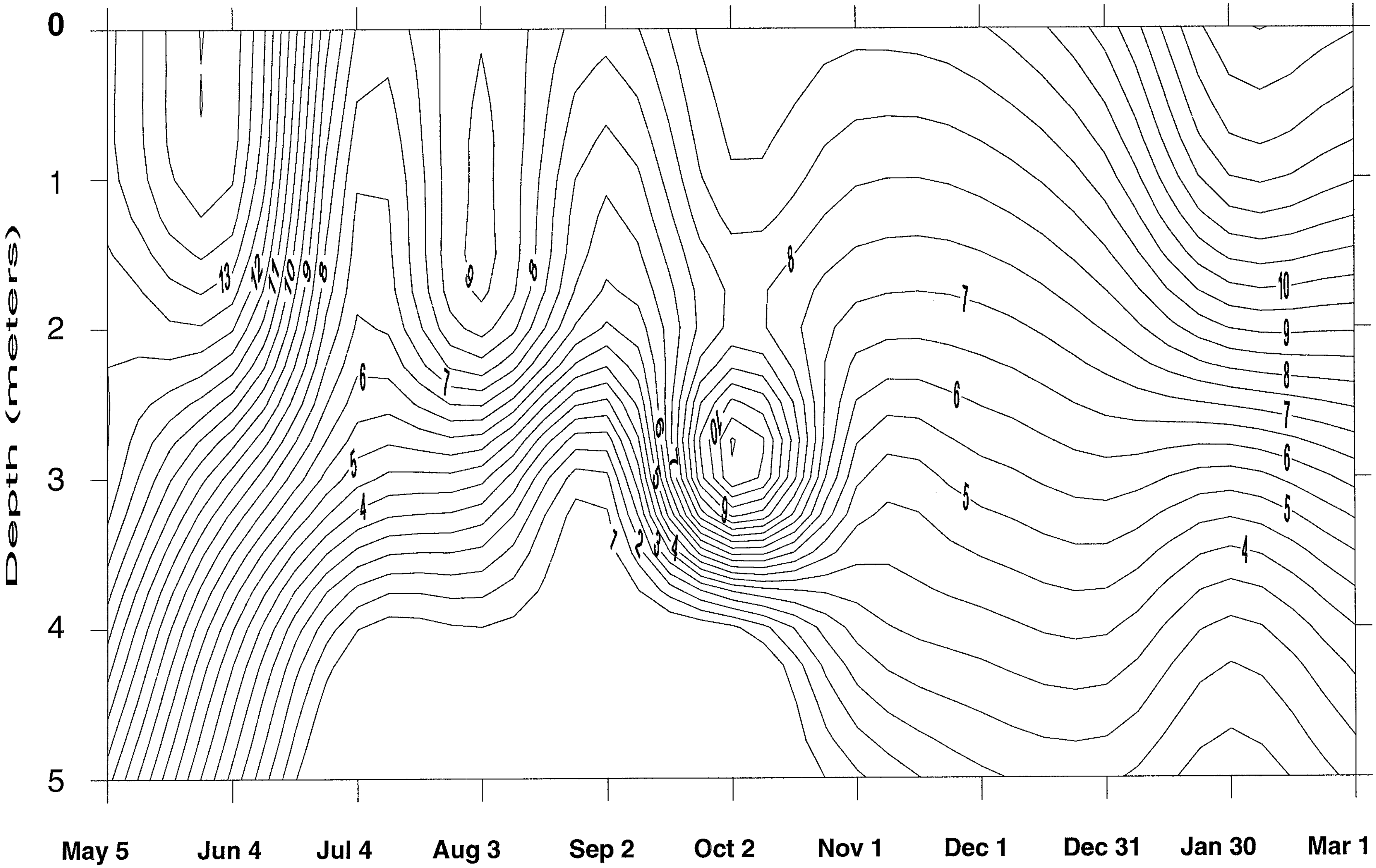


Figure 24

1996 Prairie Lake Time-Depth Diagram of Dissolved Oxygen Isopleths (mg/L)

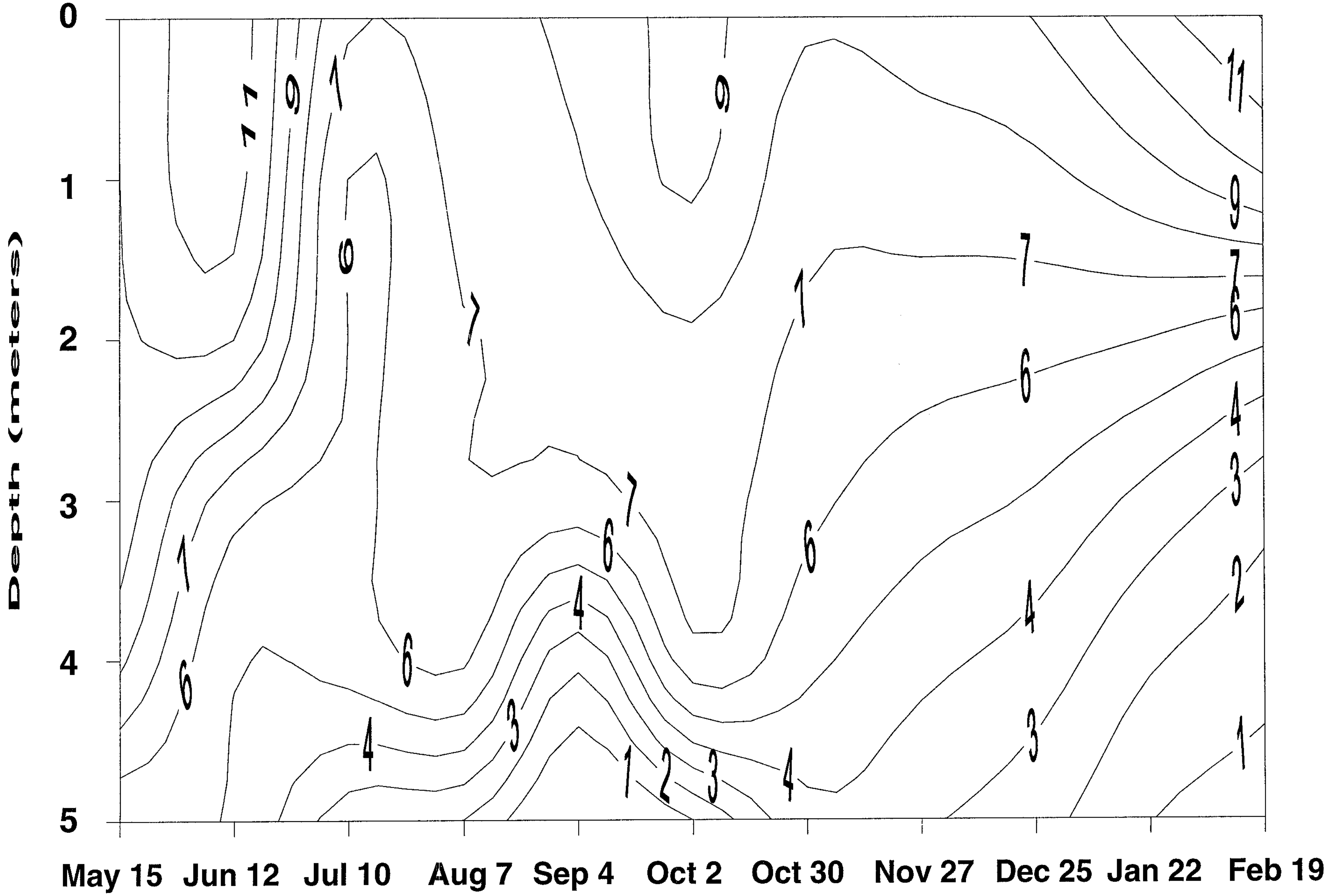


Figure 25

1996 Pokegama Lake Time-Depth Diagram of Dissolved Oxygen Isopleths (mg/L)

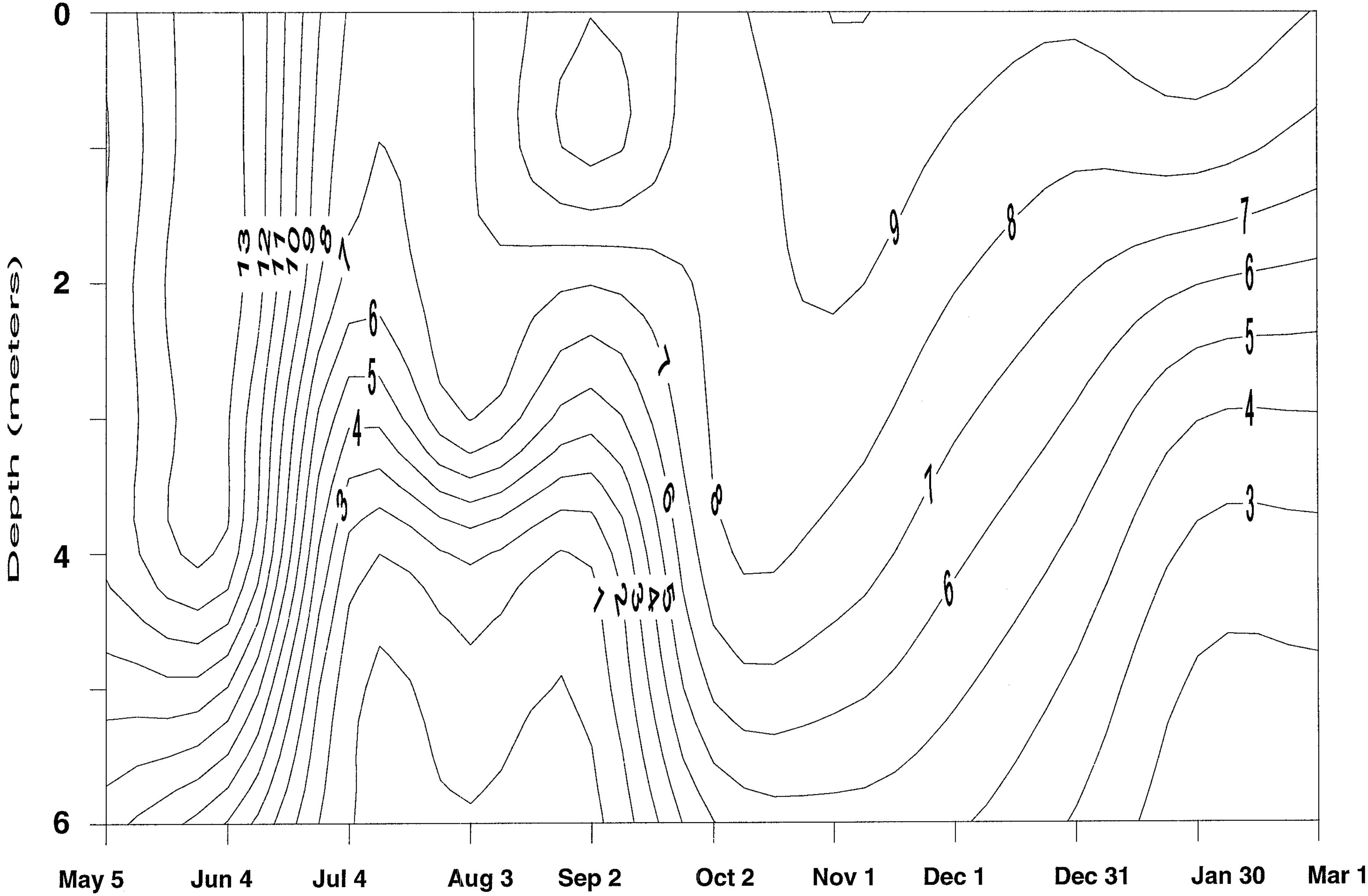


Figure 26

1996 Tenmile Lake Time-Depth Diagram of Dissolved Oxygen Isopleths (mg/L)

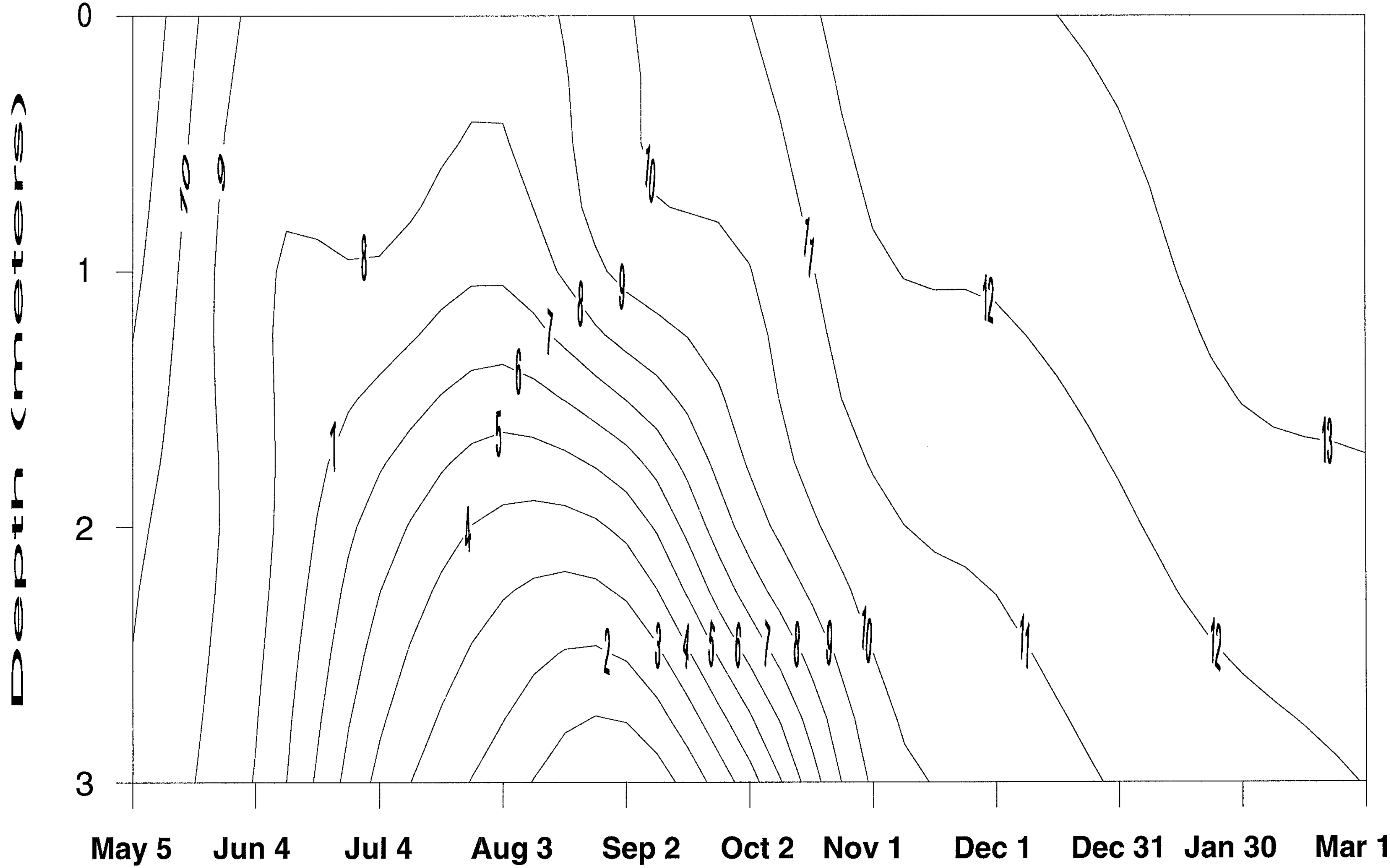


Figure 27

1996 Lake Chetek Time-Depth Diagram of Dissolved Oxygen Isopleths (mg/L)

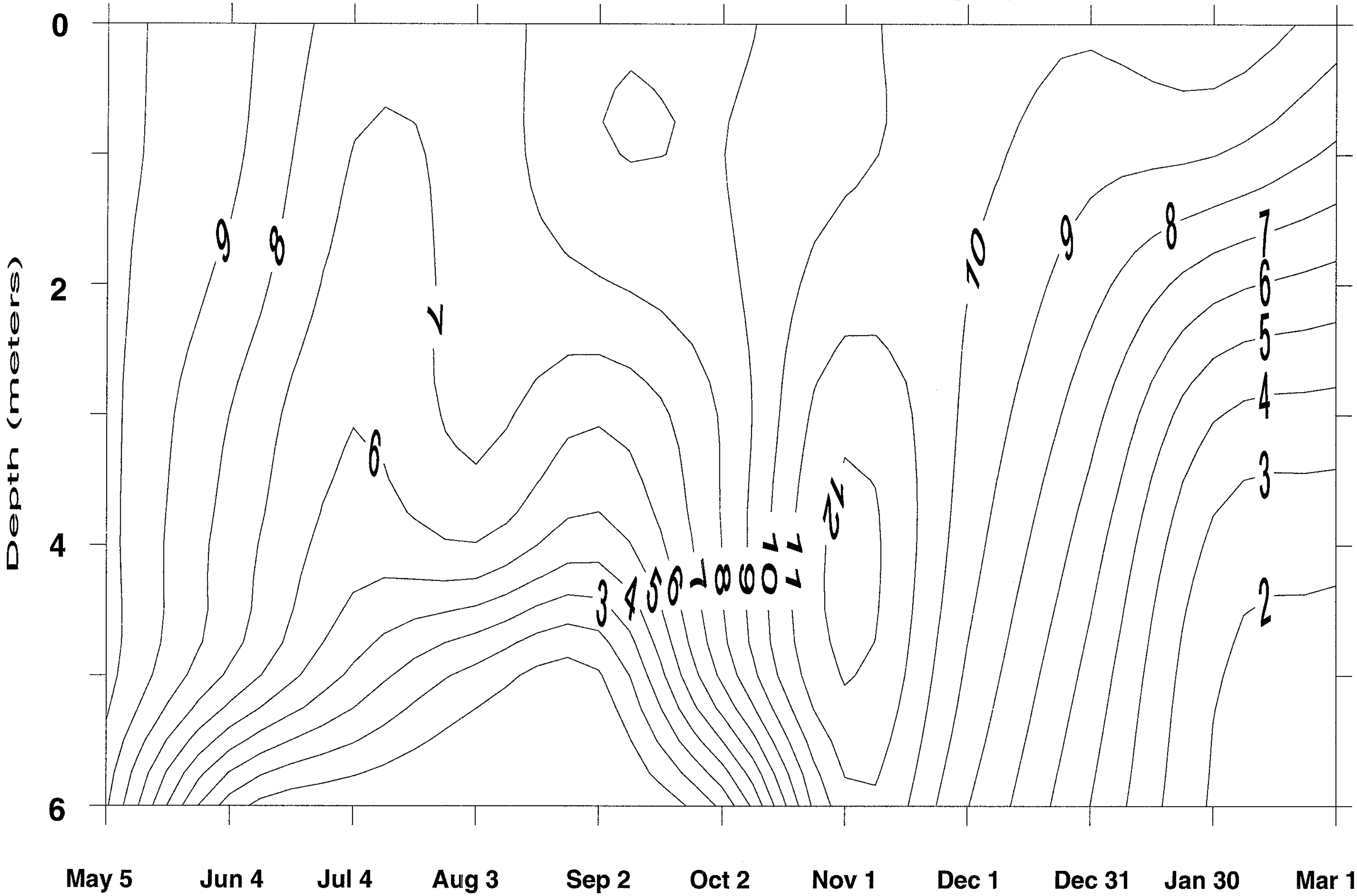


Figure 28

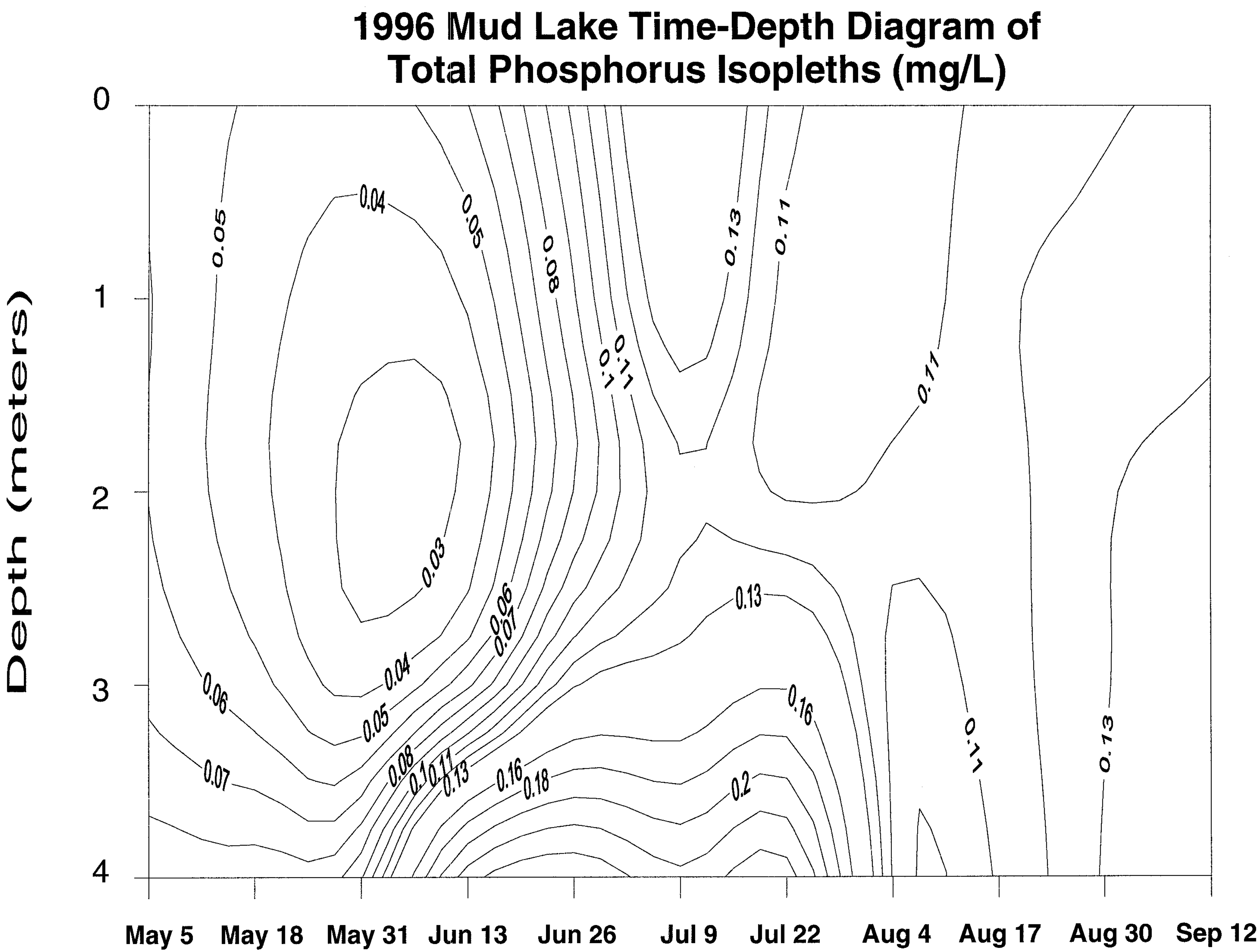

1996 Mud Lake Time-Depth Diagram of
Total Phosphorus Isopleths (mg/L)
Depth (meters)
0
1
2
3
4
May 5
May 18
May 31
Jun 13
Jun 26
Jul 9
Jul 22
Aug 4
Aug 17
Aug 30
Sep 12
0.05
0.04
0.05
0.08
0.13
0.11
0.1
0.11
0.11
0.03
0.06
0.07
0.04
0.05
0.06
0.07
0.08
0.1
0.11
0.13
0.16
0.18
0.13
0.16
0.2
0.11
0.13

Figure 29

1996 Prairie Lake Time-Depth Diagram of Total Phosphorus Isopleths (mg/L)

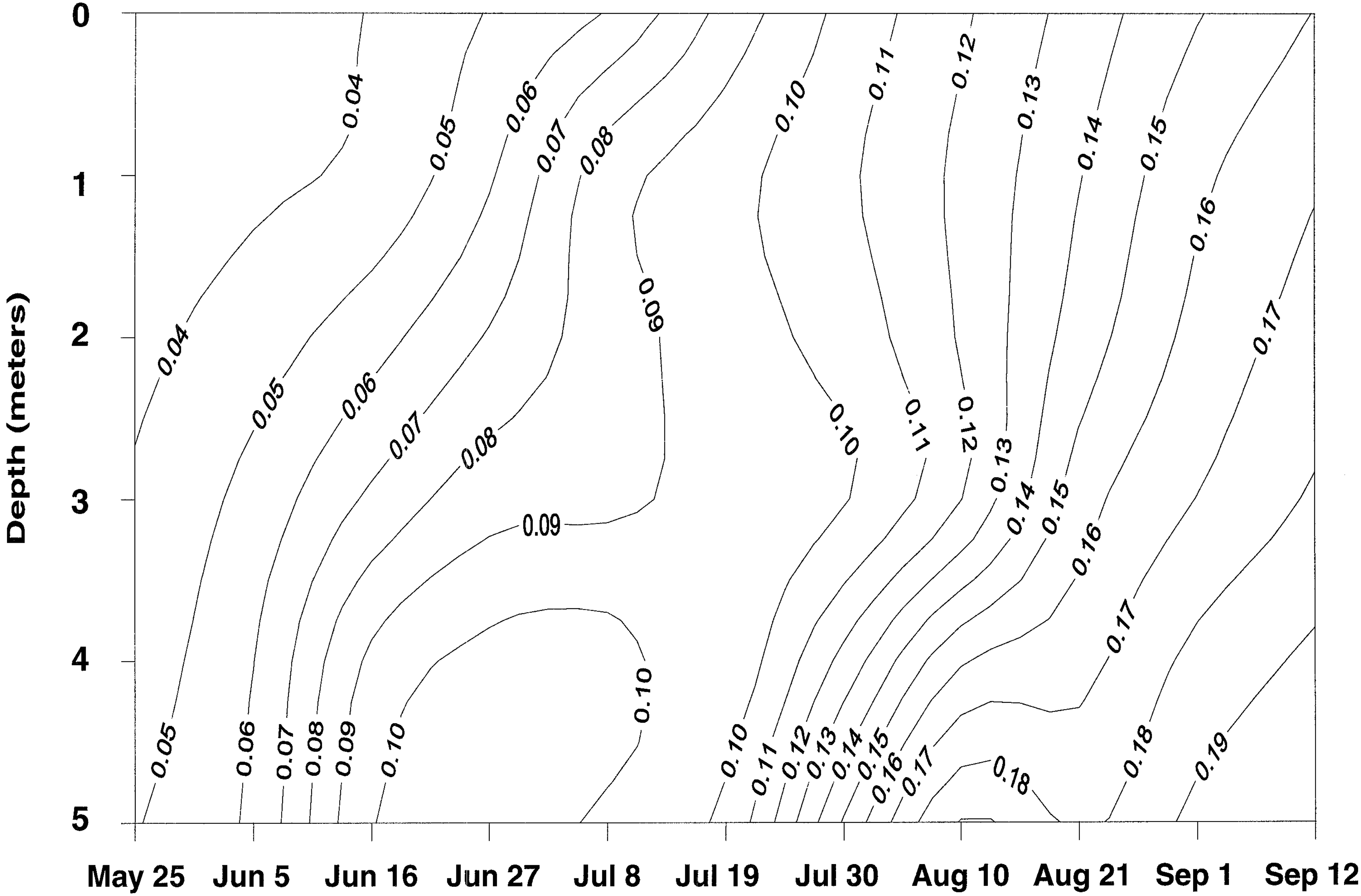


Figure 30

1996 Pokegama Lake Time-Depth Diagram of Total Phosphorus Isopleths (mg/L)

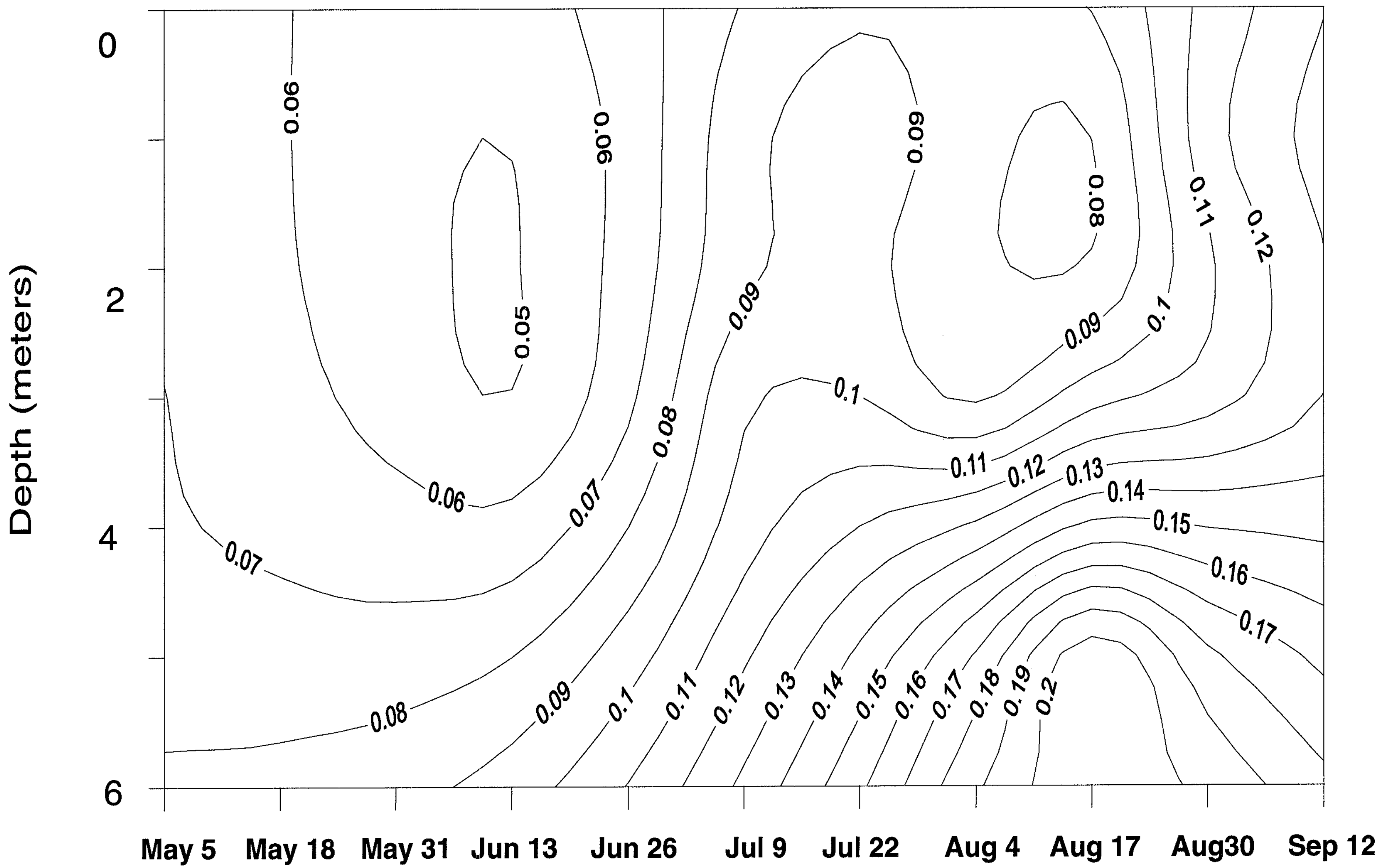


Figure 31

62

1996 Tenmile Lake Time-Depth Diagram of Total Phosphorus Isopleths (mg/L)

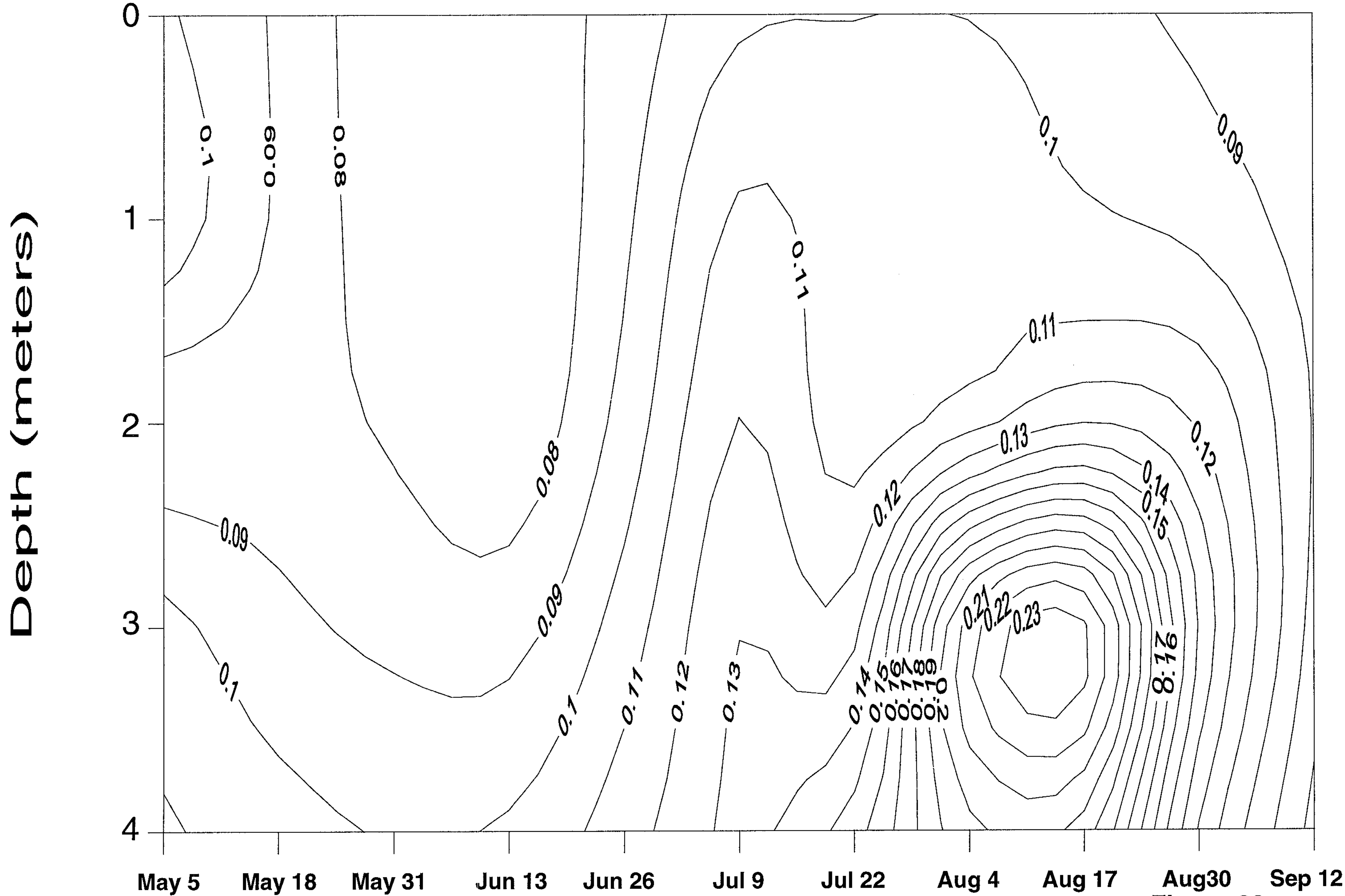


Figure 32

1996 Lake Chetek Time-Depth Diagram of Total Phosphorus Isopleths (mg/L)

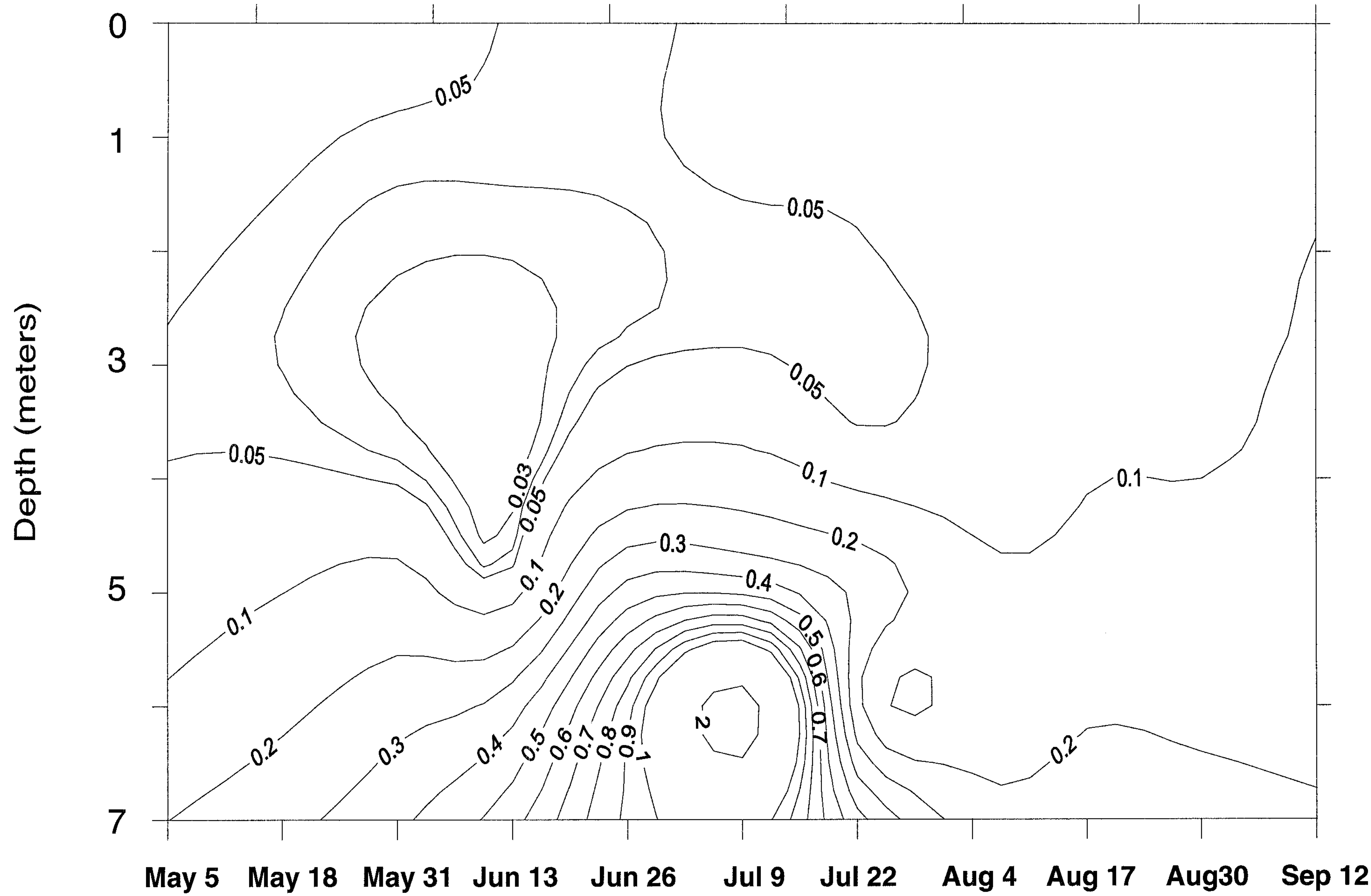


Figure 33

1996 Mud Lake Time-Depth Diagram of Specific Conductance Isopleths (umhos/cm)

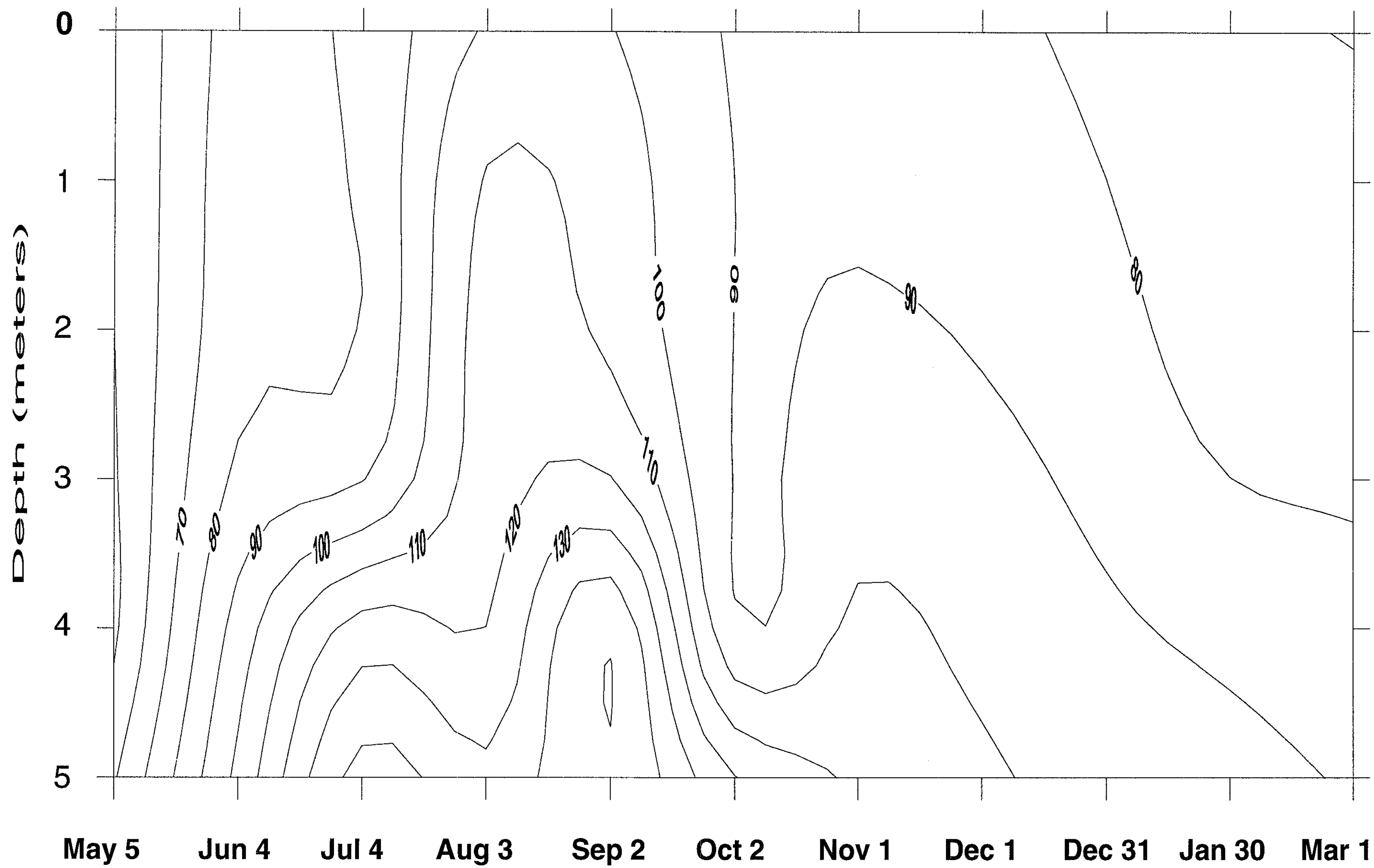


Figure 34

1996 Prairie Lake Time-Depth Diagram of Specific Conductance Isopleths (umhos/cm)

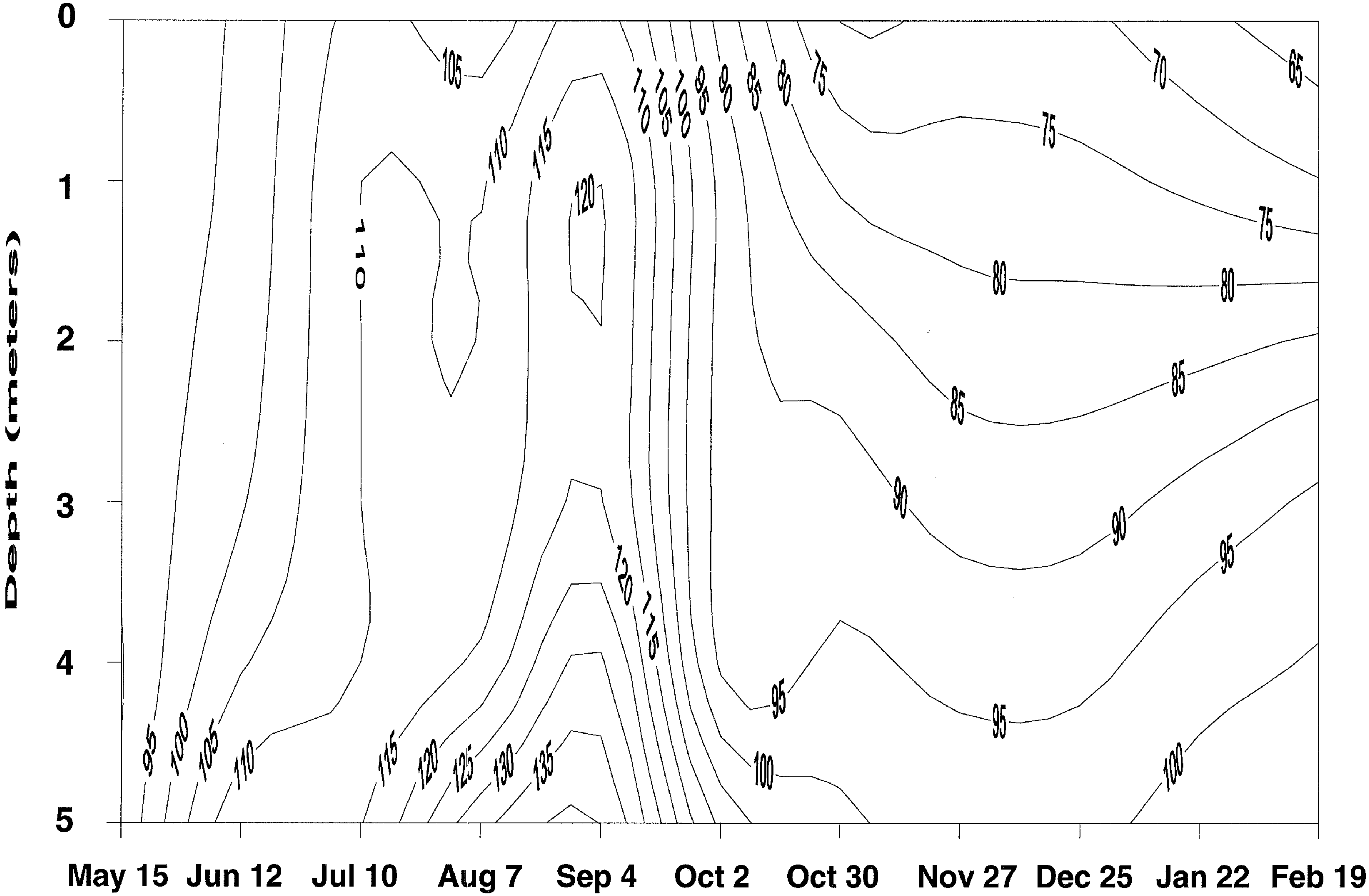


Figure 35

1996 Pokegama Lake Time-Depth Diagram of Specific Conductance Isopleths (umhos/cm)

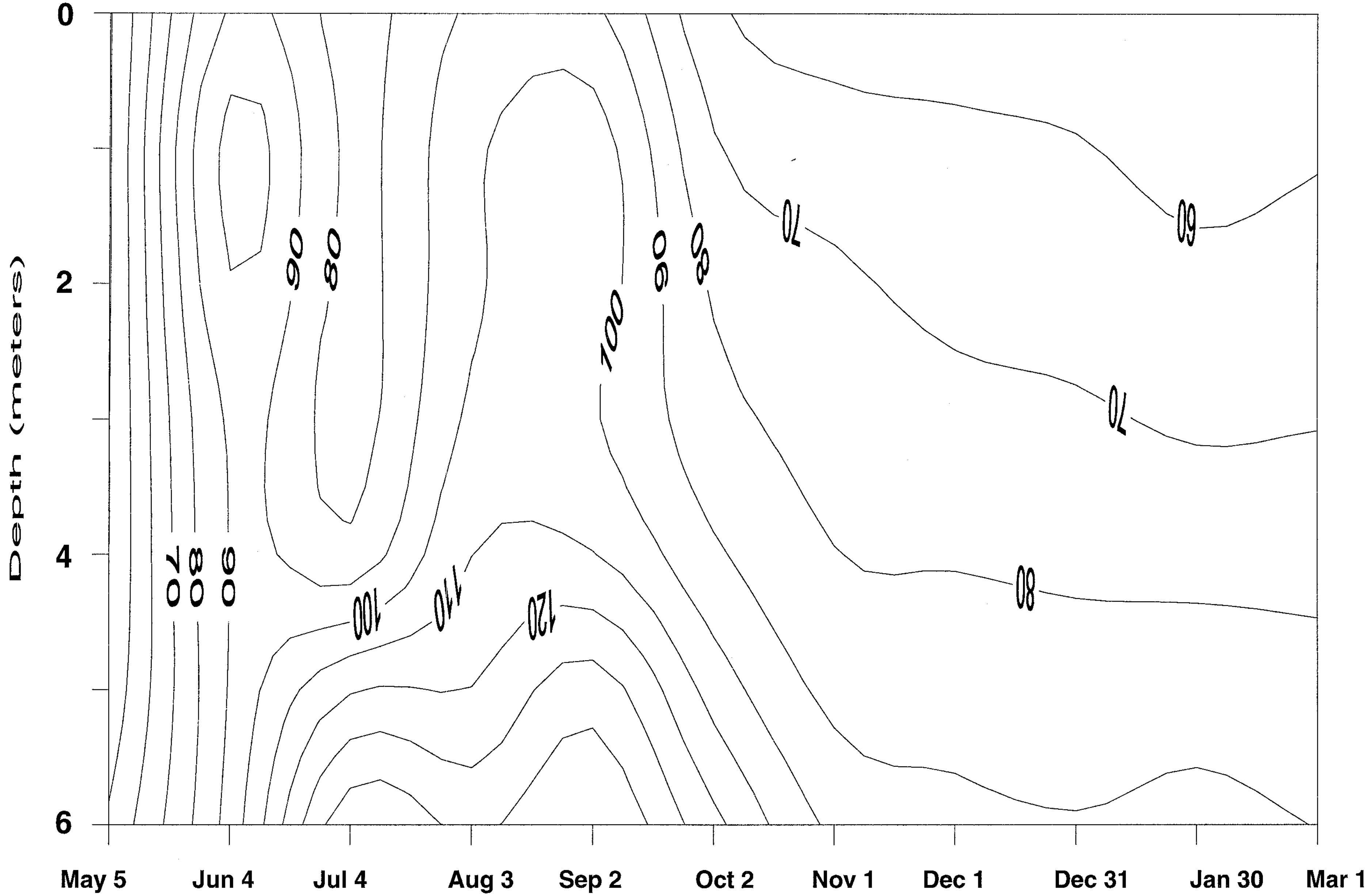


Figure 36

1996 Tenmile Lake Time-Depth Diagram of Specific Conductance Isopleths (umhos/cm)

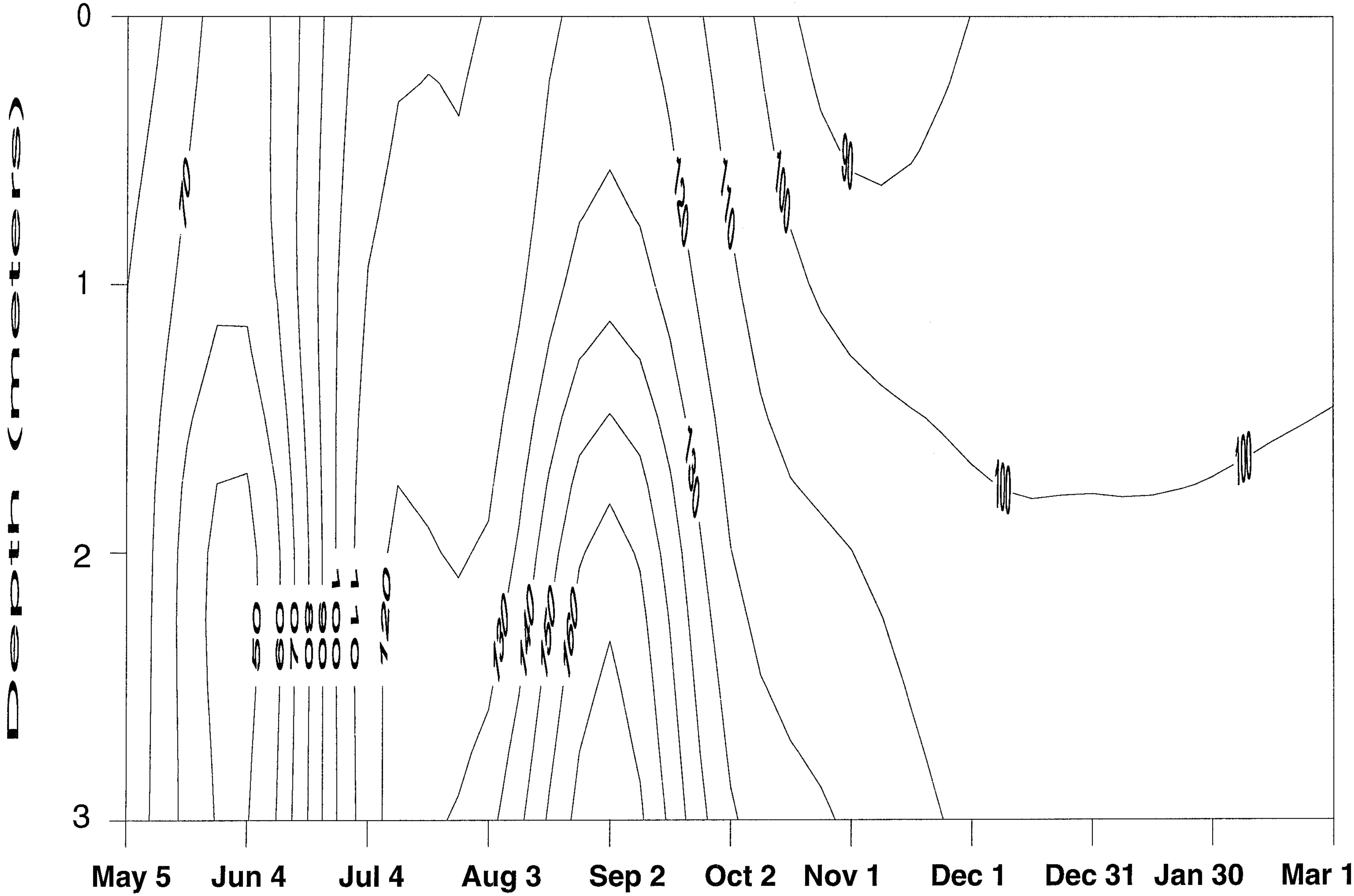


Figure 37

1996 Lake Chetek Time-Depth Diagram of Specific Conductance Isopleths (umhos/cm)

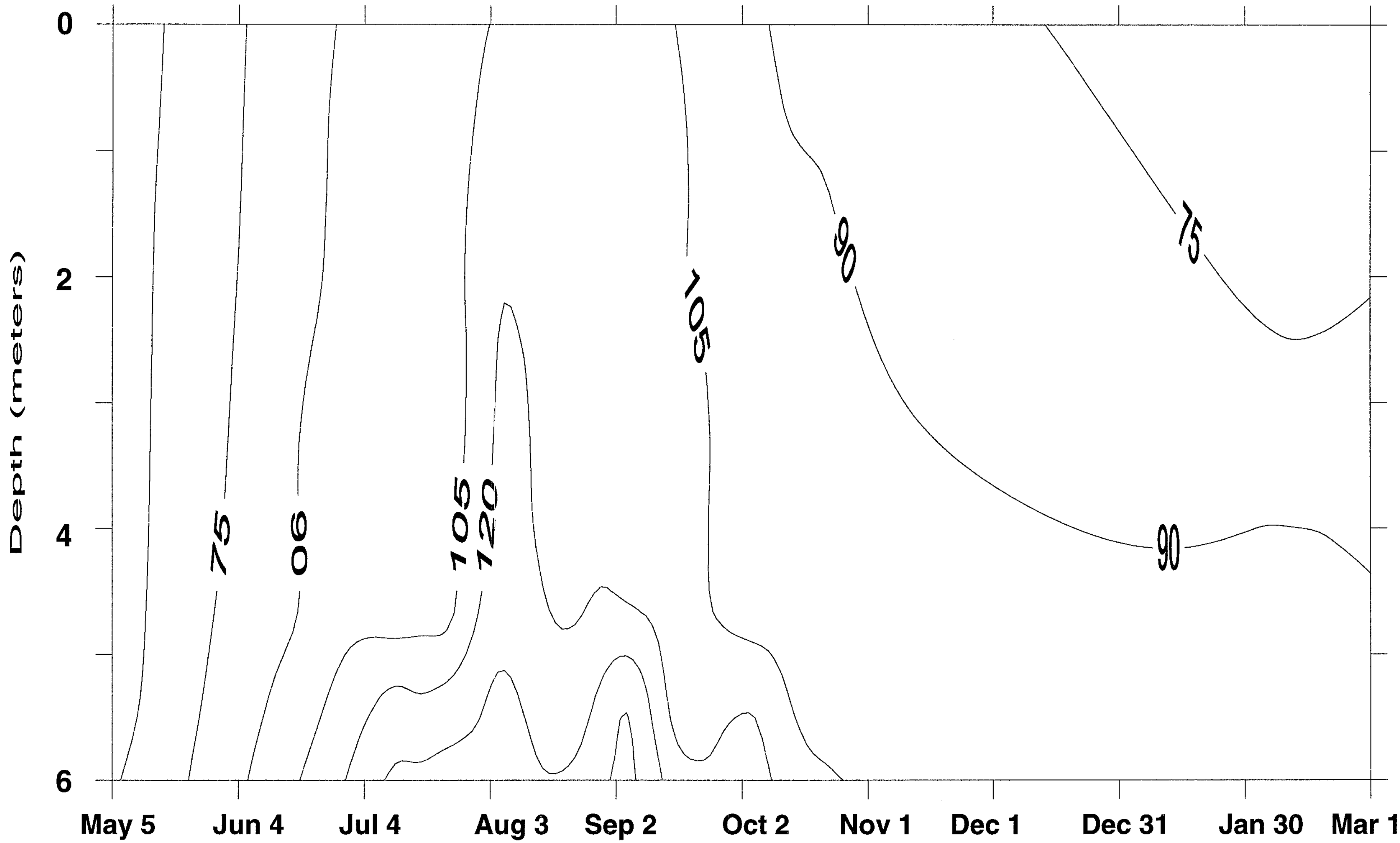


Figure 38

5.3 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.

The Chetek Lakes' macrophyte community was surveyed by the WDNR during August of 1997 to determine locations of macrophyte growth and to determine relative abundance and frequency of occurrence of species. Survey results are presented in Table 10 and Appendix K. A total of 25 species were observed in the Chetek Lakes. Survey results indicate *Elodea canadensis* (common waterweed) is the most abundant and most frequently occurring species within the lakes (i.e., occurred in 56 percent of sample locations). Filamentous algae and *Ceratophyllum demersum* (coontail) were also abundant and occurred in 24 and 31 percent of macrophyte sample locations, respectively. No vegetation was observed at approximately 26 percent of macrophyte sample locations.

Table 10 Summary of Chetek Chain of Lakes Aquatic Plant Survey (August 1997)*

Species	Common Name	Relative Abundance	% Frequency of Occurrence
Elodea Canadensis	common waterweed	328	55.9
--	filamentous algae	159	24.1
Ceratophyllum demersum	coontail	151	30.8
Nymphaea odorata	white waterlily	78	15.4
Spirodela polyrhiza	great duckweed	67	12.3
Potamogeton richardsonii	clasping-leaf pondweed	66	11.8
Lemna minor	small duckweed	66	11.8
Heteranthera dubia	water stargrass	63	13.8
Wolffia columbiana	common watermeal	48	7.7
Vallisneria americana	water celery	47	7.8
Potamogeton robinsii	fern pondweed	41	11.3
Najas sp.	bushy pondweed	26	6.2
Potamogeton amplifolius	large-leaf pondweed	24	4.1
Potamogeton crispus	curly-leaf pondweed	23	9.2
Sparganium sp.	bur-reed	15	3.1
Sagittaria sp.	arrowhead	14	4.6
Potamogeton zosteriformis	flatstem pondweed	8	4.1
Nitella sp.	muskgrass	8	2.1
Myriophyllum sp.	watermilfoil	6	1.5

72

Table 10 Summary of Chetek Chain of Lakes Aquatic Plant Survey (August 1997)* (Continued)

Species	Common Name	Relative Abundance	% Frequency of Occurrence
Nuphar variegatum	yellow waterlily	4	1.5
Ranunculus sp.	watercrowfoot	3	1
Potamogeton sp.	fine-leaf pondweed	3	1
Eleocharis acicularis	needle spikerush	2	1
Potamogeton epihydrus	ribbonleaf pondweed	2	1
Lemna trisulca	forked duckweed	2	1
Potamogeton praelongus	whitestem pondweed	1	0.5
No Vegetation	--	Not applicable	25.9

*Survey completed by the WDNR

5.4 Evaluation of Historical Secchi Disc Data

An evaluation of average summer Secchi disc data collected during the 1987 through 1998 period at Mud, Prairie, Pokegama, Tenmile, and Chetek lakes indicates year-to-year variation has occurred but the water quality of each lake has remained stable over time. A discussion of the individual lakes follows:

- Mud Lake has generally observed a summer average water transparency within the hypereutrophic (very poor water quality) category. Approximately two-thirds of the historical summer averages were lower (poorer water quality) than the 1996 summer average (See Figure 39).

- Prairie Lake has generally observed a summer average water transparency within the eutrophic (poor water quality) category. During eight of the twelve years of data, the lake's average summer water transparency was higher than the 1996 average, which was in the hypereutropic (very poor water quality) category (See Figure 40).

- Pokegama Lake has generally observed a summer average water transparency within the hypereutrophic (very poor water quality) category. A comparison of the five historical averages indicates one average was slightly lower than the 1996 summer average and three averages were higher (See Figure 41).

- Tenmile Lake has generally observed a summer average water transparency very near the boundary between eutrophic (poor water quality) and hypereutrophic (very poor water quality). The 1996 average summer value represents the median value of the period of record (See Figure 42).

- Lake Chetek has generally observed a summer average water transparency very near the boundary between eutrophic (poor water quality) and hypereutrophic (very poor water quality). The 1996 average summer water transparency was the fifth poorest of the 12 years of record (See Figure 43).

1987-1997 Mud Lake Average Summer Secchi Disc Transparencies

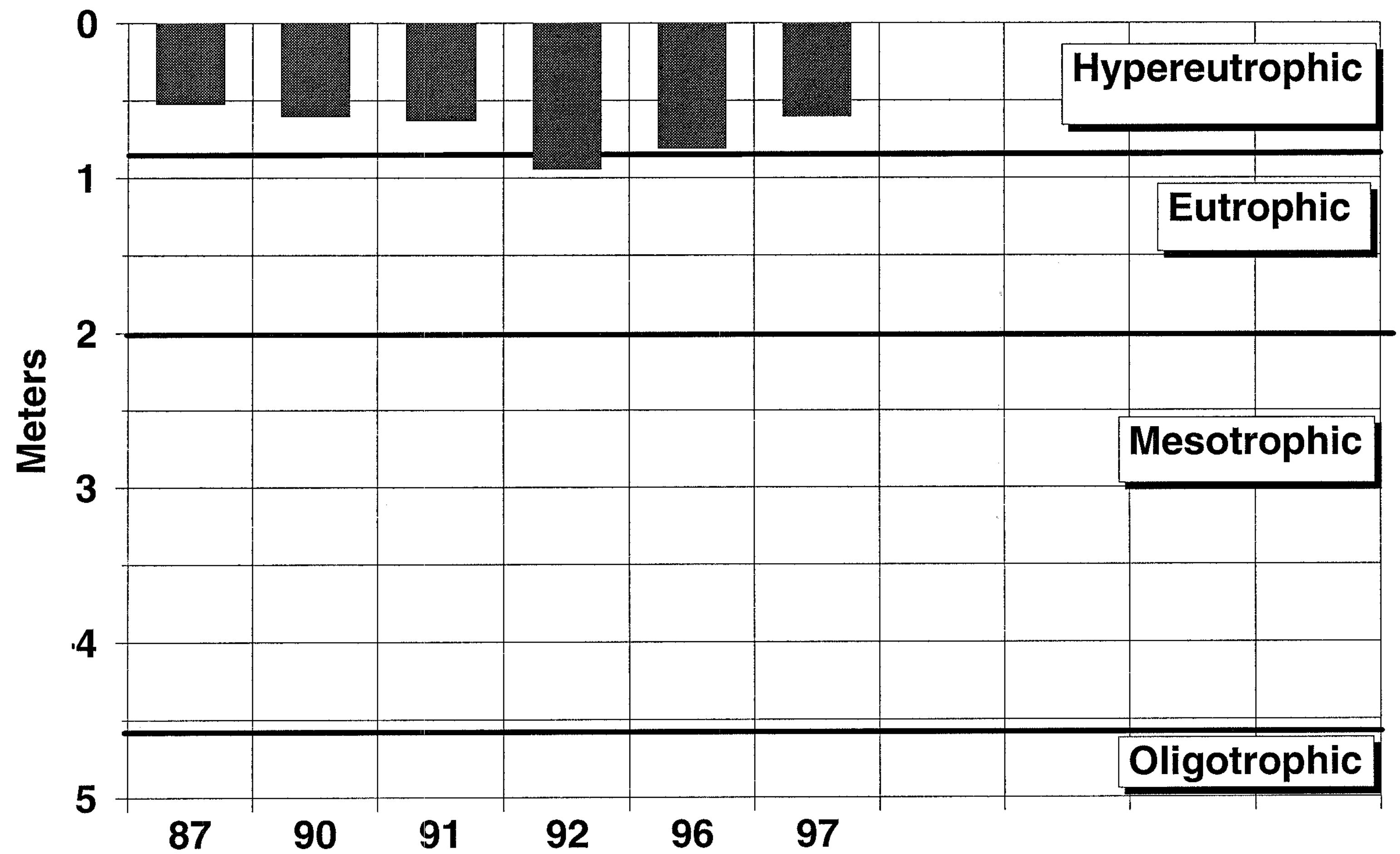
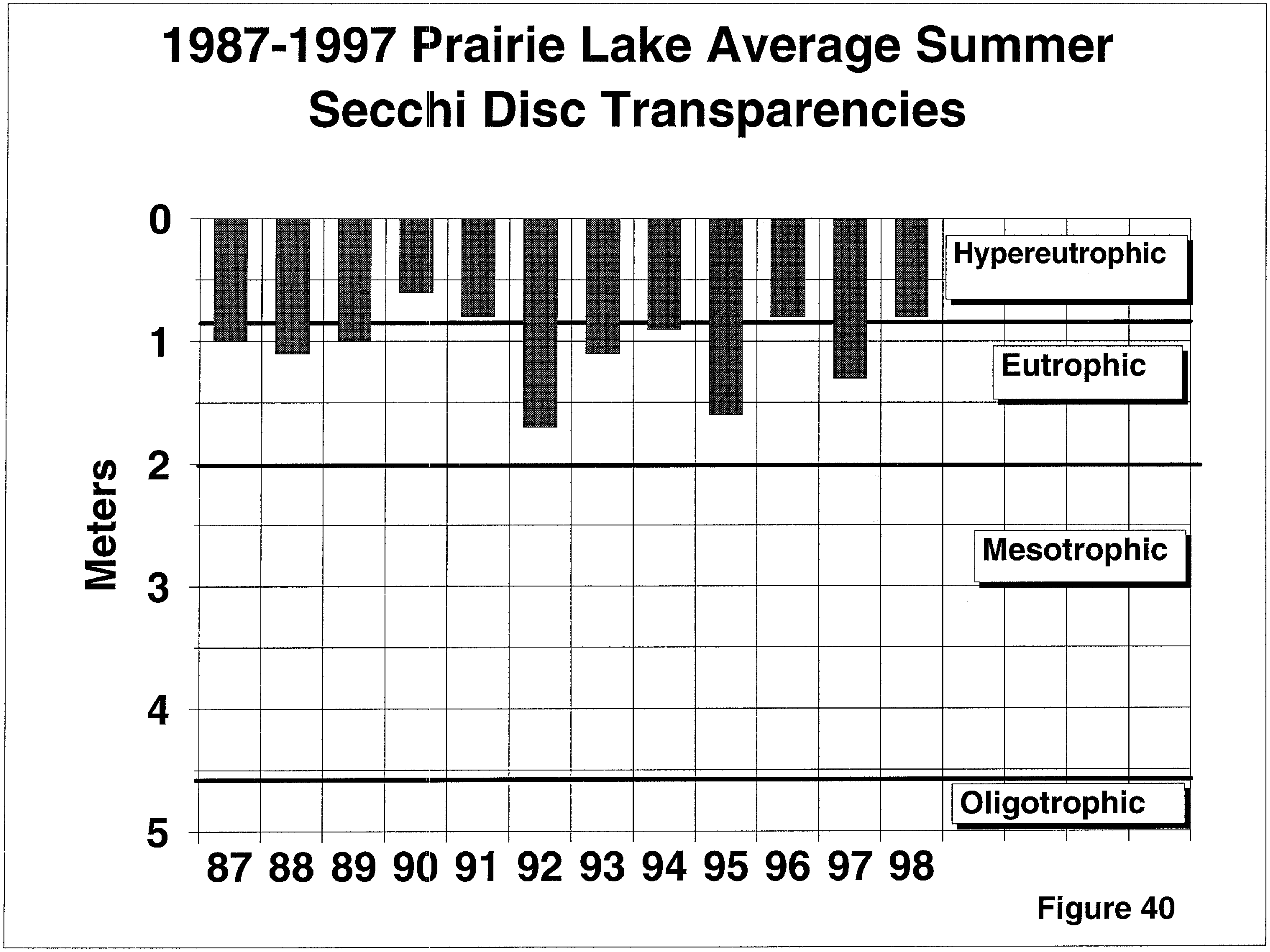


Figure 39

P:\49\03\005\qpw\4secgrap.wb2:Hist. Secchi



P:\49\03\005\qpw\3secgrap.wb2:Hist. Secchi

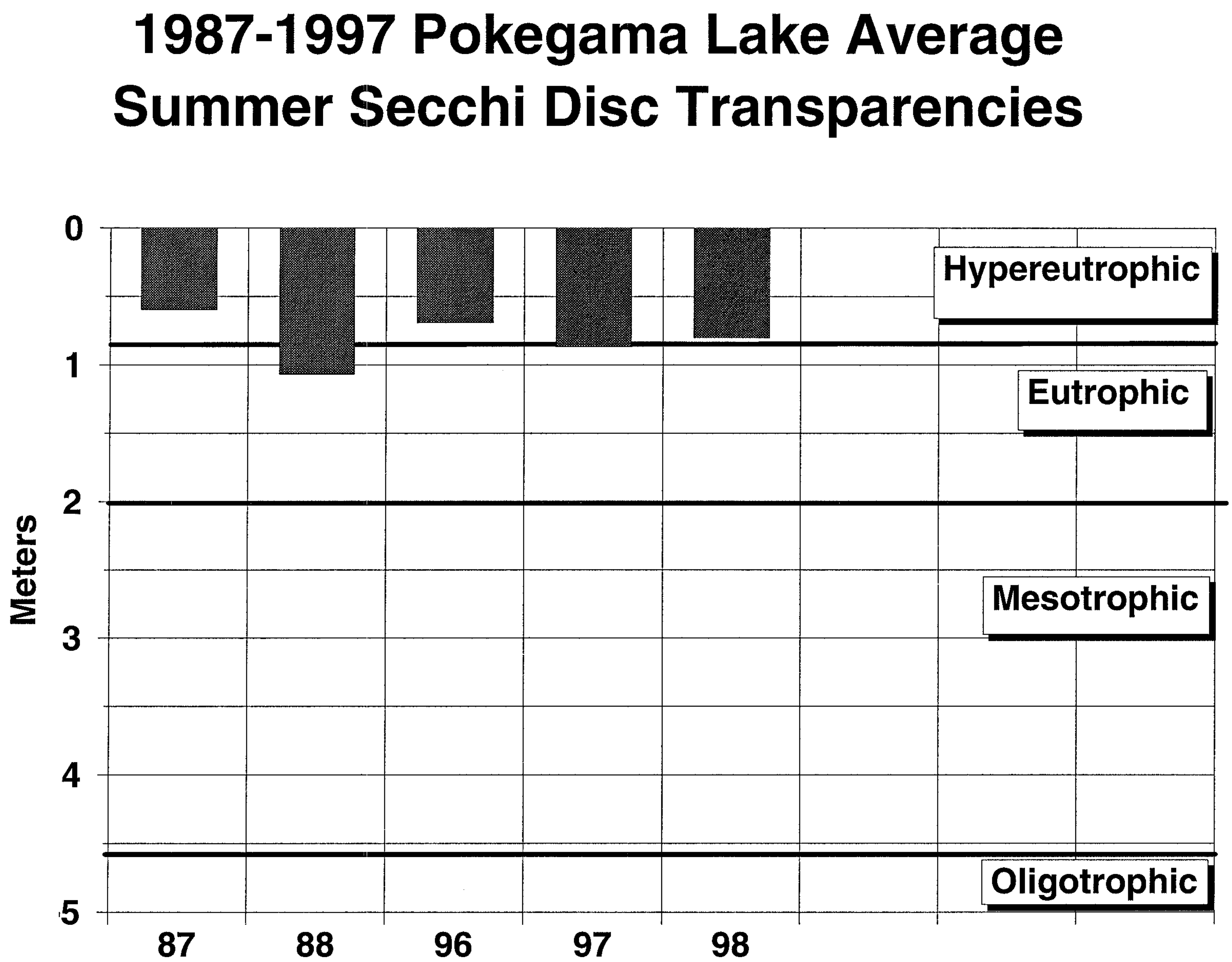


Figure 41

P:\49\03\005\qpw\5secgrap.wb2:Hist. Secchi

1987-1997 Tenmile Lake Average Summer Secchi Disc Transparencies

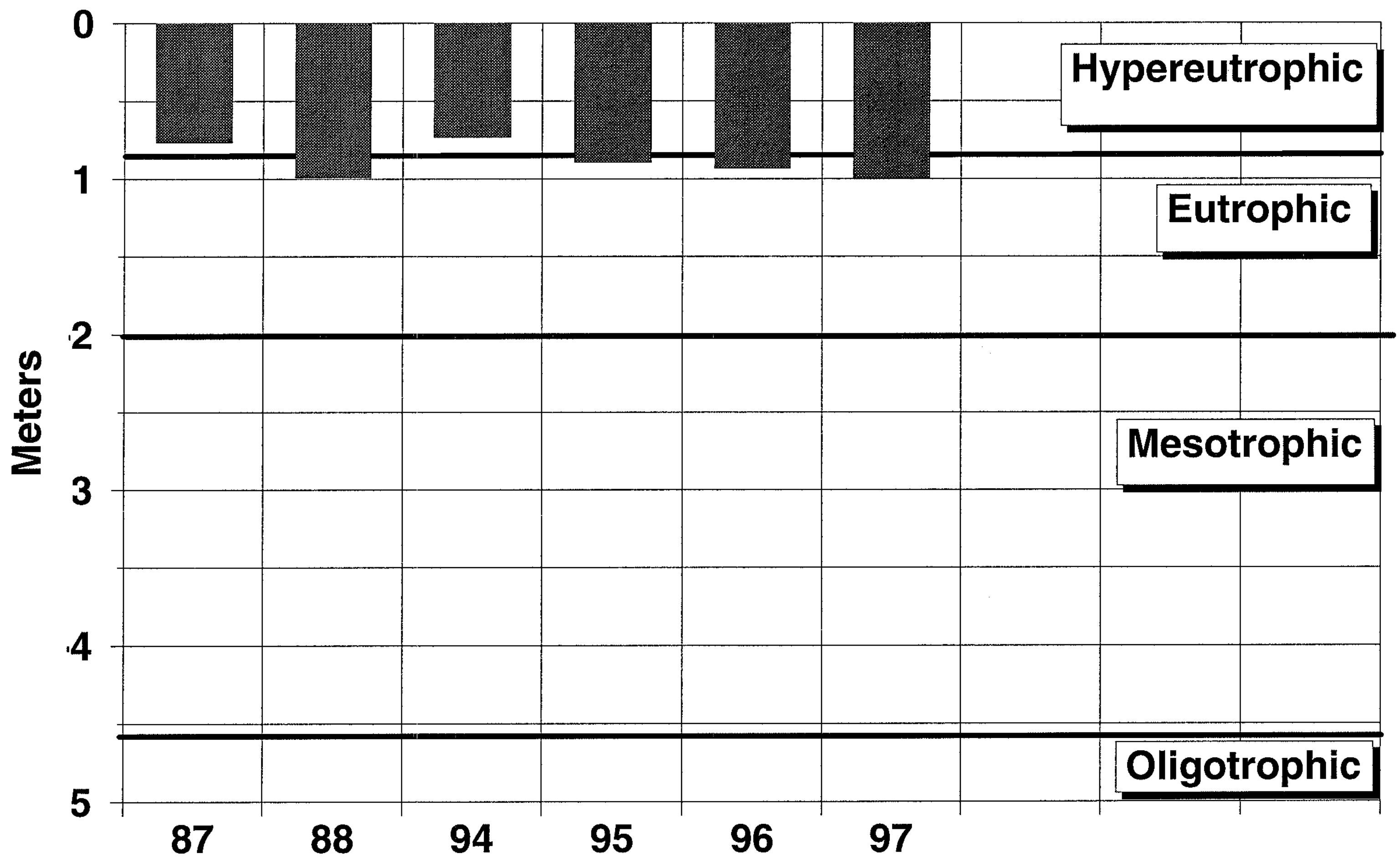


Figure 42

P:\49\03\005\qpw\6secgrap.wb2:Hist. Secchi

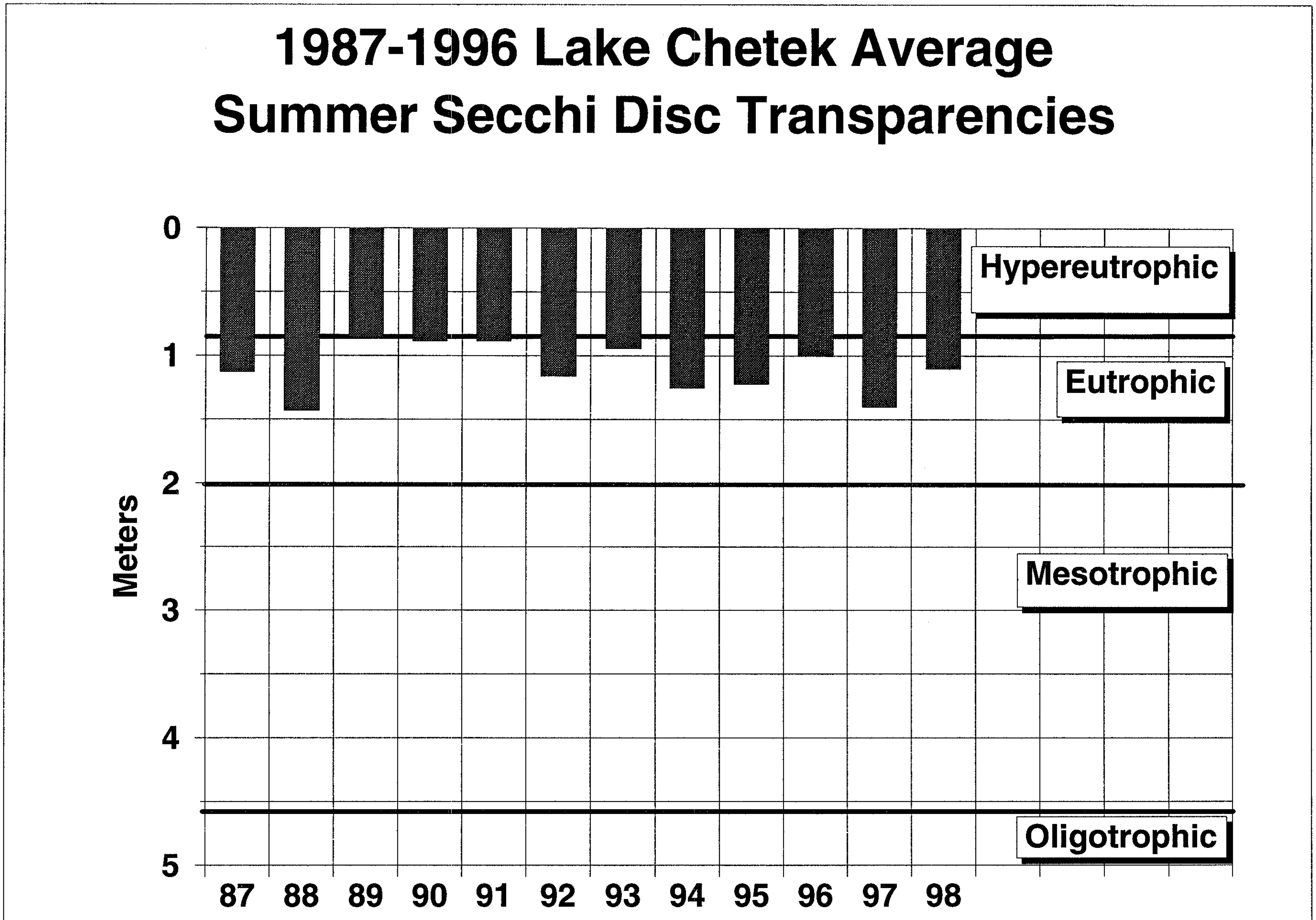


Figure 43

P:\49\03\005\qpw\7secgrap.wb2:Hist. Secchi

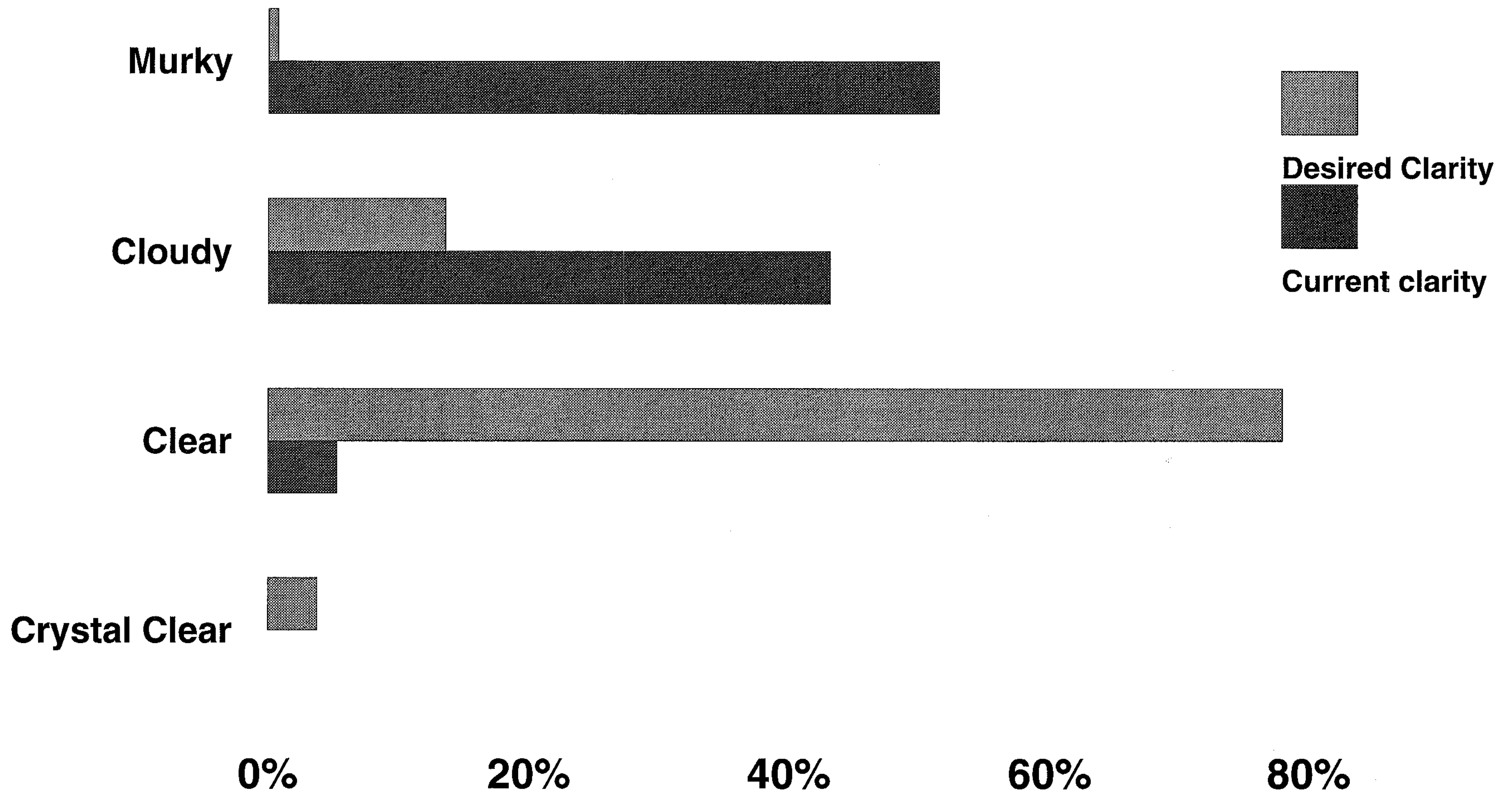
5.5 Chetek Lakes Survey Results

A 1996 survey of Chetek Lakes' riparian owners solicited opinions regarding water clarity, lake recreational activities, and lake management goals. A total of 190 surveys were sent out and 132 were completed and returned (i.e., a 69 percent return rate). The survey results indicated nearly all residents considered the lakes' current water clarity murky or cloudy, but desired a water clarity of clear (See Figure 44). Responses indicated that current and desired recreational activities are very similar, suggesting residents would make few changes in lake recreational activities if water clarity improved. However, residents indicated that use of the lake for swimming would increase if water clarity improved. Respondents indicated the primary current and desired use of Chetek Lakes is fishing (89 percent current use and 83 percent desired use). Other major uses include observing wildlife (76 percent current and 77 percent desired), enjoying the view (74 percent current and 76 percent desired), motorized boating (74 percent current and 61 percent desired), appreciating peace and tranquility (68 percent current and 75 percent desired), and swimming (65 percent current and 75 percent desired). Other lake activities include scuba diving, snorkeling, water skiing, jet skiing, canoeing, row boating, sailing, and wind surfing (See Figure 45).

Residents were asked to indicate desired lake management goals. Improvement of the lakes' water quality was selected by 92 percent of respondents as a desired lake management goal. Approximately two-thirds of respondents selected "improved fisheries" (70 percent) and "decrease weed growth" (64 percent) as lake management goals. Lake management goals selected by approximately half of respondents include "improve aesthetics" (55 percent), "protect existing fisheries" (51 percent), and "protect existing water quality of the lakes" (45 percent). Other management goals selected by respondents include "protect aesthetics" (41 percent), "protect existing weed growth" (21 percent) and "increase weed growth" (2 percent). Responses are summarized in Figure 46.

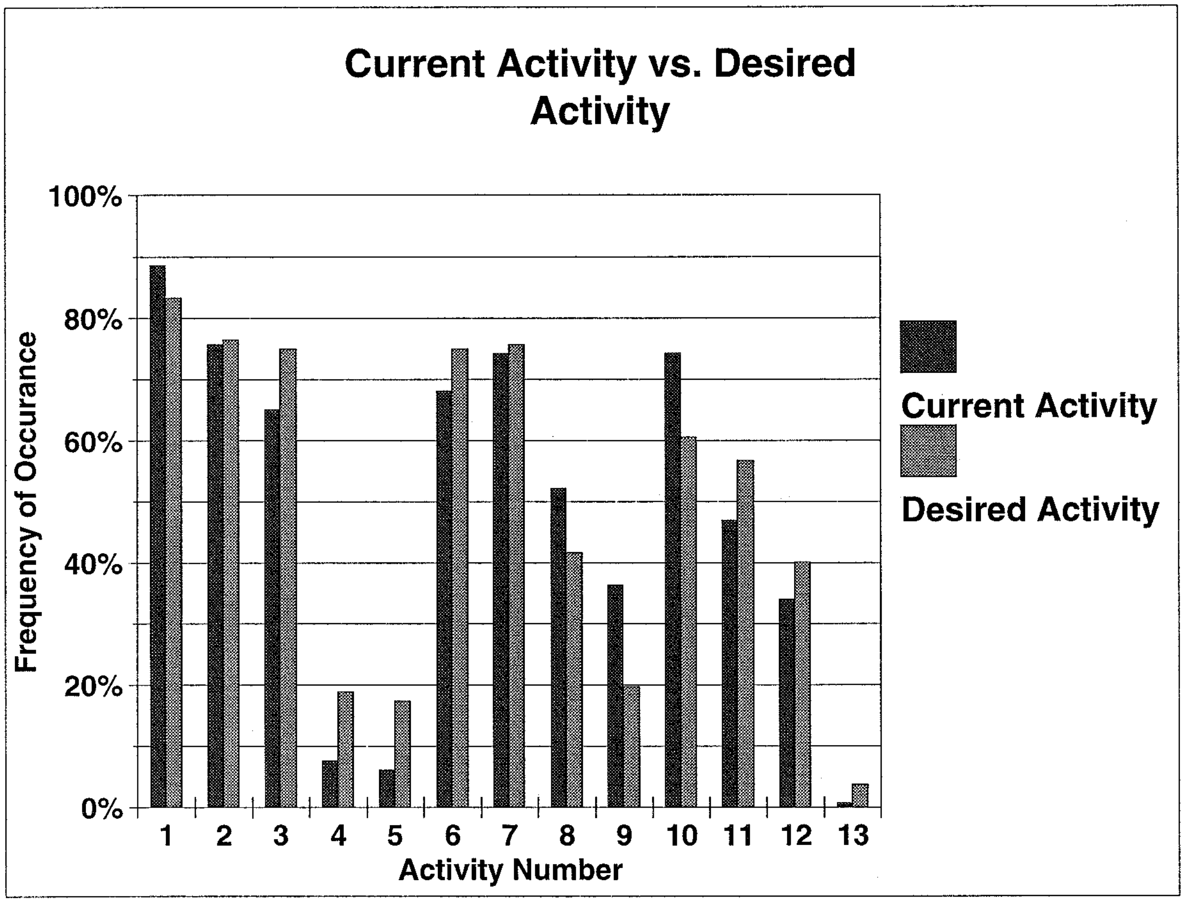
Based upon survey results, the following management goals are recommended for the Chetek Lakes:

- Improve the Lakes' Water Quality
- Improve Fisheries
- Decrease Weed Growth
- Improve Aesthetics



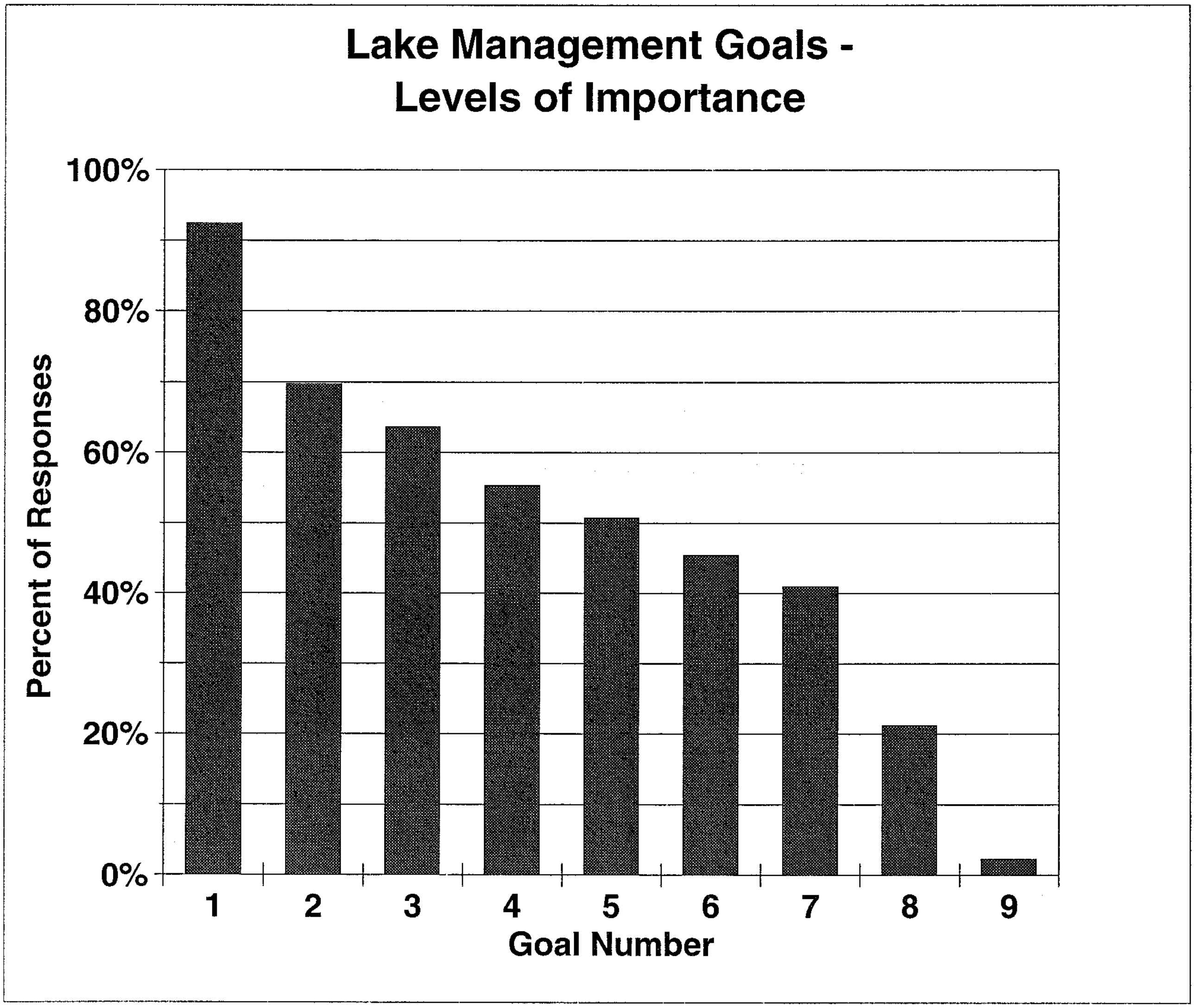
Current and Desired Clarity During the Summer Months

Figure 44



Activity Number	Activity	Current Activity (% of total responses)	Desired Activity (% of total responses)
1	Fishing	89%	83%
2	Observing Wildlife	76%	77%
3	Swimming	65%	75%
4	Scuba Diving	8%	19%
5	Snorkeling	6%	17%
6	Appreciate Peace and Tranquility	68%	75%
7	Enjoying the View	74%	76%
8	Water Skiing	52%	42%
9	Jet Skiing	36%	20%
10	Motorized Boating	74%	61%
11	Non-Motorized Canoeing, Rowing	47%	57%
12	Sailing, Wind Surfing	34%	40%
13	Other	1%	4%

Figure 45



Goal Number	Lake Management Goal	Percent of Total Who are in Favor of the Goal
1	Improve the Lakes' Water Quality	92%
2	Improve Fisheries	70%
3	Decrease Weed Growth	64%
4	Improve Aesthetics	55%
5	Protect Existing Fisheries	51%
6	Protect Existing Water Quality of the Lakes	45%
7	Protect Aesthetics	41%
8	Protect Existing Weed Growth	21%
9	Increase Weed Growth	2%

Figure 46

5.6 Rainfall, Evaporation and Lake Outlet Data

As previously mentioned, precipitation was measured at seven rain gages within Chetek Lakes' watershed and read daily by volunteers to determine daily precipitation amounts.. Five gages were read during the ice-free period of 1996 and two were read daily from October 1995 through March 1997. Total average precipitation during the 1995–96 water year (monitored) was 30.84 inches.

The monthly evaporation rates estimated from the Meyer Watershed Model ranged from 0.26 inches (in January) to 4.55 inches (in July). Monthly evaporation rates were translated into daily evaporation rates to allow estimation of the hydrologic budgets on an event basis. The daily evaporation rates were assumed to be the same for each day of each month. Total estimated evaporation during 1995–96 was 27.06 inches.

The staff gage at the dam was read daily for determining the change in storage within the lake. The gage was read on a daily basis during the period October 1995 through March 1997. The monitored lake water surface elevations had a range of approximately 1 foot. The low lake surface elevation occurred in April, 1996 and the high lake surface elevation occurred during November, 1996. The normal water surface elevation is 1036.0 feet MSL.

The staff gage readings taken at the lake outlet were used to develop an outlet rating curve for the lake. The staff gage readings and outlet rating curve were used to determine daily lake volume changes and average lake outflow volumes.

5.7 Hydrologic Budget

Table 7 shows the areas and land uses for the Chetek Lakes' subwatersheds. The 1995–96 water year (October 1, 1995 through September 30, 1996) hydrologic budgets for Mud Lake, Prairie Lake, Pokegama Lake, Tenmile Lake, and Lake Chetek are shown in Figures 47 through 51. As the budgets indicate, tributary inflows and upstream lake basins play an important role in providing water to the basins within the Chetek Lakes.

Tributary inflows comprise:

- 89 percent of the annual water load to Mud Lake
- 20 percent of the annual water load to Prairie Lake
- 20 percent of the annual water load to Chetek Lake
- 97 percent of the annual water load to Tenmile Lake

Upstream basins comprise:

- 54 percent of the annual water load to Prairie Lake
- 76 percent of the annual water load to Chetek Lake
- 88 percent of the annual water load to Pokegama Lake

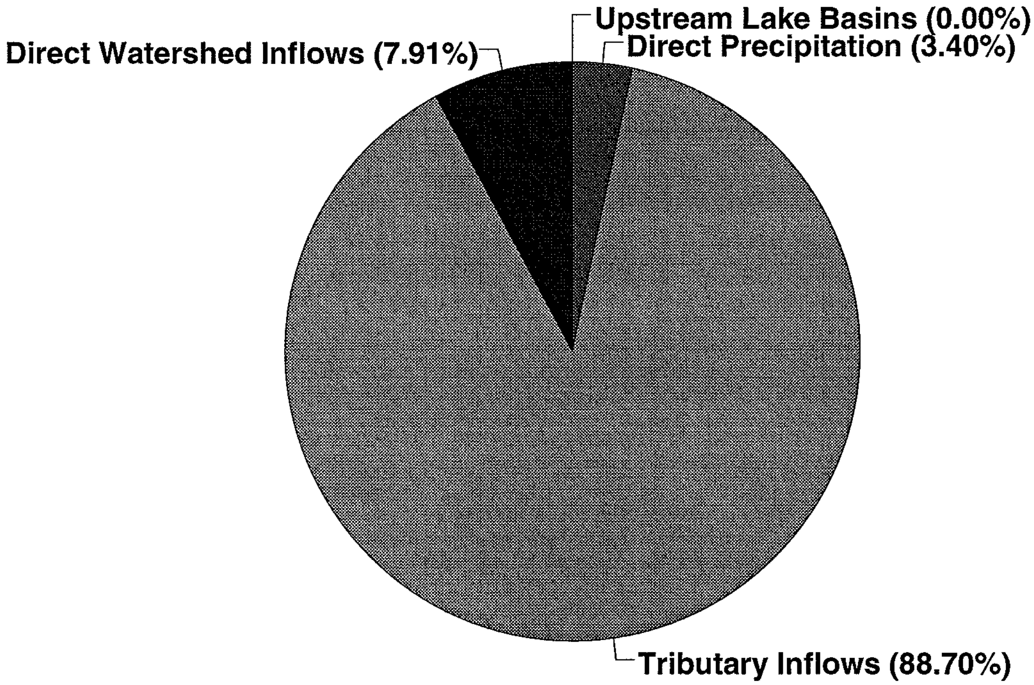
The watershed runoff volume represents an annual water yield of approximately 11 inches from the overall watershed. This compares well with the 9.7 inches of runoff published in the WILMS Model as being typical for Barron County. The runoff yield divided by the 30.84 inches of total precipitation for the monitored period results in a runoff coefficient of 0.36 (or 36 percent of the total precipitation runs off the watershed).

Evaporation (27.06 inches over the water surface area) was slightly less than precipitation (30.84 inches) during 1996. Ordinarily, evaporation would be expected to be approximately the same as the observed annual precipitation amount. Estimated evaporation for this study agrees well with average evaporation for this portion of Wisconsin which is 28 inches (Linsley, Jr., 1982).

The large amount of watershed runoff which reached the lake during 1996 indicates that watershed runoff may have a significant impact on the water quality of Chetek Lakes. The majority of the watershed runoff which reached the lake came from rainfall runoff, however, snowmelt runoff, which mainly occurred during the months of March and April, also represents a significant portion of the total inflow (45 percent of the total). As a result, snowmelt runoff can contribute a significant phosphorus load to the lakes during the spring and early-summer months.

The hydrologic budget is an important factor in determining the breakdown of nutrient loads into Chetek Lakes. Because phosphorus is the parameter of most concern, the discussion of nutrient budgets will be limited to phosphorus only.

Mud Lake Inflow
'95-'96 Water Year



Mud Lake Outflow
'95-'96 Water Year

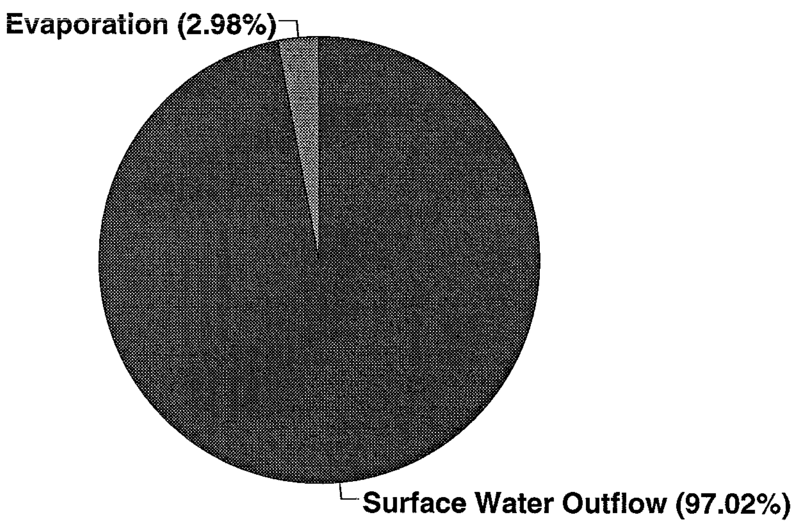
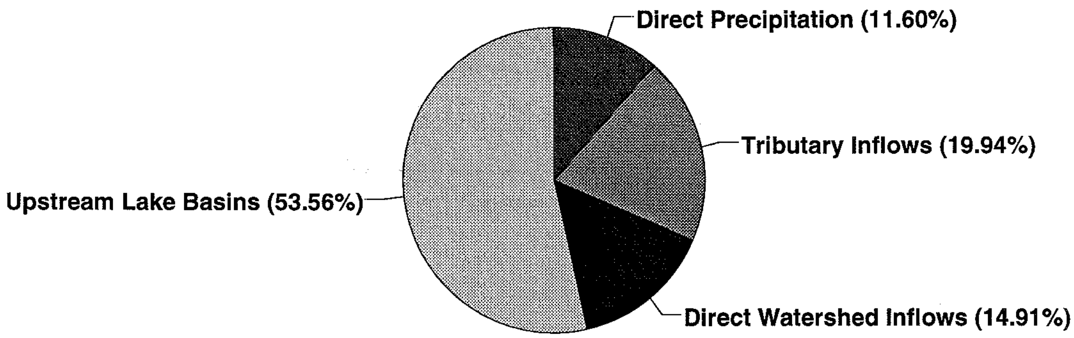


Figure 47
Mud Lake Hydrologic Budget

P:\49\03\005\report\hydrolog.wb2:Mud

Prairie Lake Inflow
'95-'96 Water Year



Prairie Lake Outflow
'95-'96 Water Year

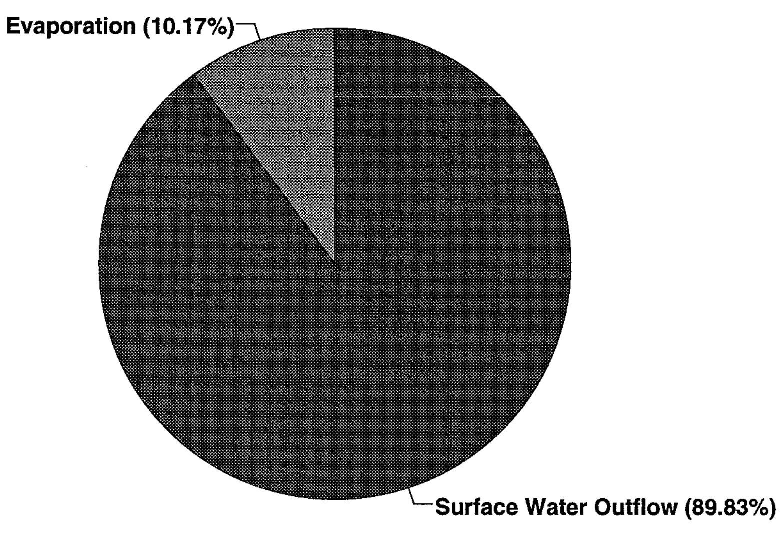
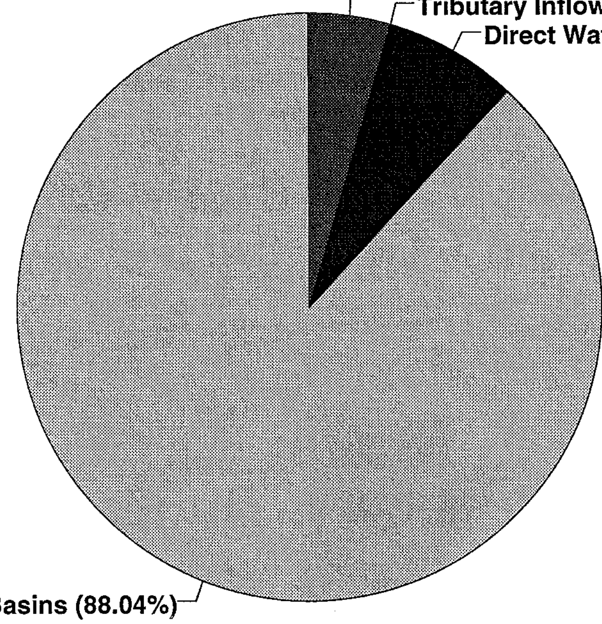


Figure 48
Prairie Lake Hydrologic Budget

P:\49\03\005\report\hydrolog.wb2:Prairie

Pokegama Lake Inflow
'95-'96 Water Year



Pokegama Lake Outflow
'95-'96 Water Year

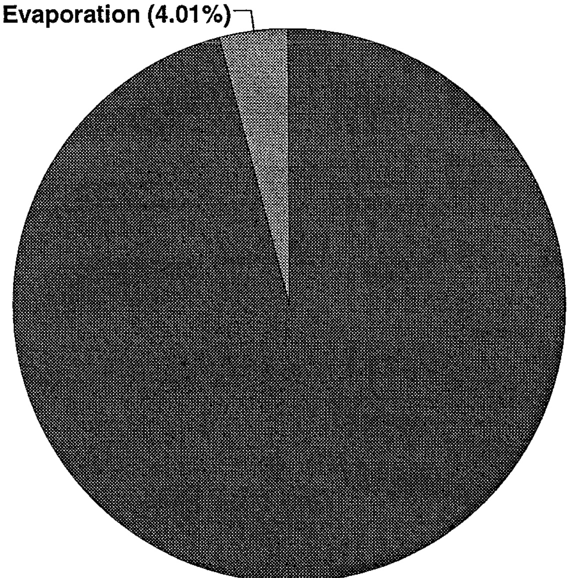
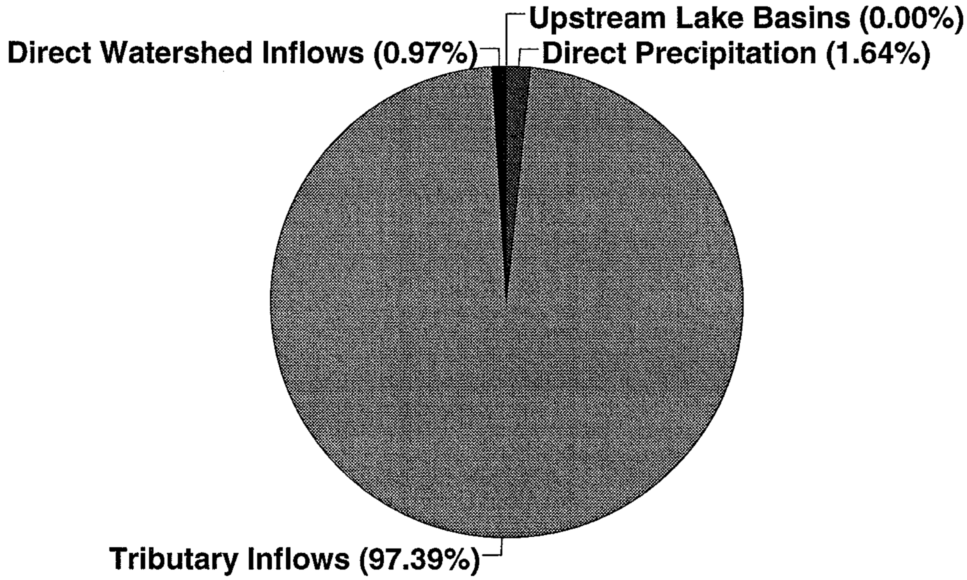


Figure 49 Pokegama Lake Hydrologic Budget

Tenmile Lake Inflow
'95-'96 Water Year



Tenmile Outflow
'95-'96 Water Year

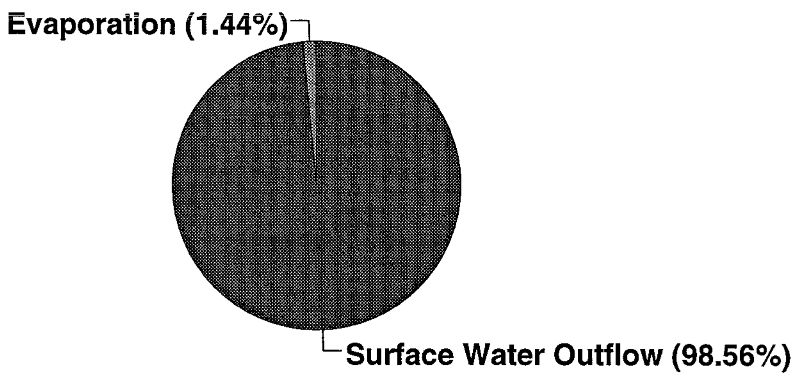
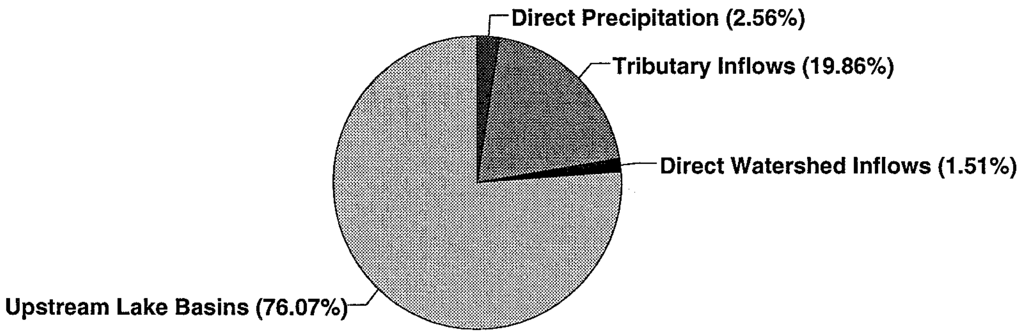


Figure 50
Tenmile Lake Hydrologic Budget

Chetek Lake Inflow
'95-'96 Water Year



Chetek Lake Outflow
'95-'96 Water Year

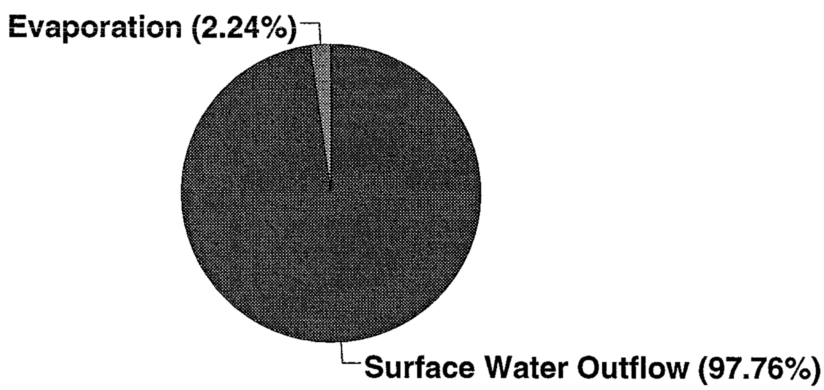


Figure 51
Chetek Lake Hydrologic Budget

P:\49\03\005\report\hydrolog.wb2:Chetek

5.8 Phosphorus Budget and Lake Water Quality Mass Balance Model

As previously mentioned, the tributary water quality data and corresponding watershed runoff volumes combined with the export rates for each of the phosphorus input sources within the direct watersheds were used to estimate the total loads to each of the lake's five basins. The computations revealed that the total annual phosphorus load into Chetek Lakes was 18,465 kilograms (40,715 pounds). The annual Chetek Lakes' total phosphorus load is presented in Figure 52. The annual phosphorus loads to the five individual basins are discussed in Sections 5.8.1 through 5.8.5. The total load to the Chetek Lakes is less than the sum of the loads to the five individual basins. The discrepancy occurs because the loads to the individual lake basins include phosphorus loaded to downstream basins from upstream basins (i.e., phosphorus moving through the lake system), while the total load to the lake system excludes the phosphorus load moving through the system from basin to basin.

Watershed runoff represents the major portion of the Chetek Lakes' phosphorus load. The watershed runoff component was estimated using the measured inflow concentrations and estimated runoff from each of the tributary watersheds along with assumed phosphorus export coefficients for each of the direct subwatersheds. The result is an estimate of 15,694 kilograms (34,605 pounds) per year from the watershed surface runoff, including an estimated 11,009 kilograms (24,275 pounds) per year from monitored inflowing streams. Therefore, the watershed runoff component represents 85 percent of the total annual load, including 60 percent from monitored inflowing streams.

Macrophyte senescence within Mud Lake represents the second highest phosphorus load to the Chetek Lakes. An estimated 1,373 kilograms (3,027 pounds) per year or 7.0 percent of the total annual phosphorus load results from senescence of curlyleaf pondweed within Mud Lake.

Internal loading from sediments, loading from atmospheric deposition, and loading from septic systems comprise the remaining 8 percent of the Chetek Lakes' phosphorus load. An estimated 769 kilograms (1,695 pounds) per year or 4 percent of the total projected load results from internal loading from sediments. An atmospheric wet and dry deposition rate used by the WILMS model of 0.25 kg/ha/yr was applied to the surface of Chetek Lakes. The computation indicates that the atmospheric component of the load is approximately 353 kilograms (778 pounds) per year or 2 percent of the total projected load. Phosphorus export rates, used in the WILMS model and published by the U.S. EPA for septic systems, were used to estimate a projected annual load of 276 kilograms (608 pounds) per year from septic system drain fields or less than 2 percent of the total projected load.

Chetek Lakes Phosphorus Sources

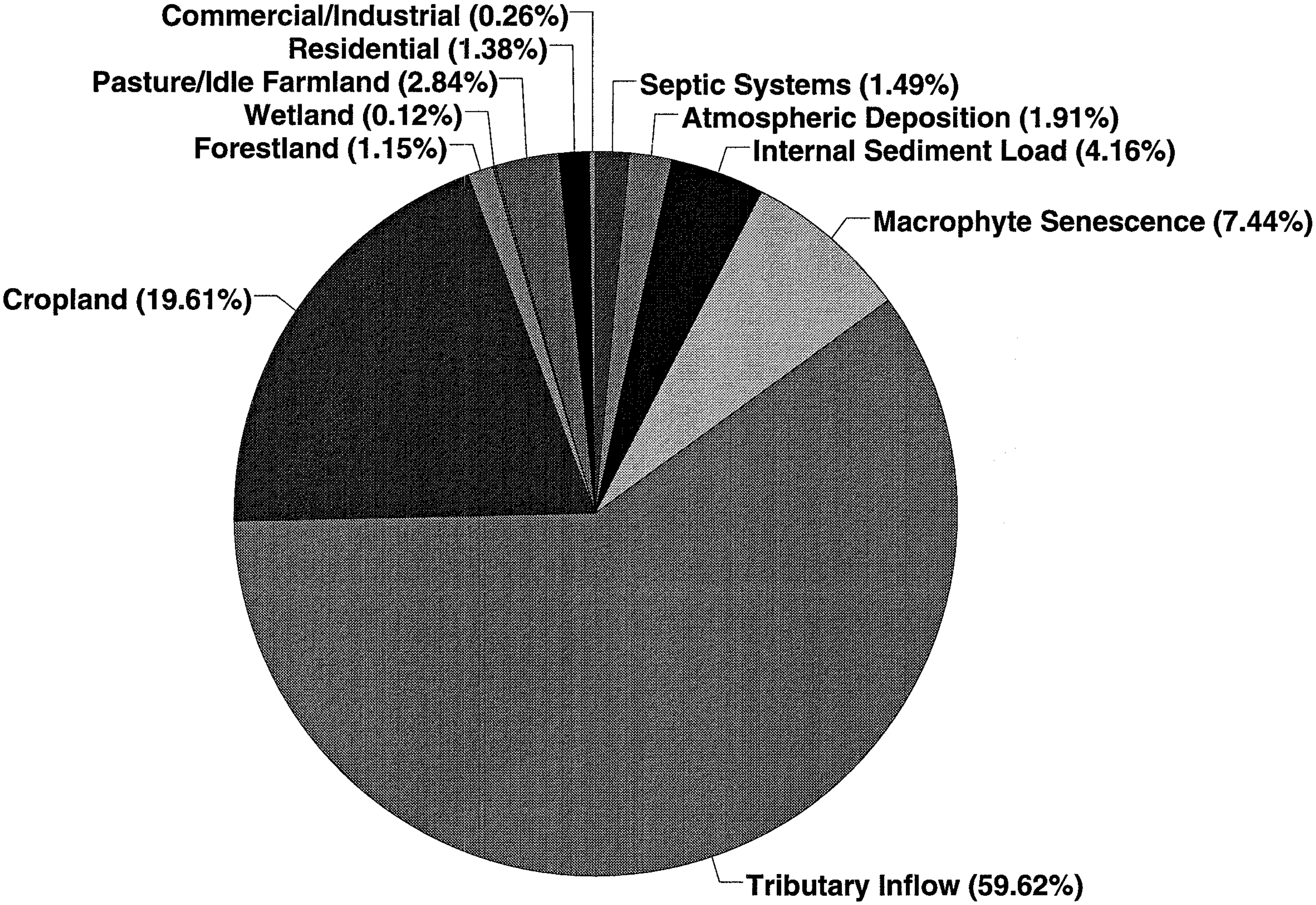


Figure 52

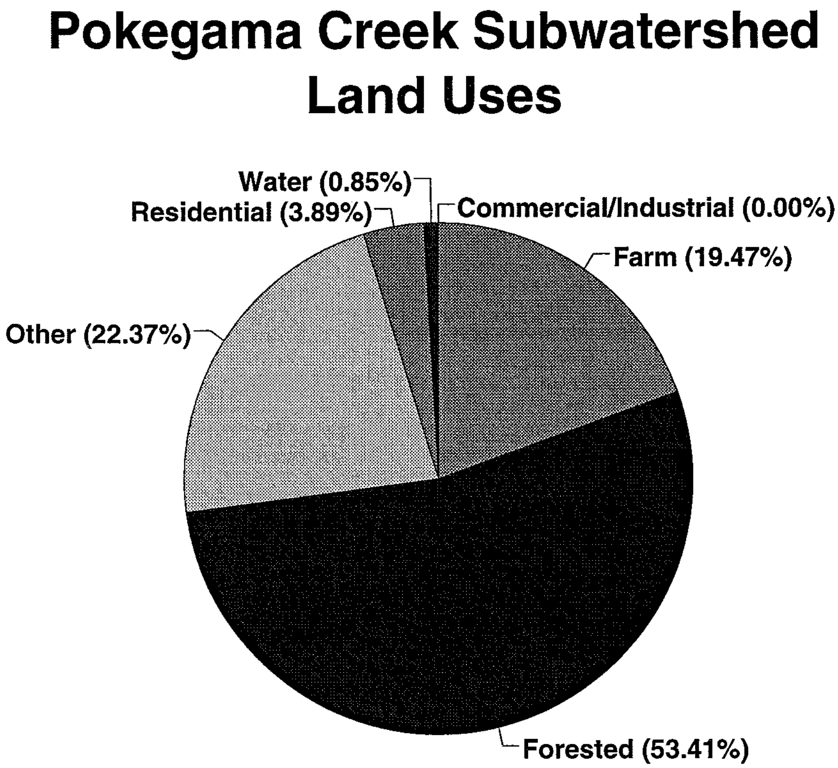
P:\49\03\005\report\phosbudg.wb2:Overall TP Budg

5.8.1 Mud Lake Modeling Results

Land use within the 36,185-acre watershed tributary to Mud Lake (See Figure 1) includes farm, forested, residential, water, and other (comprised of pastureland, CRP, and/or idle farmland). The watershed tributary to Mud Lake is divided into two subwatersheds, Pokegama Creek and Mud Lake. The Pokegama Creek subwatershed includes the land area that drains to Pokegama Creek (the creek flows into Mud Lake). The Mud Lake subwatershed includes the land area that drains directly to Mud Lake. Figure 53 presents the land uses within the Mud Lake and Pokegama Creek subwatersheds as a percent of the total subwatershed. Approximately half of the Pokegama Creek and Mud Lake subwatersheds are forested (53 and 45 percent, respectively). Approximately 19 percent of the Pokegama Creek and Mud Lake subwatersheds are farm land and approximately 25 percent are pastureland/idle farm land/CRP (22 and 26 percent, respectively).

Mud Lake has an estimated volume of 2,460 acre-feet and an estimated hydraulic residence time of 0.08 years (31 days). The annual phosphorus load to the lake basin is estimated to be 4,613 kilograms (10,172 pounds) or 4.1 pounds per acre foot. The primary sources of phosphorus are macrophyte senescence (an estimated 30 percent of the annual load) and Pokegama Creek (an estimated 56 percent of the annual load). The lake's direct watershed is estimated to contribute 11 percent of the annual load. Atmospheric deposition and septic systems are each estimated to contribute less than 1 percent of the annual load. Less than 2 percent of the annual load is calculated to result from internal loading.

Approximately 88 percent of phosphorus load entering Mud Lake flows to downstream basins Pokegama Lake and Prairie Lake (i.e., 58 percent to Pokegama Lake and 30 percent to Prairie Lake). The remaining 12 percent settles to the bottom of Mud Lake (See Figure 54).



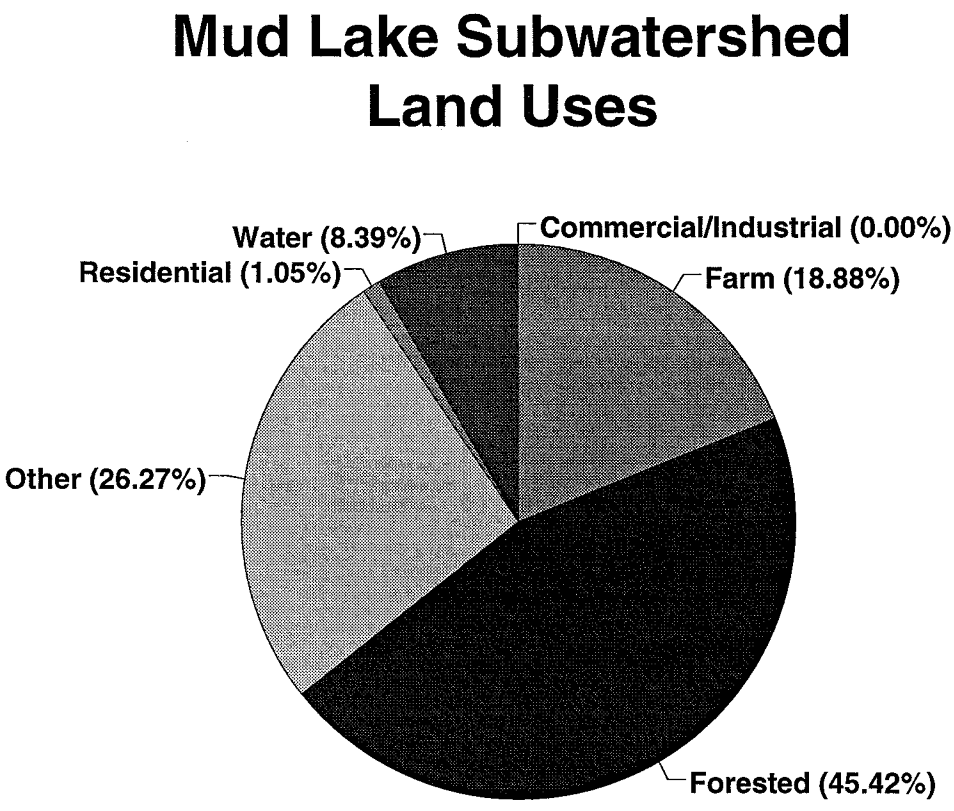
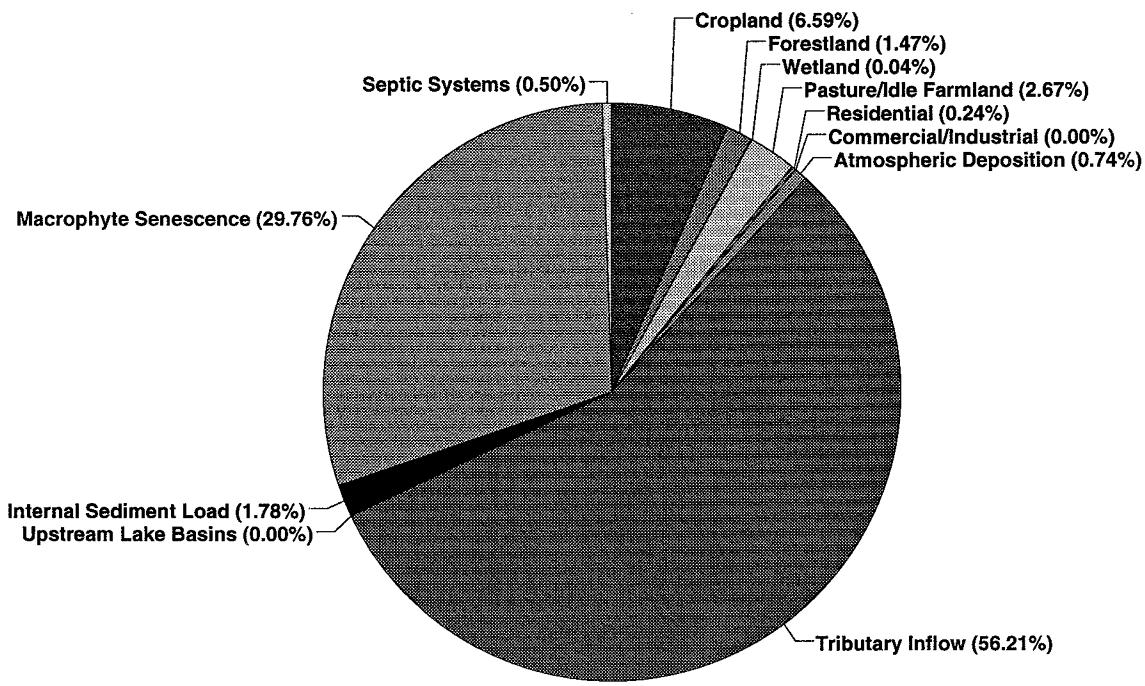


Figure 53
Pokegama Creek and Mud Lake Subwatershed Land Uses

Mud Lake Phosphorus Sources
'95-'96 Water Year



Mud Lake Phosphorus Sinks
'95-'96 Water Year

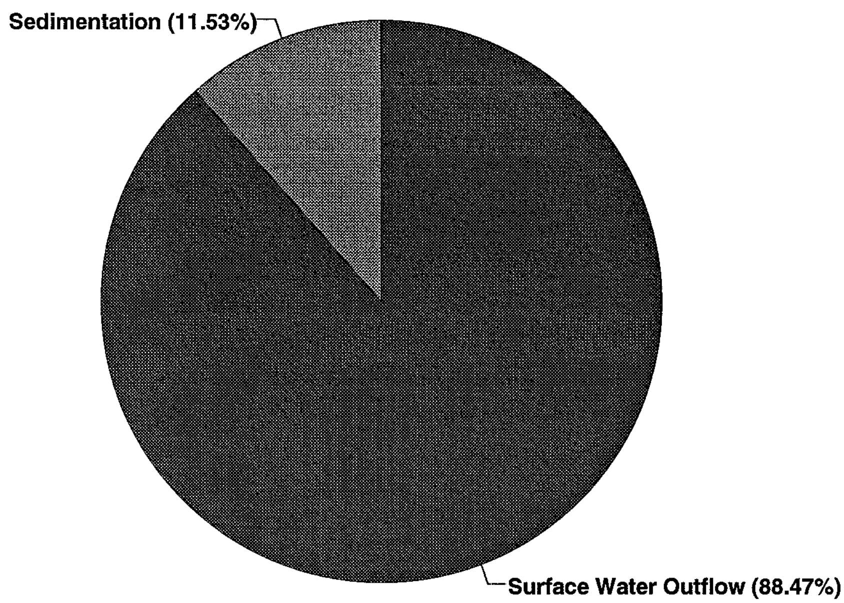


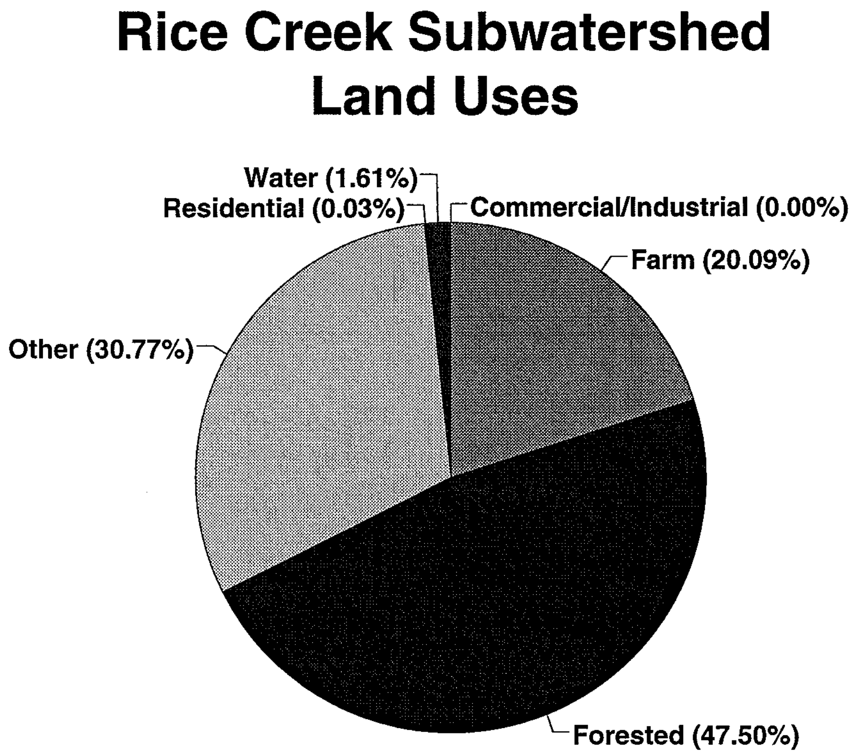
Figure 54
Mud Lake Phosphorus Budget

5.8.2 Prairie Lake Modeling Results

Land use within the 13,825-acre watershed tributary to Prairie Lake (See Figure 1) includes commercial/industrial, farm, forested, residential, water, and other (comprised of pastureland, CRP, and/or idle farmland). The watershed tributary to Prairie Lake is divided into two subwatersheds, Rice Creek and Prairie Lake. The Rice Creek subwatershed includes the land area that drains to Rice Creek (the creek flows into Prairie Lake). The Prairie Lake subwatershed includes the land area that drains directly to Prairie Lake. Figure 55 presents the land uses within the Rice Creek and Prairie Lake subwatersheds as a percent of the total subwatershed. The Rice Creek subwatershed is primarily comprised of forest land use (48 percent), pastureland, idle farmland/CRP (31 percent), and farm land use (21 percent). Approximately half of the Prairie Lake subwatershed is comprised of farm land use (49 percent). Approximately 20 percent of the Prairie Lake subwatershed is forested and approximately 15 percent is comprised of pastureland/idle farmland/CRP. Water comprises 13 percent of the Prairie Lake subwatershed.

Prairie Lake has an estimated volume of 14,035 acre-feet and an estimated hydraulic residence time of 0.47 years (about 6 months). The annual phosphorus load to the lake basin is estimated to be 5,056 kilograms (11,147 pounds) or 0.8 pounds per acre-foot. The primary sources of phosphorus are cropland within the lake's direct watershed (an estimated 44 percent of the annual load) and outflow from Mud Lake (an estimated 27 percent of the annual load). Flow from Rice Creek comprises approximately 17 percent of the annual load. The remaining watershed land uses collectively comprise approximately 6 percent of the annual load. Less than 3 percent of the annual load is calculated to result from atmospheric deposition; septic systems are estimated to comprise 2 percent of the annual load.

Approximately 55 percent of phosphorus entering Prairie Lake flows to Lake Chetek. Sedimentation removes the remaining 45 percent (See Figure 56).



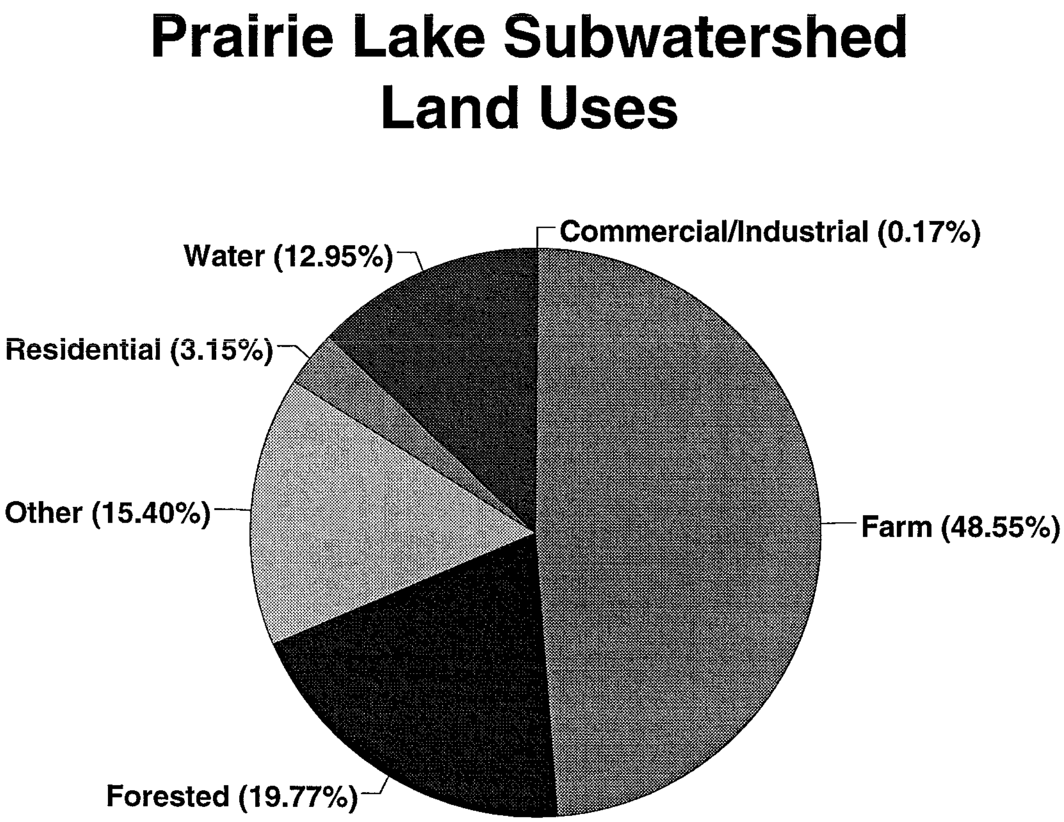
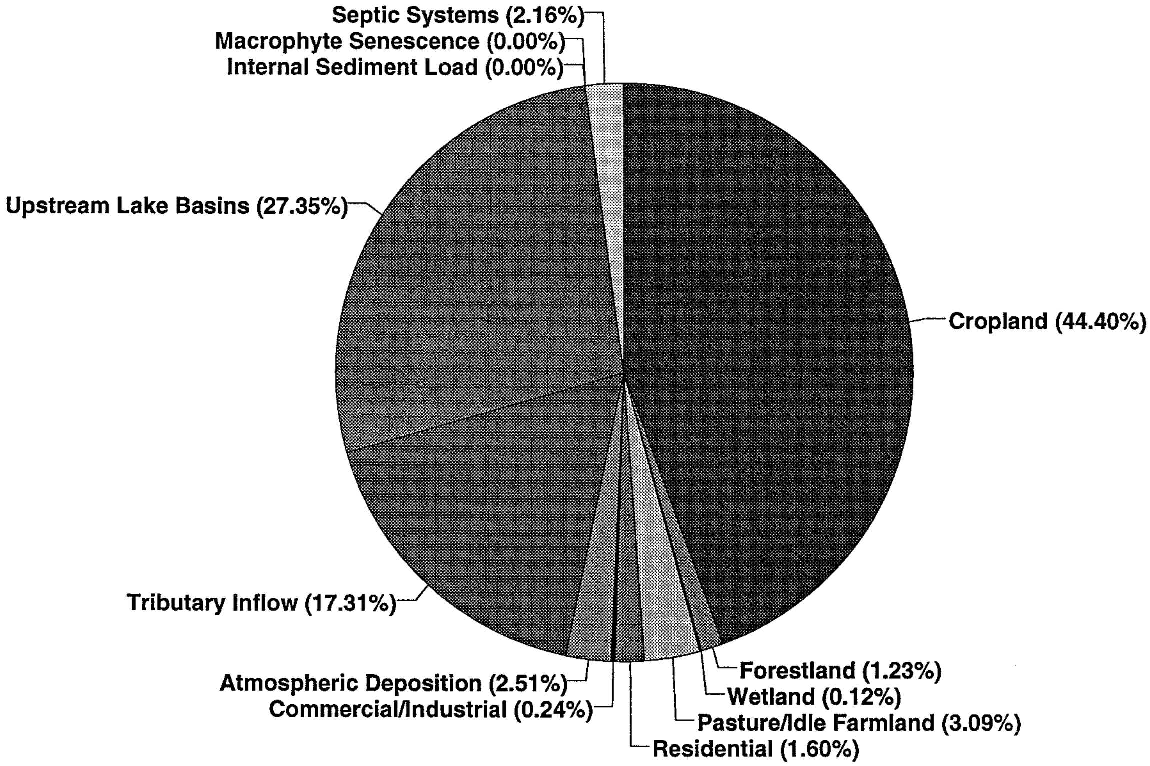


Figure 55
Rice Creek and Prairie Lake Subwatershed Land Uses

Prairie Lake Phosphorus Sources
'95-'96 Water Year



Prairie Lake Phosphorus Sinks
'95-'96 Water Year

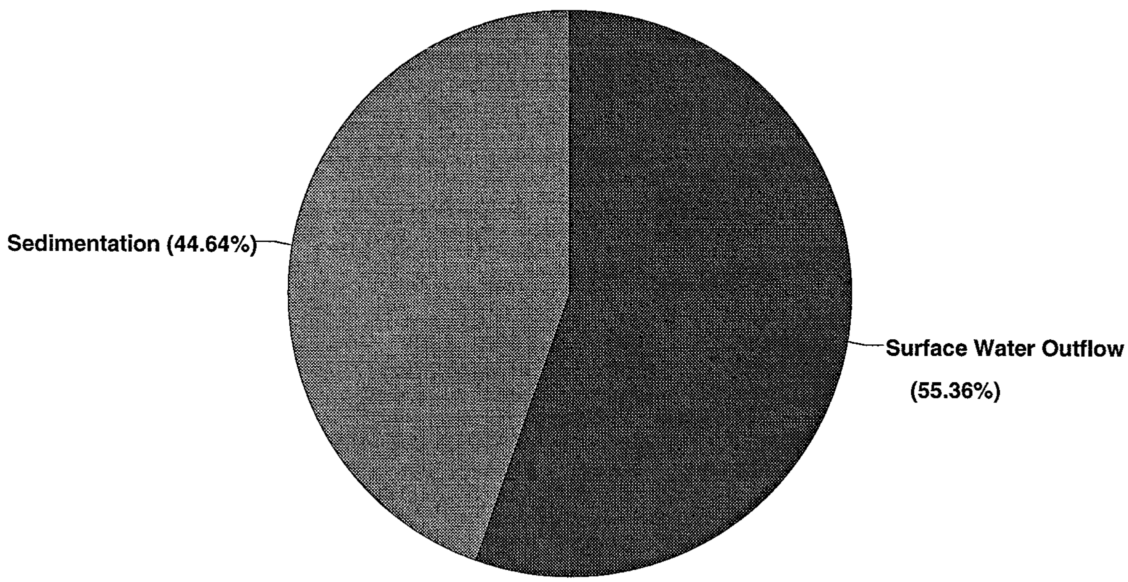


Figure 56
Prairie Lake Phosphorus Budget

5.8.3 Pokegama Lake Modeling Results

Land use within the 4,873-acre watershed tributary to Pokegama Lake (See Figure 1) includes farm, forested, residential, water, and other (pastureland, CRP, and/or idle farmland). Figure 57 presents the land uses within the Pokegama Lake subwatershed as a percent of the total subwatershed. The Pokegama Lake subwatershed is primarily comprised of forest land use (32 percent), farm land use (27 percent), and pastureland/idle farmland/CRP (26 percent).

Pokegama Lake has an estimated volume of 5,322 acre-feet and an estimated hydraulic residence time of 0.2 years (73 days). The annual phosphorus load to the lake basin is estimated to be 3,905 kilograms (8,611 pounds) or 1.6 pounds per acre-foot. The primary source of phosphorus to Pokegama Lake is Mud Lake outflow (an estimated 69 percent of the annual load). Phosphorus from the lake's direct watershed is estimated to comprise 17 percent of the annual load. Approximately 11 percent of the annual load is calculated to result from internal loading. Septic systems and atmospheric deposition are each estimated to contribute 1 percent of the annual load.

Approximately 69 percent of phosphorus entering Pokegama Lake flows to Lake Chetek. Sedimentation removes the remaining 31 percent (See Figure 58).

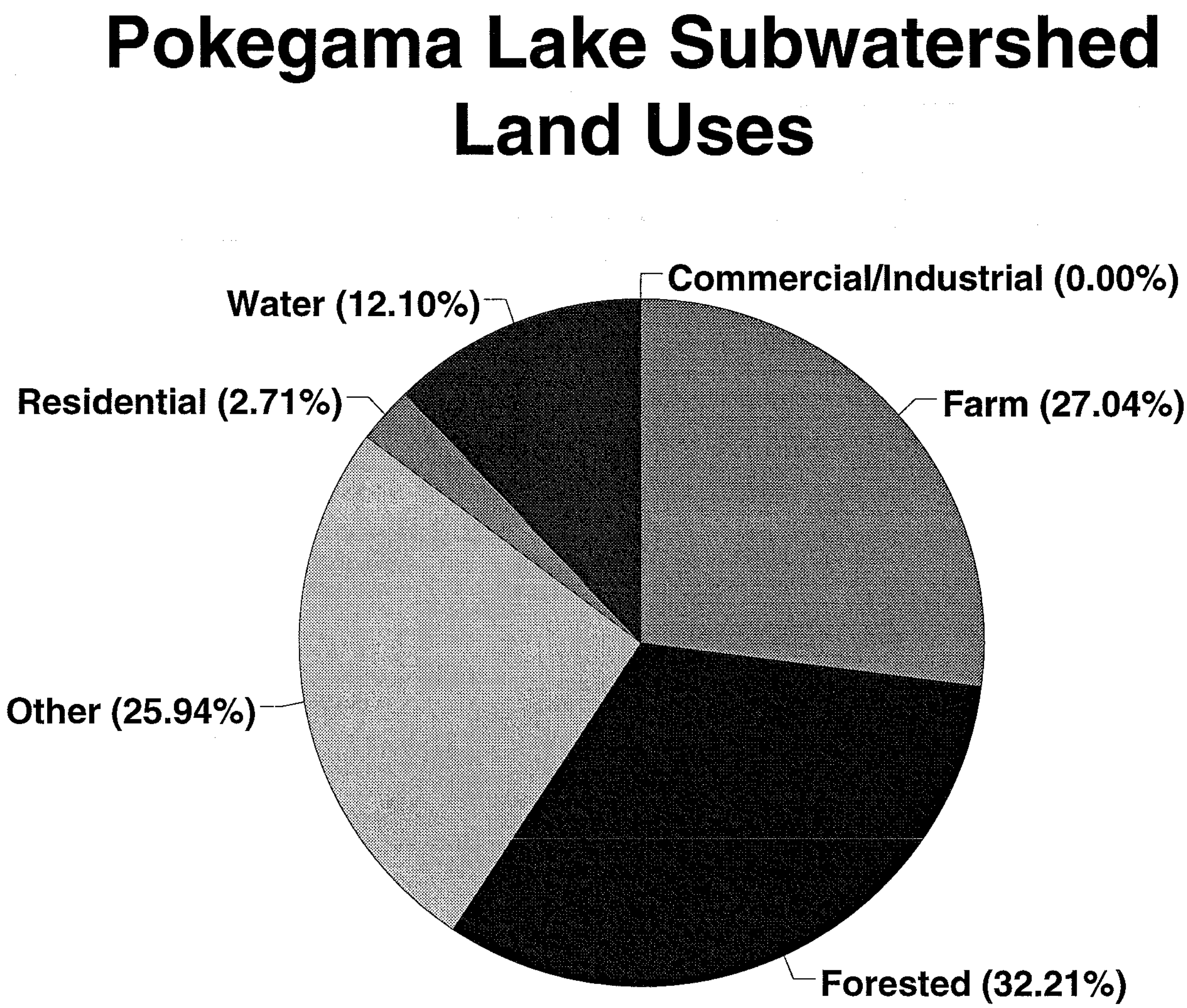
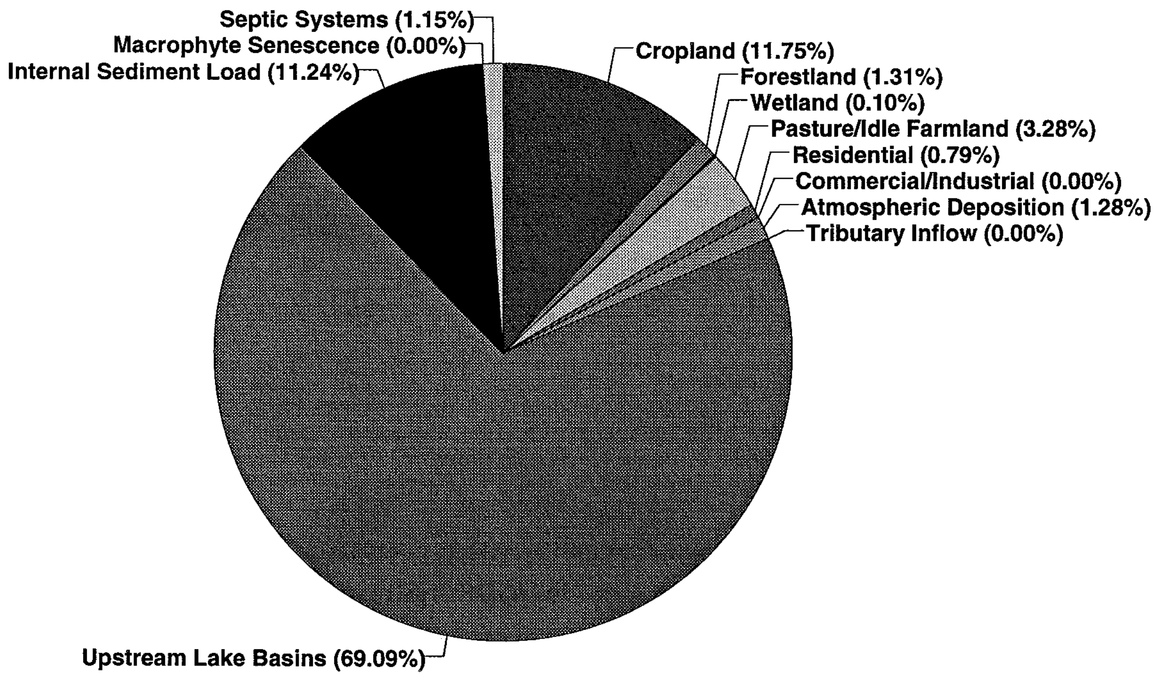


Figure 57
Pokegama Lake Subwatershed Land Uses

Pokegama Lake Phosphorus Sources
'95-'96 Water Year



Pokegama Lake Phosphorus Sinks
'95-'96 Water Year

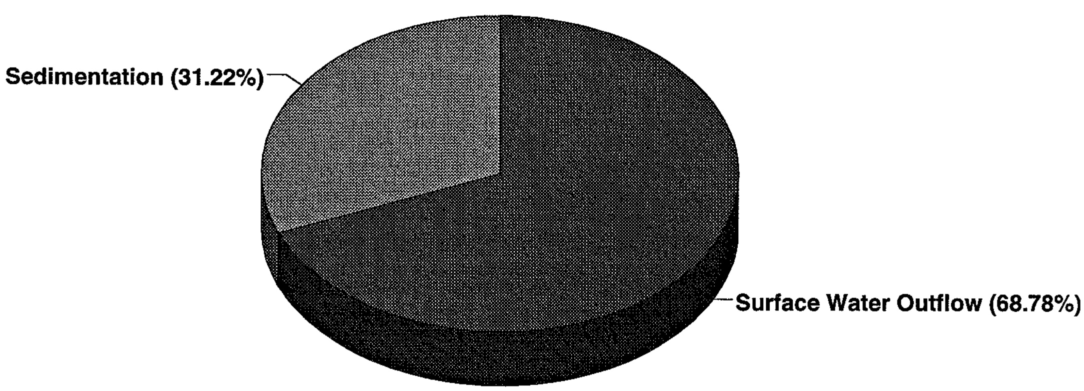


Figure 58
Pokegama Lake Phosphorus Budget

5.8.4 Tenmile Lake Modeling Results

Land use within the 39,772-acre watershed tributary to Tenmile Lake (See Figure 1) includes farm, forested, residential, water, and other (pastureland, CRP, and/or idle farmland). The Tenmile Lake watershed is divided into three subwatersheds, Tenmile Creek, Short Creek, and Tenmile Lake. The Tenmile Creek subwatershed includes the land area that drains to Tenmile Creek (the creek flows into Tenmile Lake). The Short Creek subwatershed includes the land area that drains into Short Creek (the creek flows into Tenmile Lake). The Tenmile Lake subwatershed includes the land area that drains directly to Tenmile Lake. Figure 59 presents the land uses within the Tenmile Creek, Short Creek, and Tenmile Lake subwatersheds as a percent of the total subwatershed.

Farm and forest land uses each comprise approximately one-third of the Tenmile Creek subwatershed (34 percent each). Pastureland/idle farmland/CRP (16 percent) and water (15 percent) land uses comprise nearly all of the remaining one-third of the Tenmile Creek subwatershed.

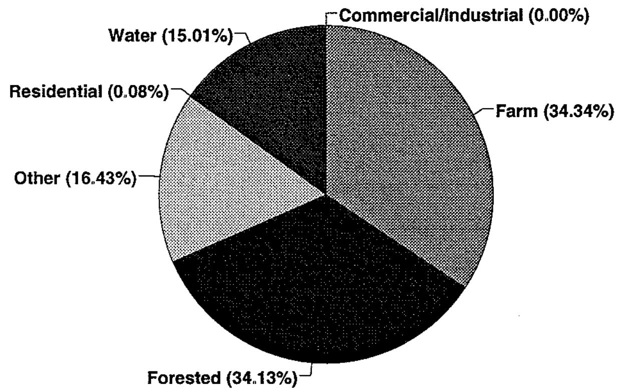
Farm and pastureland/idle farmland/CRP land uses each comprise approximately one quarter of the Short Creek subwatershed (26 percent and 28 percent, respectively). Approximately one-third of the Short Creek subwatershed is forested (35 percent). Water comprises approximately 11 percent of the Short Creek subwatershed.

Approximately one-third of the Tenmile Lake subwatershed is residential. Farm and forest land uses each comprise approximately one quarter of the Tenmile Lake subwatershed (28 percent and 22 percent, respectively). The remaining 16 percent of the Tenmile Lake subwatershed is comprised of commercial/industrial (9 percent) and pastureland/idle farmland/CRP (7 percent) land uses.

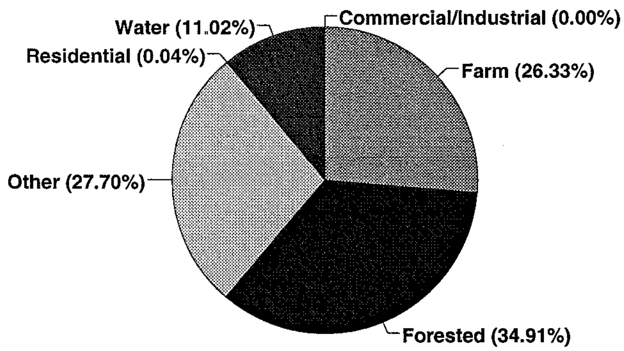
Tenmile Lake has an estimated volume of 2,369 acre feet and an estimated hydraulic residence time of 0.04 years (approximately 15 days). The annual phosphorus load to the lake basin is estimated to be 4,698 kilograms (10,357 pounds) or 4.4 pounds per acre-foot. The primary source of phosphorus is Tenmile Creek (an estimated 88 percent of the annual load). Short Creek contributes an estimated 8 percent of the annual load. The lake's direct watershed contributes less than 2 percent of the annual load. Septic systems and atmospheric deposition are each estimated to contribute less than 1 percent of the annual load. Approximately 1 percent of the annual load is calculated to result from internal sediment loading.

Approximately 91 percent of phosphorus entering Tenmile Lake flows to Lake Chetek. Sedimentation removes the remaining 9 percent (See Figure 60).

Tenmile Creek Subwatershed Land Uses



Short Creek Subwatershed Land Uses



Tenmile Lake Subwatershed Land Uses

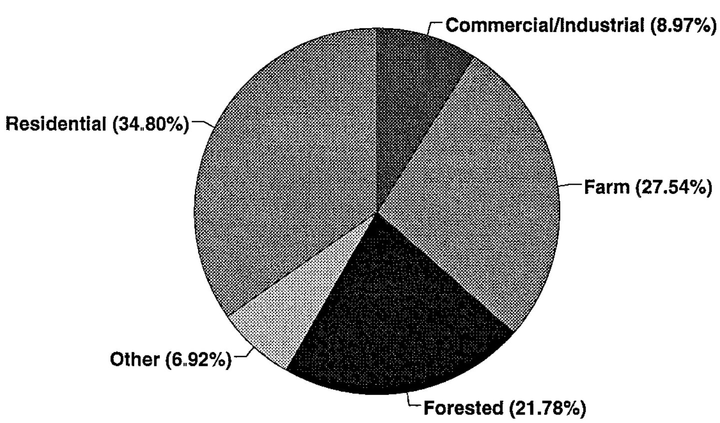
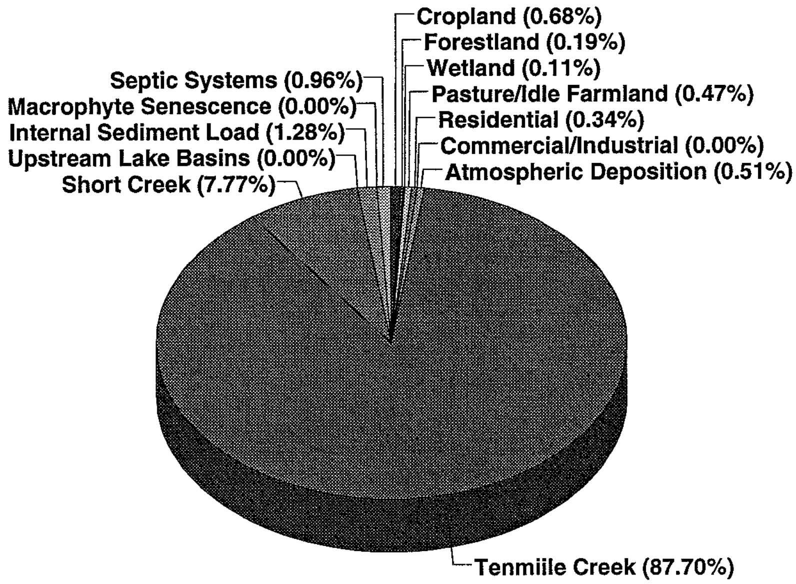


Figure 59
Tenmile Creek, Short Creek, and Tenmile Lake Subwatershed Land Uses

Tenmile Lake Phosphorus Sources
'95-'96 Water Year



Tenmile Lake Phosphorus Sinks
'95-'96 Water Year

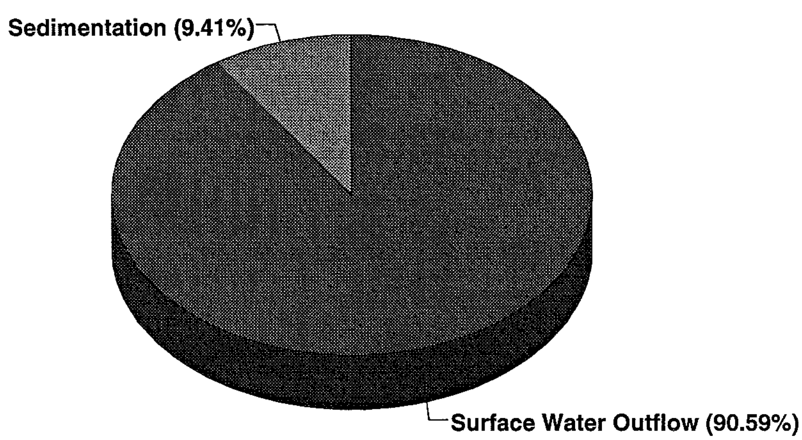


Figure 60
Tenmile Lake Phosphorus Budget

5.8.5 Lake Chetek Modeling Results

Land use within the 29,157-acre watershed tributary to Lake Chetek (See Figure 1) includes commercial/industrial, farm, forested, residential, water, and other (pastureland, CRP, and/or idle farmland). The watershed tributary to Lake Chetek is divided into two subwatersheds, Moose Ear Creek and Lake Chetek. The Moose Ear Creek subwatershed includes the land area that drains to Moose Ear Creek (the creek flows into Lake Chetek). The Lake Chetek subwatershed includes the land area that drains directly to Lake Chetek. Figure 61 presents the land uses within the Moose Ear Creek and Lake Chetek subwatersheds as a percent of the total subwatershed.

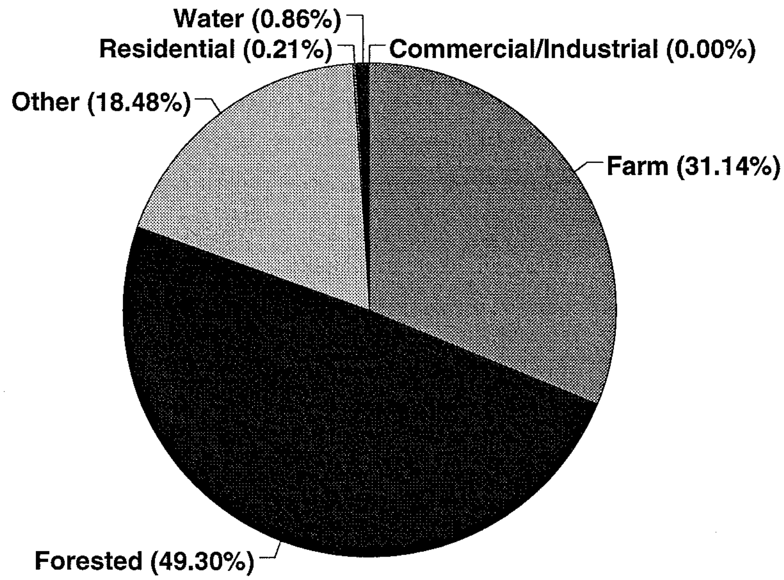
Approximately one-half of the Moose Ear Creek subwatershed is comprised of forest land use (49 percent) and approximately one-third is comprised of farm land use (31 percent). Approximately 18 percent of the Moose Ear Creek subwatershed is comprised of pastureland/idle farmland/CRP land uses.

Water and farm land uses each comprise approximately one quarter of the Lake Chetek subwatershed (28 percent and 26 percent, respectively). Approximately 20 percent of the Lake Chetek subwatershed is comprised of pastureland/idle farmland/CRP. Approximately 15 percent of the Lake Chetek subwatershed is comprised of forest land uses. Residential land uses (10 percent) and commercial/industrial (1 percent) land uses comprise the remaining portion of the Lake Chetek subwatershed.

Lake Chetek has an estimated volume of 9,991 acre-feet and a hydraulic residence time of 0.12 years (approximately 44 days). The annual phosphorus load to the lake basin is estimated to be 14,026 kilograms (30,922 pounds) or 3.1 pounds per acre-foot. The primary source of phosphorus is upstream lake basins (an estimated 70 percent of the annual load). Moose Ear Creek contributes an estimated 22 percent of the annual load. The lake's direct watershed contributes approximately 6 percent of the annual load. Septic systems and atmospheric deposition are each estimated to contribute less than 1 percent of the annual load. Approximately 1 percent of the annual load is calculated to result from internal sediment loading.

Approximately 71 percent of phosphorus entering Lake Chetek flows out the Chetek River. Sedimentation removes the remaining 29 percent (See Figure 62).

Moose Ear Creek Subwatershed Land Uses



Lake Chetek Subwatershed Land Uses

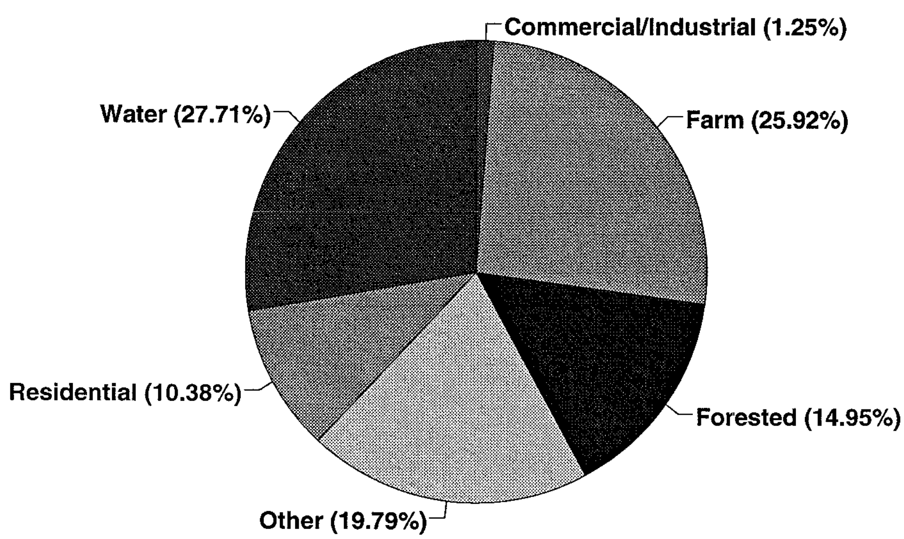
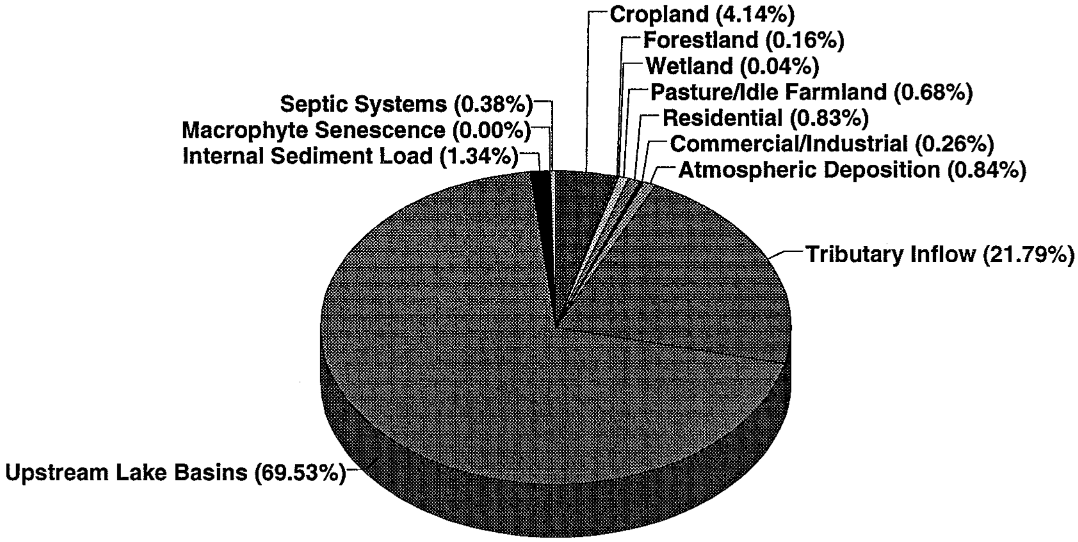


Figure 61
Moose Ear Creek and Chetek Lake Subwatershed Land Uses

Chetek Lake Phosphorus Sources
'95-'96 Water Year



Chetek Lake Phosphorus Sinks
'95-'96 Water Year

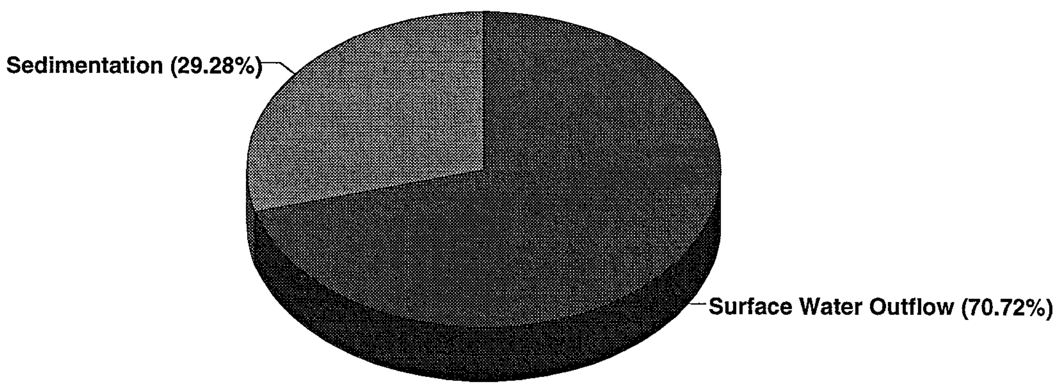


Figure 62
Chetek Lake Phosphorus Budget

5.9 Model Calibration

Each of the phosphorus input loadings was used to calibrate the lake mass balance model to the water quality observed in each of the lake's basins during 1996. A comparison of observed and predicted average total phosphorus concentrations is presented on Figure 63. The calibrated model predicts an average total phosphorus concentration that is the same as the observed average epilimnetic (i.e., surface water, upper 6 feet) total phosphorus concentration in Mud Lake, Pokegama Lake, and Lake Chetek. The predicted total phosphorus concentration in Prairie Lake was 2 µg/L higher than the observed average epilimnetic total phosphorus concentration. The predicted total phosphorus concentration in Tenmile Lake was 11 µg/L lower than the observed average total phosphorus concentration.

Chetek Lakes: Predicted and Observed Average Total Phosphorus Concentration

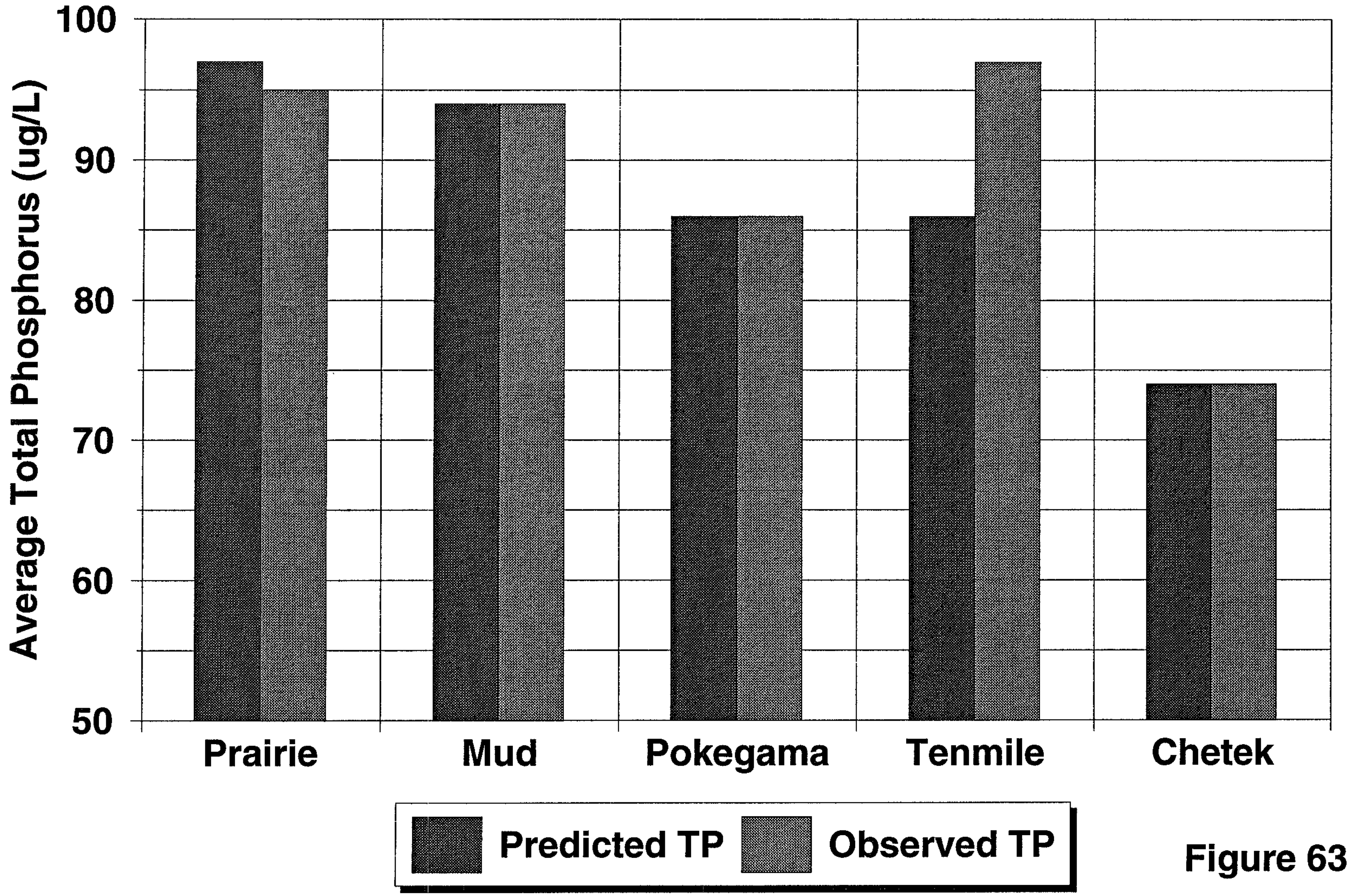


Figure 63

P:\49\03\005\report\modelcal.wb2:model calibrati

6.0 Recommendations and Management Actions

Completion of a Lake Management Plan for Chetek Lakes is recommended to improve the lakes' water quality. Prior to the completion of the management plan, the following project is recommended to confirm or fine-tune estimates presented in this report:

1. A study of the curlyleaf pondweed coverage and density and the phosphorus content of the curlyleaf pondweed in Mud Lake is recommended to fine tune the estimate of phosphorus loading from macrophyte senescence. The study results will provide needed information for the design of an effective curlyleaf pondweed management plan. Because curlyleaf pondweed senescence is estimated to comprise 43 percent of Mud Lake's annual phosphorus load, management of curlyleaf pondweed is expected to improve the lake's water quality.

2. A study of the flow between Mud Lake and Prairie Lake is recommended to fine tune the estimate of phosphorus loading from Mud Lake to Prairie Lake. The results of the flow study will be used in the Chetek Lakes' management plan to determine the likely reduction in phosphorus loading to Prairie Lake from implementation of a Mud Lake curlyleaf pondweed management plan.

3. An analysis of the Chetek Lakes' system using the Bathtub model is recommended to fine tune estimates of flow and phosphorus loading between basins. The analysis will provide a more accurate estimate of phosphorus movement between basins and resultant basin water quality. Because phosphorus loading from upstream basins represents an important phosphorus loading component for Prairie, Pokegama, and Chetek lakes, the analysis is recommended to provide a more accurate estimate of water quality improvement to these basins following implementation of watershed and/or in-lake management practices. Therefore, completion of the Bathtub modeling analysis is recommended prior to completion of the Chetek Lakes Management Plan. Data from the current project and data from completion of the first two recommendations will be used in the Bathtub modeling analysis of the Chetek Lakes.

Development of a management plan for the Chetek Lakes and the lakes' watershed affords the opportunity to evaluate potential lake water quality improvement practices and the water quality impacts of different watershed and lake management scenarios. The following management plan development project is recommended:

1. **Establish a long-term water quality goal for each lake basin**

2. **Determine potential watershed management practices in the Chetek Lakes watershed**—Implementation of watershed management practices in the Tenmile Creek watershed is expected to provide the greatest opportunity to improve the water quality of Tenmile Lake. Implementation of watershed management practices in Prairie Lake's direct watershed is expected to provide the greatest opportunity to improve the water quality of Prairie Lake. Implementation of watershed management practices in the Tenmile Creek and Prairie Lake watersheds are secondarily expected to improve the water quality of Lake Chetek.

3. **Determine potential in-lake management practices (e.g., curlyleaf pondweed management in Mud Lake)**—Reduction of phosphorus loading from curlyleaf pondweed senescence is expected to result in water quality improvement to Mud Lake, Prairie Lake, Pokegama Lake, and Lake Chetek. Approximately 43 percent of Mud Lake's annual phosphorus load is believed to result from curlyleaf pondweed senescence. Approximately 84 percent of the phosphorus added to Mud Lake from curlyleaf pondweed senescence flows to either Pokegama Lake or Prairie Lake. Approximately 69 percent of the phosphorus entering Pokegama Lake flows into Lake Chetek, while approximately 55 percent of the phosphorus entering Prairie Lake flows into Lake Chetek. Therefore, reduction of phosphorus loading to Mud Lake will improve its water quality and the water quality of downstream lakes.

4. **Model the estimated water quality benefits from implementation of watershed and in-lake management practices identified in Numbers 2 and 3**

5. **Determine whether implementation of watershed and/or in-lake management practices will result in goal achievement**—If goal achievement will not result from implementation of management practices, a goal evaluation is recommended to determine whether changes are warranted.

6. **Develop a management plan for Chetek Lakes and its watershed**

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 Co., 1999. Big Lake Macrophyte Management Implementation—Preliminary Data Summary.

Bannerman, R.T., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. 1983. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin.* Vol. I. EPA, Water Planning Division. PB 84-114164.

Burwell, R.E., D.R. Timmons and R.F. Holt, 1975. *Nutrient Transport in Surface Runoff as Influenced by Soil Cover and Seasonal Periods.* Soil. Sci. Soc. Amer. Proc. **39:** 523-528.

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

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.

Dillon, P.J. and F.H. Rigler, 1974. *A test of a simple nutrient budget model predicting the phosphorus concentration in lake water.* J. Fish. Res. Bd. Can. **31:** 1771-1778.

Einsele W., 1936. Arch. Hydrobiol. 29: 664-686.

Eisenreich, S.J., Emmling, P.J., and Beeton, A.M., 1977. *Atmospheric Loading of Phosphorus and Other Chemicals to Lake Michigan.* Internat. Assoc. Great Lakes Res. 3(3-4):291-304.

Engel, S. 1985. *Aquatic Community Interactions of Submerged Macrophytes: Phytoplankton, Zooplankton, Macrophytes, Fishes, Benthos.* Technical Bulletin No. 156, Department of Natural Resources, Madison, Wisconsin.

Engel, S. 1999. Personal Communication.

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.

Hensler, R.F., R.J. Olsen, S.A. Witzel, O.J. Attoe, W.H. Paulson and R.F. Johannes, 1970. *Effect of Method of Manure Handling on Crop Yields, Nutrient Recovery and Runoff Losses.* Trans. ASAE **13:** 726-731.

Landon, R.J., 1977. *Characterization of Urban Stormwater Runoff in the Tri-County Region.* 208 Water Quality Management Plan. Michigan Tri-County Regional Planning Commission. 136 pp.

Linsley, R.K., Jr., M.A. Kohler, and J.L.H. Paulhus, 1982. *Hydrology for Engineers,* Third Edition. McGraw-Hill Book Company. New York, New York.

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

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

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

Nurnberg, G.K., 1984. *The prediction of internal phosphorus load in lakes with anoxic hypolimnia.* Limnol. Oceanogr. **29:** 111-124.

Nurnberg, G.K., 1985. *Availability of phosphorus upwelling from iron-rich anoxic hypolimnia.* Arch. Hydrobiol. **104:** 459-476.

Nurnberg, G.K. and R.H. Peters, 1984. *The importance of internal phosphorus load to the eutrophication of lakes with anoxic hypolimnia.* Int. Ver. Theor. Angew. Limnol. Verh. **22:** 190-194.

Nurnberg, G.K., M. Shaw, P.J. Dillon and D.J. McQueen, 1986. *Internal phosphorus load in an oligotrophic Precambrian Shield lake with an anoxic hypolimnion.* Can. J. Fish. Aquat. Sci. **43:** 574-580.

Osgood, R.A., 1989. *Assessment of Lake Use-Impairment in the Twin Cities Metropolitan Area.* Prepared for the Minnesota Pollution Control Agency. Metropolitan Council Publication 590-89-130. 12 pp.

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.

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.

Richardson, C.J., and Merva. G.E., 1976. *The Chemical Composition of Atmospheric Precipitation from Selected Stations in Michigan.* Water, Air and Soil Pollution, 6:373-385.

Singer, M.J. and R.H. Rust, 1975. *Phosphorus in Surface Runoff from a Deciduous Forest.* J. Environ. Quality **4:** 307-311.

Thorson, D. 1997. *The Lakes of Barron County.* Barron County Land Conservation Department, Barron, Wisconsin.

Walker, W.W., Jr., 1987. *Empirical Methods for Predicting Eutrophication in Impoundments. Report 4. Phase III: Applications Manual.* Technical Report E-81-9.

Zehner, J., 1998. Personal Communication.