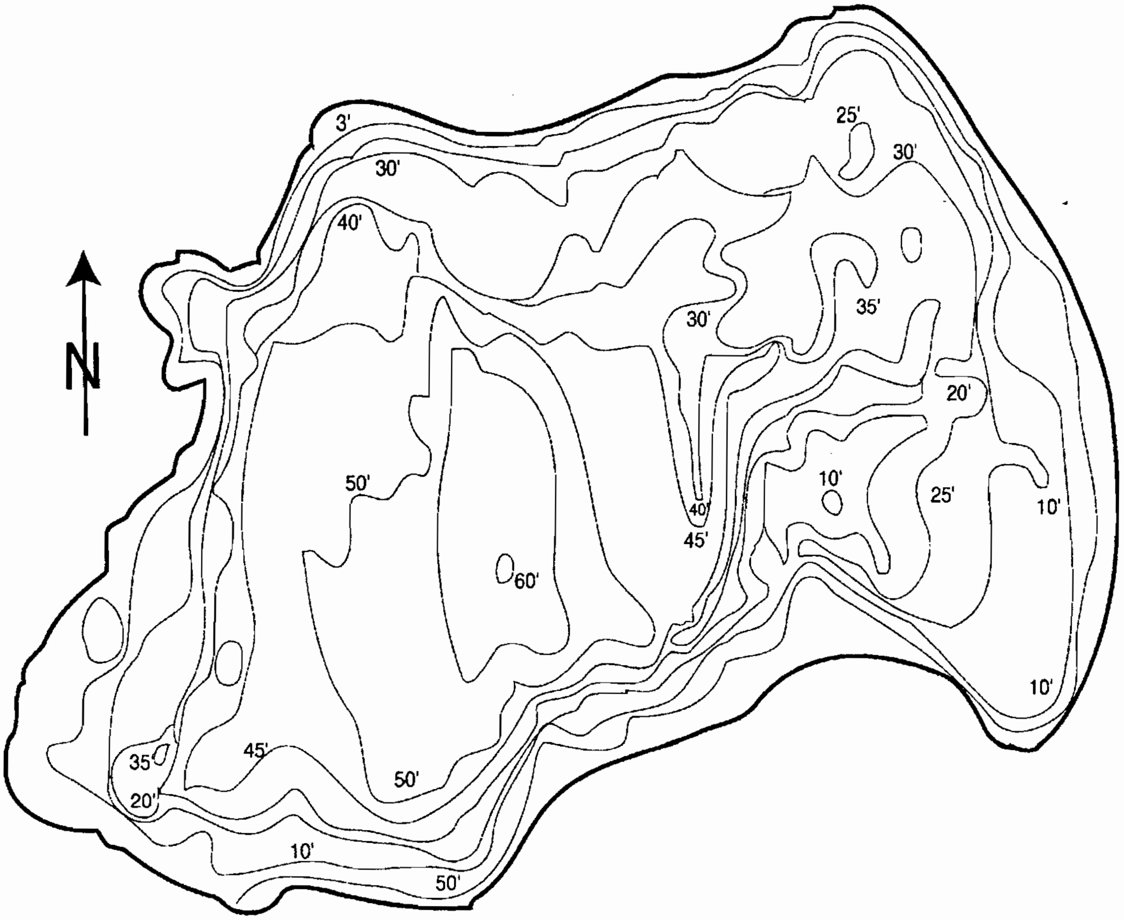
Grindstone Lake Water Quality Study



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Eric Nilsson	President of Grindstone Lake Association
Jim Rigotti	Grindstone Lake Association Volunteer team leader Collect Secchi Disk data
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FORWARD

This report summarizes the results of a water quality investigation of Grindstone Lake for the preparation of a comprehensive management plan for the lake. Basic in-lake and tributary water quality data were collected from May through early November of 1998 to determine the existing conditions of the lake. This data was then used to estimate annual hydrologic and phosphorus budgets for the lake in order to examine the relationship between watershed land use activities and lake water quality.

In the preparation of this report, it was necessary to estimate the yields of water and phosphorus to the lake from various watershed land use activities using export rate coefficients extrapolated from other studies. These coefficients represent the annual mass loading of water or phosphorus to the lake per unit of source (i.e., cubic meters of water or pounds of phosphorus per acre of forested land). Selection of these coefficients was done by carefully screening a range of values for each watershed land use activity and selecting the values that seemed most appropriate given the existing watershed conditions. The suitability of the selected export rate coefficients for phosphorus were further evaluated in terms of how well they predicted in-lake water quality conditions when used in a phosphorus mass balance model. However good these model predictions are, they result from an estimation process that involves the best professional judgement of the modeler. Being mindful of the limitations associated with the estimation procedures used in this study, it is my professional opinion that my estimated hydrologic and phosphorus budgets are reasonably accurate in portraying the relative contributions to Grindstone Lake's total annual phosphorus budget from its constituent sources.

Executive Summary

The study described by this report was initiated by the Lac Courte Oreilles (LCO) Conservation Department and the Grindstone Lake Homeowners Association (GLHA) to assess the existing water quality of Grindstone Lake and provide information for the development of a lake management plan. The study involved collection of data from Grindstone Lake and its watershed during 1998. Annualized hydrologic and phosphorus budgets were then modeled for existing watershed land use conditions.

The water quality data show that Grindstone Lake has good water quality. Total phosphorus, chlorophyll-a and Secchi disk data were generally within the mesotrophic (moderate algal growth, minimal or no recreational use impairment) category and were very close to the oligotrophic category (nutrient poor, minimal algal growth, no recreational use impairments). Water clarity was better than expected based upon total phosphorus and chlorophyll-a concentrations. Summer Secchi disk readings averaged over 19 feet, summer total phosphorus readings average 13.3 ug/L, and summer chlorophyll-a readings averaged 1.92 ug/L.

The results of the phosphorus budget analysis for the lake estimated that the total annual phosphorus loading to Grindstone Lake was 3,758 pounds per year, based on the 1997-98 data. Grindstone Creek contributed the largest amount of phosphorus (1,161 lbs or 30.9%). A high volume of low phosphorus water is discharged from the creek on a year round basis, which results in the significant loading to the lake. The next largest phosphorus source to the lake is from atmospheric (aerial) deposition. The atmospheric component of the phosphorus loading is computed to be nearly 778 lbs or 20.7%. Agricultural land uses which include row crop, mixed agriculture, and pasture/grassland comprise the next largest loading to the lake of 598 lbs or 15.9%. The computations reveal that septic systems and residential uses comprise nearly three percent (120 lbs) and thirteen percent (494 pounds) of the annual load respectively. Wetlands are estimated to comprise 1.8% (68 lbs) and the forested portion of the watershed contributes nearly 500 lbs of phosphorus which is 13.3% of the loading. Cranberry bogs are estimated to contribute approximately 13 pounds (0.4%) and internal loading comprises 0.7% or 26 lbs of phosphorus.

The impacts of cultural eutrophication on Grindstone Lake were estimated by modeling pre-development in-lake phosphorus concentrations and comparing the estimated pre-development phosphorus concentrations with current phosphorus concentrations (i.e. post-development conditions). Cultural eutrophication describes the acceleration of the natural eutrophication process caused by human activities. Four modeling scenarios were completed to assess the impacts of cultural eutrophication. The four scenarios consisted of the following:

1. Estimating the in-lake phosphorus concentration assuming forested land use

(i.e. pre-development condition) instead of agricultural land use (i.e. current or post-development condition).

2. Estimating the in-lake phosphorus concentration assuming forested land use (i.e. pre-development condition) instead of residential land use (i.e. current or post-development condition).

3. Estimating the in-lake phosphorus concentration assuming natural wetlands (i.e. pre-development condition) instead of cranberry farm land use (i.e. current or post-development condition).

4. Estimating the in-lake phosphorus concentration assuming forested land use and natural wetlands (i.e. pre-development conditions) instead of agricultural, residential, and cranberry farm land uses (i.e. current or post-development conditions).

The model indicates that the assumed conversion of forested land use to agricultural land use results in a 2 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of two feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

The model indicates that the assumed conversion of forested land use to residential land use results in a 2 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of two feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

The model indicates that the assumed conversion of natural wetlands to cranberry farm land use results in no change to the total in-lake phosphorus concentration, and consequently there would be no noticeable water quality change.

The model indicates that the assumed conversion of forested land use and natural wetlands to agricultural, residential, and cranberry farm land uses results in a 4 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a very noticeable water quality change. The estimated 4 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of 4.6 feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

The development of a comprehensive lake management plan for Grindstone Lake is recommended in order to prevent further degradation of the water quality. This plan should include:

1. The development of a long-term water quality goal for the lake;
2. An evaluation of different watershed development scenarios to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options;
3. Recommendations for ultimate watershed development relative to achieving the lake's water quality goal (i.e. minimum lot size, maximum area of impervious surface, etc.);
4. Recommendations for watershed best management practices under future development conditions;
5. Recommendations for ordinances to control watershed development;
6. Recommendations for the riparian owner management practices;
7. Recommendations for best management plans to protect sensitive lands including wetlands, steep slopes, undeveloped land, shoreline, etc.;
8. Algal study to determine species abundance and distribution;
9. A macrophyte study to determine the spatial coverage, density, and species composition of the macrophyte community. A special area of concern would be identification of Eurasian Water Milfoil;
10. Volunteer monitoring program to record long-term water quality database.

Grindstone Lake Water Quality Study

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Introduction 1.0

Grindstone Lake located in Sawyer County, Wisconsin, is considered a unique and significant water resource by the Lac Courte Oreilles Band of Lake Superior Chippewa Indians (LCO), the Grindstone Lake Association (GLHA), and the Wisconsin Department of Natural Resources (WDNR). The lake is a soft-water drainage lake which flows into Lac Courte Oreilles Lake. Grindstone Lake has a surface area of approximately 3,116 acres and a volume of approximately 92,111 acre-feet. The maximum depth is 60 feet. Approximately 67% of the lake is over 20 feet deep and only about 5% is less than 3 feet deep. The total shoreline of the lake spans 10.5 miles. The lake is noted for an excellent fisheries and has a wide variety of species including small and largemouth bass, walleye, muskellunge, northern pike and panfish. The lakeshore property owners, the LCO tribal members and the general public, via the public accesses, utilize the lake for a wide variety of activities, including fishing, boating, skiing, swimming, SCUBA diving, snorkeling, and viewing wildlife.

Over the past few years, complaints and concerns that the water quality of the lake may be degrading have become increasingly more numerous. Most notable are concerns due to the increase of green slime on the rocks and boat lifts around the shore and the observation of large floating mats of algae. Boats left in the water are also now being stained when they never used to be. Claims of decreased water quality are also common from individuals who have been diving in the lake for many years. Due to the cultural and economic significance of this lake to the LCO Reservation and Sawyer County, the LCO Conservation Department determined that a comprehensive monitoring program was necessary to assess the current water quality status of Grindstone Lake and to help protect the lake from degradation. Consequently the LCO Conservation Department along with the Grindstone Lake Association initiated a project for a water quality study which is the first stage in developing a management plan for the lake.

The study included a data collection phase, the completion of an annualized phosphorous and hydrologic budget along with a watershed evaluation for the lake. This information will be used to help develop a management plan for the lake to help ensure the integrity of the lake is protected from the increased pressure on the lake due to increased development and recreational uses.

1.1 Report Coverage

This report will answer the following questions that apply to properly managing a lake:

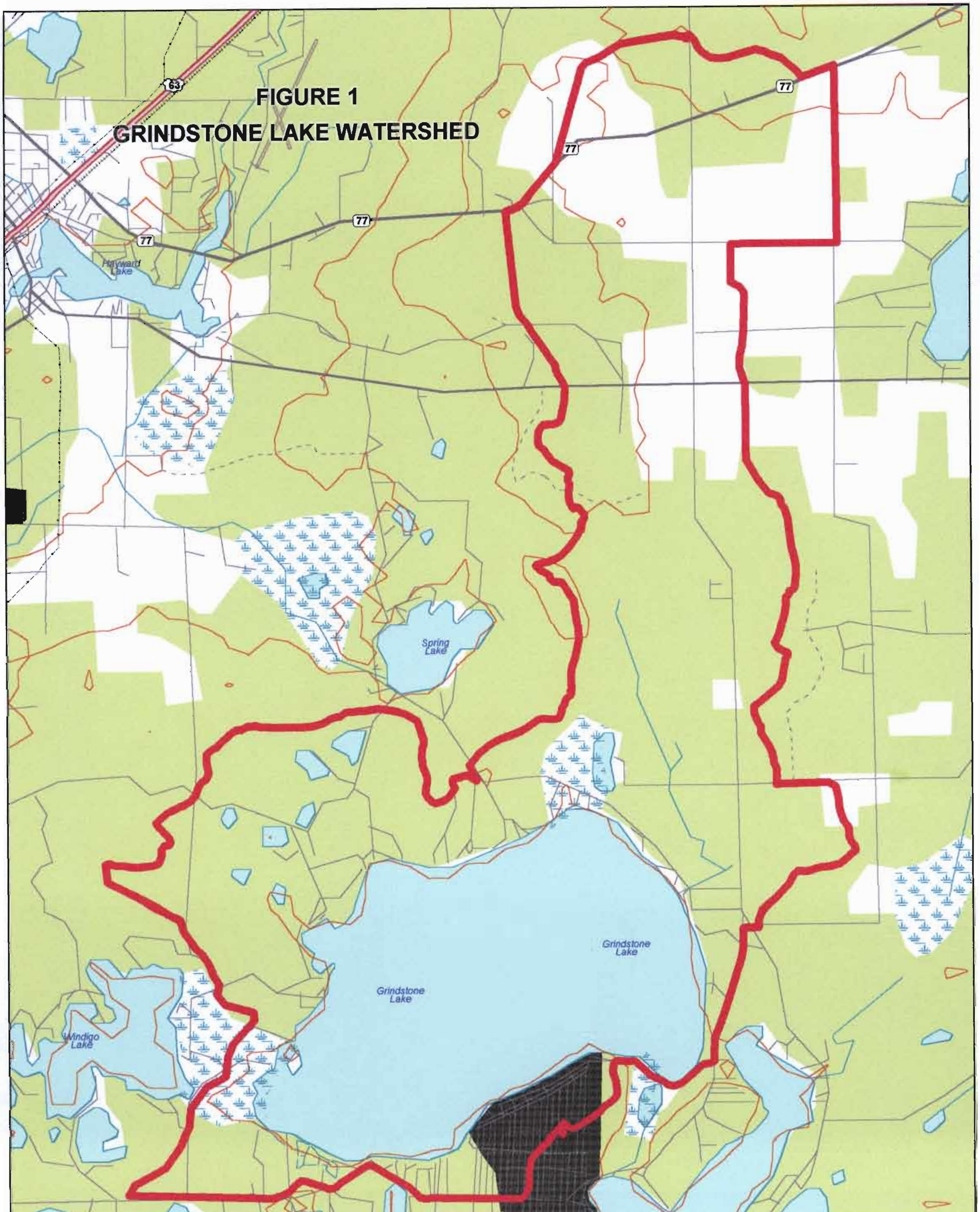
1. What is the general condition of the lake?
2. Are there problems associated with the lake?

To answer the first question, this report begins with a description of the Grindstone Lake watershed, the lake, and the methods of data collection and analysis. The results of the 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 background information section is also included in this report. Section 2.0 covers general concepts in lake water quality.

FIGURE 1
GRINDSTONE LAKE WATERSHED



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 2000 ft Scale: 1 : 56,250 Detail: 11-7 Datum: WGS84

2.0 General Concepts in Lake Water Quality

There are many concepts and terminology that are necessary to describe and evaluate the water quality of a lake. This section provides a brief discussion of the following topics:

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

2.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in a lake. As a lake naturally ages and becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fills in the lake's basin. The 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 which is caused by human activities. Nutrient and sediment inputs from construction, houses, septic tanks, lawn fertilizers, and storm water 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 such as profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds.

The main cause of cultural eutrophication is uncontrolled development within a lakes watershed and/or development without the use of Best Management Practices (BMP's). Creating and implementing a lake management plan prior to the development of the lake's watershed is the best way to try to prevent and minimize the impacts from cultural eutrophication.

2.2 Trophic States

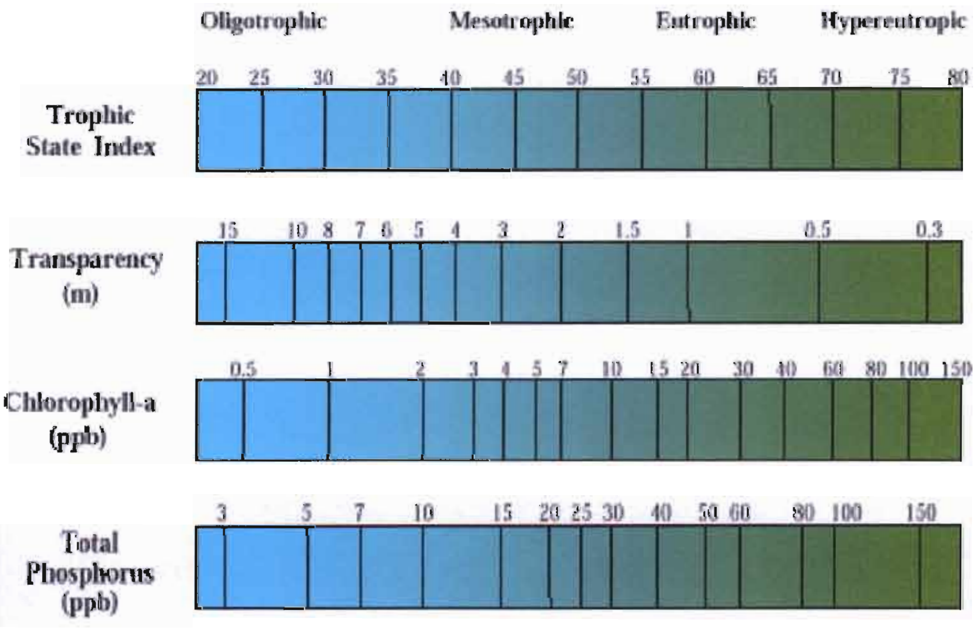
Not all lakes are in the same stage of eutrophication because of varying nutrient status. Criteria have been established to evaluate the existing nutrient "status" of a lake. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, chlorophyll-a concentrations, and Secchi disk transparencies. A TSI value can be obtained from any one of those parameters. TSI values range upward from zero, designating the condition of the lake in terms of its degree of fertility. The trophic status indicates the severity of a lake's algal growth problems and the degree of change needed to meet its recreational goals. Determining the trophic status of a lake is therefore an important step in diagnosing water quality problems. Carlson's Trophic State Index is often used in interpreting water quality data (see Figure 1). For a general guideline, Table 1 can also be referred to.

Table 1: Trophic Status and TSI Ranges

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

Figure 2: Carlson's Trophic State Index

TSI < 30	Classic Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TSI 40 - 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TSI 50 - 60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60 - 70	Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
TSI 70 - 80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



After Moore, 1. And K. Thomton, [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

2.3 Limiting Nutrients

The quantity of algae in a lake is usually limited by the water's concentration of an essential element or nutrient. This is the "limiting nutrient." 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 or algae, will limit it's growth.

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content in lake water provides ratios of N:P. By comparing the ratio, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with a N:P ratio greater than 15 (Byron, et. al. 1997). It has been amply demonstrated that phosphorus is usually the nutrient in limited supply in fresh waters. Therefore, reducing phosphorus in the lake is required to reduce algal abundance and improve water transparency. The failure to reduce the phosphorus concentrations entering the lake will allow the process of accelerated eutrophication to continue.

2.4 Nutrient Recycling and Internal Loading

Watershed runoff, which includes overland flow and groundwater infiltration, or direct atmospheric depositon are the two ways in which phosphorus can enter a lake. It would therefore seem reasonable that phosphorus in a lake can be decreased by reducing these external loads of phosphorus to the lake. However, all lakes accumulate phosphorus, along with other nutrients, in the sediments from the settling of particles and dead organisms. In some lakes this stored phosphorous can be reintroduced into the lake water and become available again for plant uptake. This release of the nutrients from the sediments to the lake water is known as "internal loading." The amount of phosphorus coming from internal and external loads vary with each lake. Internal loading can be estimated from depth profiles 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 has a profound influence on a lake's chemistry and biology. As the the ice melts and the air temperature warms in the spring, lakes generally progress from being completely mixed to stratified with only an upper warm well-mixed layer of water (epilimnion), and cold temperatures in a bottom layer (hypolimnion). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in midsummer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic). Complete loss of oxygen changes the chemical conditions in the water and allows phosphorus that had remained bound to sediments to reenter the lake water.

Phosphorus concentrations in the hypolimnion can continue to rise as the summer progresses until oxygen is once again reintroduced. The dissoloved oxygen concentration will increase if the lake sufficiently mixes to disrupt the thermal stratificaiton. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration into the hypolimnion to allow for the growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed again. In shallow lakes mixing can occur frequently throughout the summer with sufficient wind energy. In deeper lakes only extremely high wind energy is sufficient to destratify a lake during the summer and complete mixing only occurs in the spring and fall. The 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 epilimnetic water and some of it becomes available for algal growth, while the remainder combines with iron in the water to form an amorphous ferric-hydroxy-phosphate complex that re-precipitates to the lake's bottom sediments.

2.6 Riparian Zone

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

The riparian zone is important for the following reasons:

- Acts as a filter from outside impacts
- Stabilizes the bank with an extensive root system
- Helps control or filter erosion
- Provides screening to protect visual quality and hides man's activities and buildings

- Provides the natural visual backdrop as seen from the lake
- Provides organic material to the lake's food web.
- Offers cover and shade for fish and other aquatic life
- Provides valuable wildlife habitat

The riparian zone is the area most often impacted and riparian vegetation is lost when man enters the scene. Cabins, homes, lawns, or other structures may replace native riparian vegetation. Additional riparian vegetation may be eliminated to provide a larger view from the house or it may be mowed and its value to the lake is lost.

The loss of riparian vegetation results in the deterioration of many lake values besides water quality. Wildlife habitat is lost, the scenic quality suffers, fish habitat is impacted, bank stability may be weakened and the potential for erosion increases. The vegetation in the riparian zone filters phosphorus and sediments from runoff water, which in turn protects the water quality of the lake.

2.7 Watershed

The area of land that drains to the lake is called the lake's watershed. This area may be small, as is the case of small seepage lakes. Seepage lakes have no stream inlet or outlet and their watersheds include only the land draining directly to the lake. On the other hand, a lake's watershed may be large, as in drainage lakes such as Grindstone and particularly Lac Courte Oreilles Lake. Drainage lakes have both stream inlets and an outlet and therefore their watersheds include the land draining to the streams in addition to the land draining directly to the lake. The water draining to a lake may carry pollutants that affect the lake's water quality. Therefore, water quality conditions of the lake are a direct result of the land use practices within the entire watershed. Poor water quality may reflect poor land use practices or pollution problems within the watershed. Good water quality conditions suggest that proper land uses are occuring in the watershed or there is minimal development within the watershed.

All land use practices within a lake's watershed impact the lake and determine its water quaity. 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 watershed, phosphorus exported from the watershed, and the relationship between the lake's water quality and it's watershed must be understood.

2.7.1 Water Quality Impacts of Various Land Uses In the Tributary Watershed

The impacts of various land uses on the water quality of Grindstone Lake will be estimated by modeling the water quality which would result from removing from the lake's phosphorus load the estimated annual phosphorus loading from various land uses. The estimated impacts of various land uses to the water quality of Grindstone Lake may be used by the LCO Conservation Department and other agencies to estimate the potential water quality improvements which could result from the implementation of Best Management Practices (BMP's) in the watershed.

3.1 Lake Water Quality Data Collection

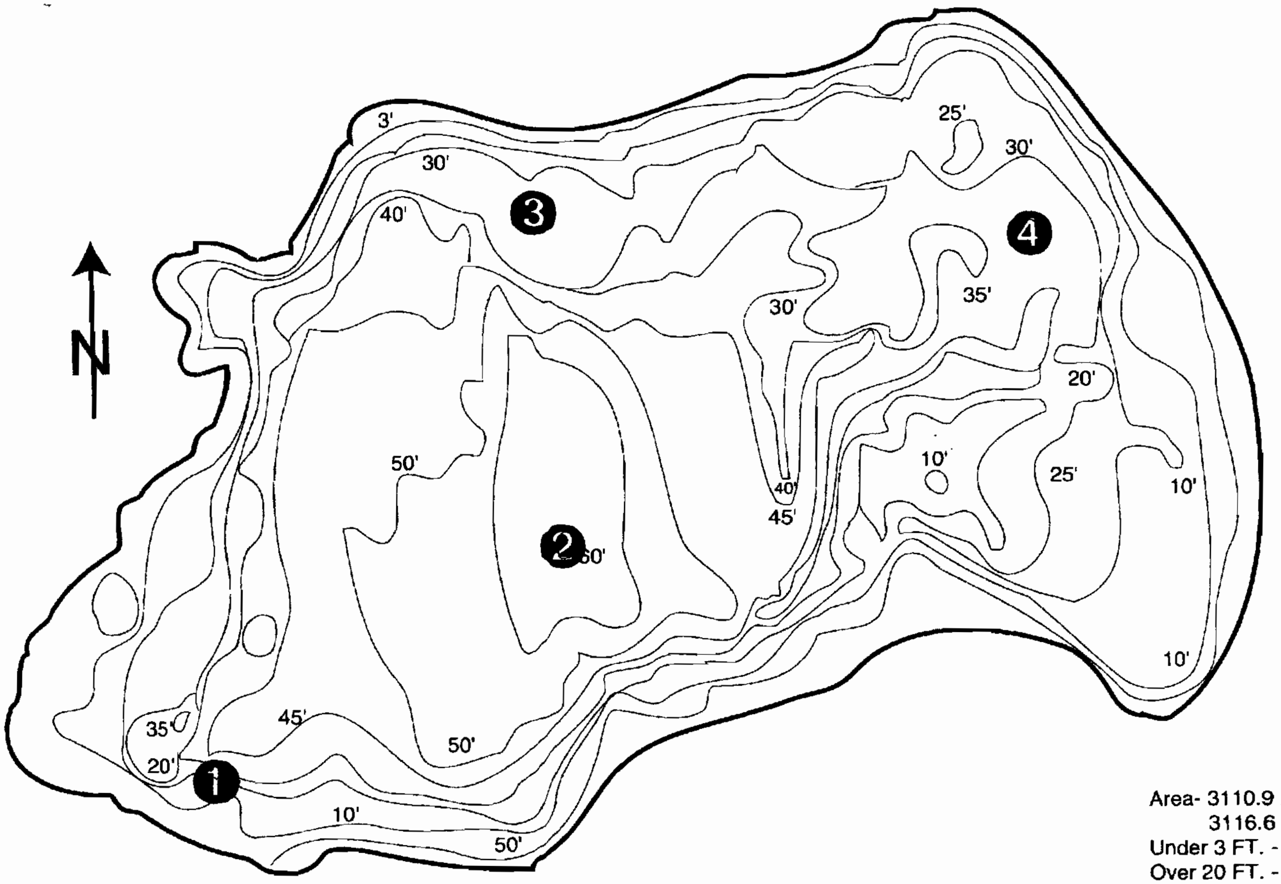
The 1998 sampling program involved the collection of water samples from four monitoring stations in Grindstone Lake. See Figure 3 for the locations of the stations. The samples were collected approximately monthly through the period of May through September. The sampling depths are summarized in Table 2. These dates spanned the lake's period of elevated biological activity throughout the summer months. Field parameters were measured approximately biweekly and Secchi disk transparency was measured approximately weekly from May through November.

Table 2: Grindstone Lake Sampling Station Depths

Sampling Station	Maximum Depth (Meters)	Sampling Depths (Meters)					
1	9.1	0 - 2*	5	7	NB**	--	--
2	18.2	0 - 2	5	9	13	16	NB
3	12.1	0 - 2	5	7	9	NB	--
4	10.9	0 - 2	5	8	NB	--	--

**0 -2 meter sample is a composite sample*
***NB indicates sample taken 0.5 meter from the bottom (Near Bottom)*

Table 3 indicates the water quality parameters measured at each station, and specifies at what depth and how frequent the samples or measurements were collected. The dissolved oxygen, temperature, specific conductance, total dissolved solids, pH, and Secchi disk transparency were measured in the field; whereas the water samples analyzed in the laboratory by the Wisconsin State Laboratory of Hygiene for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, chlorophyll *a*, and alkalinity.



Area- 3110.9 Acres
3116.6 - With Islands
Under 3 FT. - 5.3%
Over 20 FT. - 67%
Volume - 92.110.0 Acre FT.
Total ALK - 52 P.P.M.
Shoreline - 10.5 Miles
Max. Depth - 60 FT.

Figure 3

Grindstone Lake Sample Locations

Table 3: Grindstone Lake Water Quality Parameters

Parameters	Depth (Meters)	Sample Frequency			
		Approximately weekly	Approximately Biweekly	Approximately Monthly	Quarterly
Dissolved Oxygen	Surface to bottom Profile		X		
Temperature	Surface to bottom Profile		X		
Specific Conductance	Surface to bottom Profile		X		
total Dissolved Solids	Surface to bottom Profile		X		
pH	Surface to bottom Profile		X		
Chlorophyll *a*	0 - 2			X	
Secchi Disk	--	X			
Total Phosphorus	See Table 2			X	
Soluble Reactive Phosphorus	0 - 2			X	
Total Kjeldahl, Ammonia, and Nitrate+Nitrite Nitrogen	0 - 2			X	
Alkalinity	0 - 2				X

3.2 Lake Level Monitoring

One staff gauge was installed in Grindstone Lake shortly after ice-out. The gauge was read on a daily basis from May through mid-November by a Grindstone Lake Association volunteer. The lake level data will be used in the determination of the lake's hydrologic budget.

3.3 Precipitation Monitoring

One rain gauge accurate to within 1/100th-of-an-inch was installed near the lake and read daily by a Grindstone Lake Association volunteer from May through mid-November. Precipitation recorded at the Hayward Ranger Station was obtained for the time period not recorded by the volunteer.

3.4 Inflow/Outflow Monitoring Methods

Grab samples were collected from the inlet and the outlet on approximately a monthly basis during May through October. The inlet also had grab samples taken during one spring, three summer, and one fall storm. All samples were analyzed for total phosphorus. Discharge was also measured during each sampling event. Staff gauges were installed at the inlet and outlet and read on a daily basis from the end of May through September for the inlet and until early November for the outlet. A stage discharge rating curve was developed for the inlet and outlet to predict their flows. See Figure 4 and Figure 5.

3.5 Evaluation of the Watershed

The Grindstone Lake Watershed, including the lake, encompasses 12,842 acres or 20.1 miles^2 (see Figure 1). The various land uses within the watershed are indicated in Table 4.

Table 4: Grindstone Watershed Land Uses

Land Use
Row Crop
Mixed Agriculture
Pasture/Grassland
Medium Density Residential

Rural Residential
Wetlands
Forest
Commercial Cranberry Bog

3.6 Phosphorus and Hydrologic Budgets

The nutrient balance of a lake is defined by the quantities of nutrients contributed to or removed from the lake by various inflow and outflow routes and is analogous to and dependent upon the hydrologic balance for the lake. It has been amply demonstrated that most often phosphorus is the nutrient that limits algal growth in lakes, as is the case in Grindstone Lake. To develop an understanding of the pattern of phosphorus transport through Grindstone Lake, monitoring data was combined with the results of the hydrologic monitoring to develop an annualized hydrologic and phosphorus budget for the lake.

3.6.1 Annualized Hydrologic Budget Calculations

The hydrologic budget for Grindstone Lake based on the 1997-98 water year (October 1, 1997 through September 30, 1998) was calculated by measuring or estimating the important components of the budget. The important components of the budget for Grindstone Lake include:

- Precipitation
- Runoff (Overland and Groundwater Flow)
- Evaporation
- Change in lake storage
- Stream Inflow
- Lake Outflow
- Groundwater Flow

A mass balance approach was used to determine the annualized hydrologic budget for Grindstone Lake. The general water balance equation used for Grindstone Lake was:

$$\Delta S = O + E - P - R - I + \Delta GW$$

Where:

ΔS = change in lake storage volume
O = Lake Outflow
E = evaporation from the lake surface
P = precipitation
R = runoff from the watershed
I = Inflow
ΔGW = Net Groundwater Flow (Groundwater inflow - Groundwater outflow)

Rain gages accurate to within 1/100th-of-an-inch were installed at four locations around Grindstone Lake and read daily by volunteers from the end of May through the middle of November to determine daily precipitation amounts within the watershed. The readings from the four gauges were used to determine the average precipitation over the monitored period. Data from the Hayward Ranger Station was used for the periods not monitored by the volunteers. The precipitation data was used to determine direct precipitation on the lake's surface.

Evaporation from the surface of Grindstone Lake was estimated from pan evaporation rates obtained from the Marshfield Agricultural Research Center. An evaporation coefficient of 0.7 was used to convert the pan evaporation to actual field evaporation. Evaporation for the winter months (November - April) were assumed to be similar to the evaporation rates over the winter months computed for a study on Lac Courte Oreilles Lake by Barr Engineering during 1995-96 (Barr Engineering, 1998).

A staff gauge was installed in Grindstone Lake and read daily from May 29 through November 21. The staff gauge reading was used to determine the daily lake volume changes.

The average runoff rate for Sawyer County Wisconsin was used as a basis for determining the runoff rate for the Grindstone watershed. This value was adjusted to reflect the lower amount of precipitation during the 1997 - 1998 water year. The precipitation was approximately 13% below normal, therefore the runoff was adjusted to be 13% less than average also.

The net groundwater flow (inflow minus outflow) was estimated for the period from June through September since the precipitation, change in storage, inflow, outflow, and the other parameters were either known or estimated for that period using generally accepted practices. An average daily groundwater flow was determined for that period. The average daily flow was then used to compute an annual groundwater flow contribution.

The annual yield of surface water runoff from the Grindstone watershed was determined by dividing the predicted watershed runoff volume by the watershed area to compute an annual areal yield expressed in inches of water. The runoff yield was divided by the total precipitation to determine the estimated runoff coefficient for the watershed.

3.6.2 Annualized Phosphorus Budget

The annualized phosphorus budget for Grindstone Lake under existing land use conditions was estimated with the assistance of a phosphorus mass balance model. The mathematical equations within the model help to interpret the relationship between phosphorus loads, water loads and lake basin characteristics to the observed in-lake total phosphorus concentration. The model used in this study was the Wisconsin Lake Model Spreadsheet (WILMS) developed by the WI Department of Natural Resources (Panuska and Wilson, 1994). The equation used within the WILMS model for the Grindstone study was one developed by Dillon, Rigler and Kirchner which has the form of:

$$P = \frac{L(1-R)}{zp}$$

Where:

P = Predicted mixed lake total phosphorus concentration
L = Areal total phosphorus load
R = Fraction of inflow total phosphorus retained in the lake
z = Lake mean depth
p = Lake flushing rate

This equation provided the best fit to the observed data and past modeling experience by Wisconsin Department of Natural Resources personnel indicates that the Dillion, Rigler, Kirchner model often does an adequate job of describing the phosphorus response of northern Wisconsin lakes (Panuska and Wilson, 1994).

The Watershed land use data and published phosphorus export coefficients, which are based on watershed land use data, were used to determine phosphorus loading from the watershed. Water quality data (i.e. collected from the lake) was used to calibrate the model.

The important components of the phosphorus budget for Grindstone Lake include:

- Watershed surface runoff from agricultural, forested, residential, wetland and cranberry bog land uses
- Atmospheric wet and dry deposition on the lake surface
- Septic system loading
- Tributary loading
- Internal loading

The watershed surface runoff components of the phosphorus budget were estimated using an assumed phosphorus export coefficient for each land use type within the watershed of Grindstone Lake. Table 5 lists the land use along with its corresponding export coefficient.

Table 5: Land Use Phosphorus Export Coefficients

Land Use	Export Coefficient (lbs/acre)
Row Crop Agriculture	0.62
Mixed Agriculture	0.71

Pasture/Grassland	0.10
Medium Density Urban Residential	0.53
Rural Residential	0.08
Wetlands	0.09
Forest	0.08
Cranberry Bogs	0.62
Lake Surface (atmospheric deposition)	0.25

All of the phosphorus export coefficient values are within the ranges suggested by the WILMS model and generally agree with the most likely default value suggested by the model (Panuska and Lilly, 1995).

The WILMS model does not provide an export rate for commercial cranberry bogs. As was mentioned in Table 5, the phosphorus export rate coefficient for the cranberry bog on Grindstone lake was 0.62 lbs/acre-year. This value corresponds with the data collected in the Manitowish Waters cranberry area (Konrad and Bryans, 1974) and data from Thunder Lake (Dunst et al., 1982). Dunst et al. (1982) further stated that the calculated export rate is probably a reasonable minimum value given the variability in marsh management. This is also the same value which was used for the cranberry bog land uses for a study conducted on Lac Courte Oreilles Lake (Barr, 1998).

The internal loading for Grindstone Lake was estimated by using the total phosphorus data from the lake's water column. The summer internal load was calculated by multiplying the percentage of the hypolimnetic phosphorus released to the surface waters. The mass of hypolimnetic phosphorus is determined by the sediment phosphorus release rate, the lake basin surface area experiencing anoxia, and the duration of the hypolimnetic anoxia. The dissolved oxygen profiles were used to estimate the duration of anoxia. Typically phosphorus has a chance to redissolve into the water column from the sediments when the bottom water becomes anoxic, ie. dissolved oxygen levels less than 0.5 mg/liter. For the most part, dissolved oxygen levels remained above the 0.5 mg/L threshold for most of the summer. However, from late August thru the later part of September the bottom eight feet of water became anoxic and some internal loading did appear to occur as was suggested by the elevated total phosphorus samples collected near the bottom. The surface area of the lake bottom experiencing anoxia was based on the depths of the observed anoxia and the morphometry of the lake. An average sediment total phosphorus release rate of 11.8 mg/m^2-day was used. This release rate was estimated from the increase in phosphorus levels in the hypolimnion over the period of anoxia. The fraction of the hypolimnetic total phosphorus released to the surface waters, which would now be available to algae for growth, was estimated to facilitate the calibration of the model. The fraction of the total hypolimnetic phosphorus estimated to be released was 5%. Based upon these estimations, internal loading within Grindstone Lake appeared to be minor. The amount of phosphorus contributed to the loading of the lake was approximately 25.6 lbs (11.6 kg).

The phosphorus export rate computations used in the WILMS model were used to estimate an annual load from the septic systems along Grindstone Lake. The equation used to estimate the septic load was:

$$\text{Total Septic System Load (Kg/yr)} = E_{st} * \text{\# of capita-yrs} * (1-SR)$$

Where:

E_{st} = export coefficient to septic tank systems (0.55 Kg/capita/yr)

capita-yrs = # of people occupying a dwelling each year = (# of permanent residents/dwelling)*(# of permanent dwellings) + (# of seasonal residents/dwelling)*(days/yr)*(# of seasonal dwellings)

SR = weighted soil retention coefficient (.83 for value used in model)

Aerial photos and the USGS quadrangle maps were used to determine the number of septic systems (dwellings) along the shore of Grindstone Lake. A total of 638 dwellings were determined to be in the watershed. The only dwellings assumed to be contributing septic drainage to the lake were those with waterfront property. The following assumptions were used in determining the loading from septic systems:

- 330 units along lakeshore contribute to septic load
- 35% of residences are year round; 65% seasonal
- 3 persons/year-round residence; 5 persons/seasonal residence
- Seasonal dwellings occupied 100 days/yr
- 13.5% of systems assumed to be failing (average of Round Lake and Lac Courte Oreilles Lake comprehensive septic system surveys)

The accuracy of the phosphorus export coefficients to predict the phosphorus loading to the lake was evaluated by comparing the predicted in-lake phosphorus concentration with the observed concentrations of the samples which were collected. The modeled predicted total phosphorus concentration was the same as the observed average epilimnetic (i.e. surface water or upper 6 feet) total phosphorus concentration. The data therefore supports the annual phosphorus export coefficients selected for the model.

4.0 Results and Discussion

4.1 Compiled Data

Water quality data acquired during the 1999 monitoring program are compiled in Appendices A through G. Appendix A presents the tabulated in-lake water quality. Appendix B contains the profiling data. Appendix C contains the lake level data used to determine changes in lake volume. Appendix D contains the precipitation data which was collected by a Grindstone Lake Association volunteer. Appendix E contains the inflow staff gauge data, Appendix F contains the outflow staff gauge data and Appendix G contains a summary of the flows and total phosphorus data for the inlet and outlet. Appendix H provides the model output for the calibrated WILMS simulation run.

4.2 1998 Lake Water Quality Conditions

4.2.1 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.

While nitrogen can limit algal growth, it can be obtained from the atmosphere by certain algal species. This is termed nitrogen fixation. Thus, phosphorus is the only essential nutrient that can be effectively managed to limit algal growth.

Lakes with nitrogen (N) to phosphorus (P) ratios greater than 15:1 are considered to be phosphorus limited. Values between 10:1 and 15:1 are to be considered transitional lakes, while lakes with a ratio below 10:1 are to be considered nitrogen limited (Byron, et. al. 1997). The ratio for Grindstone Lake was 28:1, thus indicating the lake to be phosphorus limited.

The total phosphorus data collected from Grindstone Lake during 1998 were generally within the mesotrophic (i.e. moderate amounts of nutrients) category. The average summer total phosphorus concentrations for all four stations in Grindstone Lake were within the mesotrophic range (see Figure 6). Figures 7 - 10 show how the phosphorus levels changed throughout the monitoring period for each station.

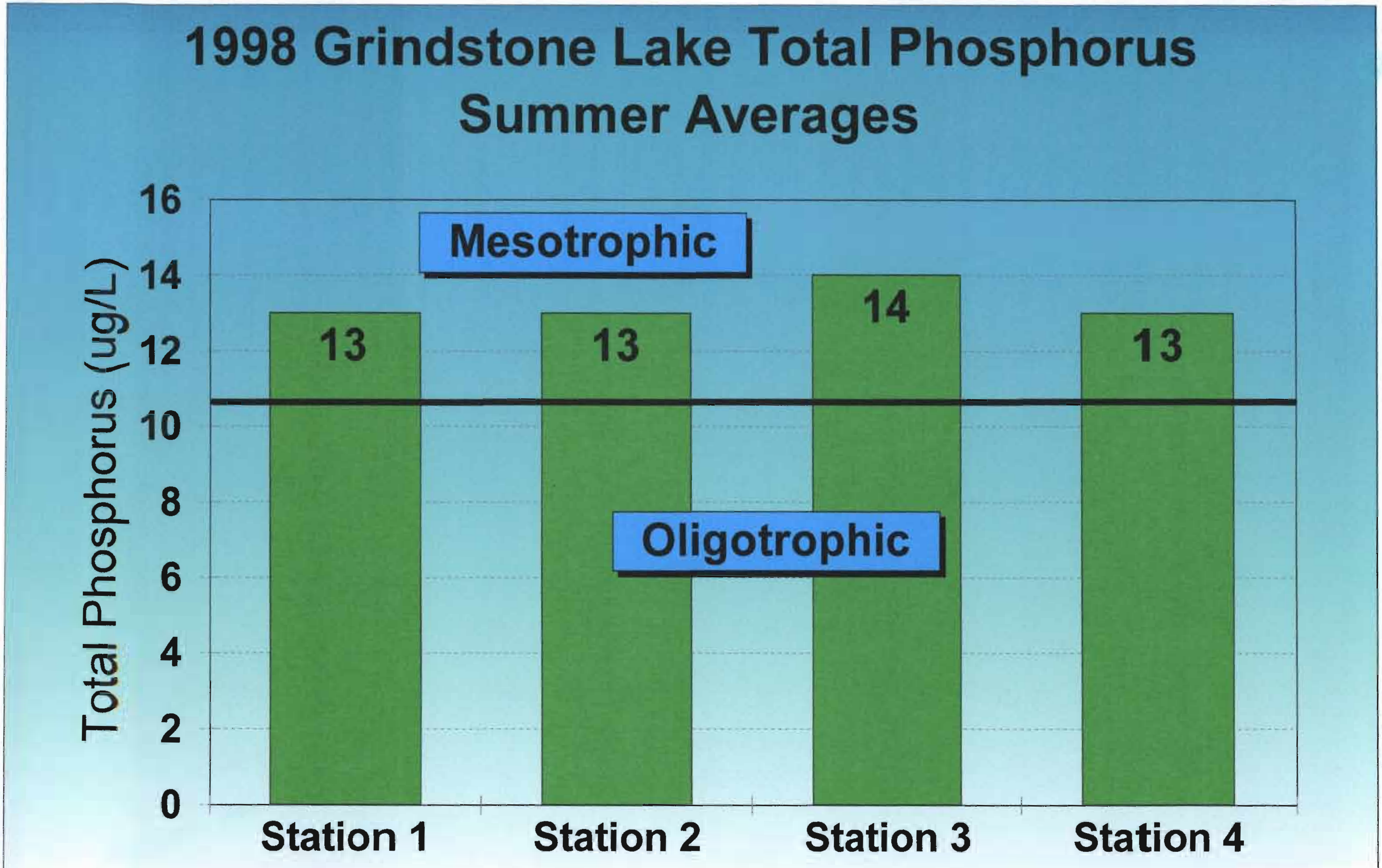

1998 Grindstone Lake Total Phosphorus
Summer Averages
Total Phosphorus (ug/L)
16
14
12
10
8
6
4
2
0
Mesotrophic
Oligotrophic
13
13
14
13
Station 1
Station 2
Station 3
Station 4

Figure 6

Grindstone Lake: 1998 Total Phosphorus
Station 1

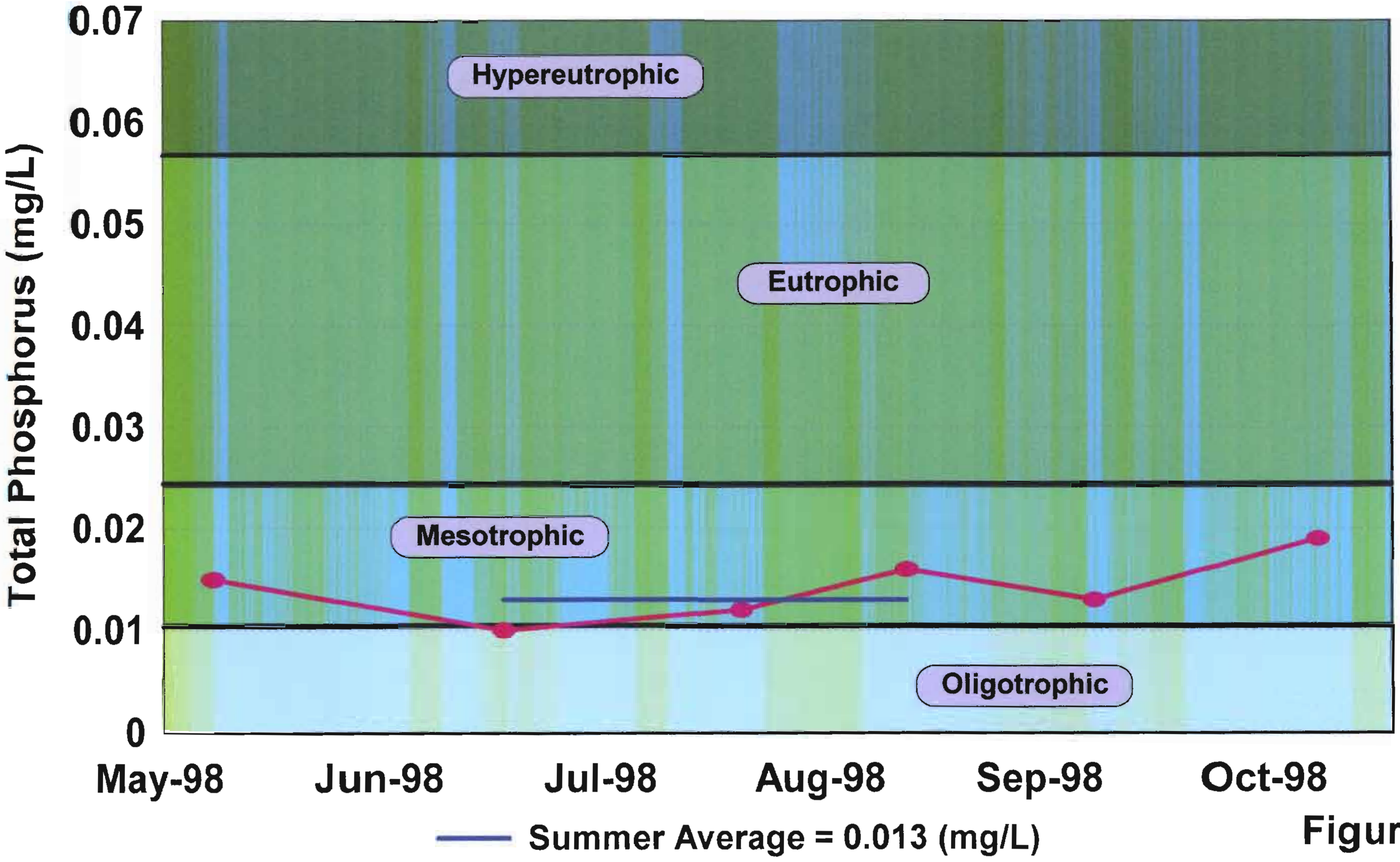


Figure 7

Grindstone Lake: 1998 Total Phosphorus
Station 2

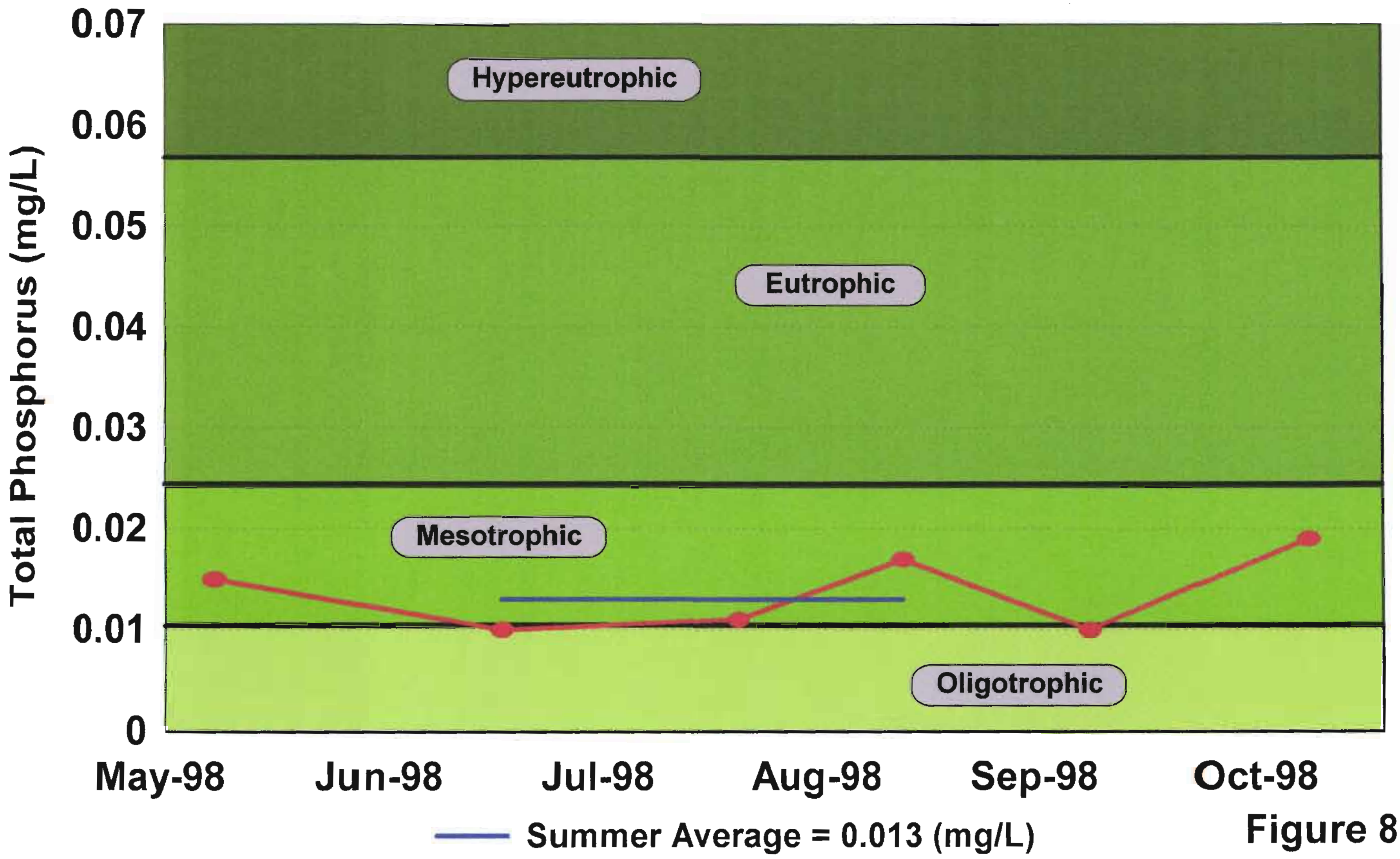


Figure 8

Grindstone Lake: 1998 Total Phosphorus
Station 3

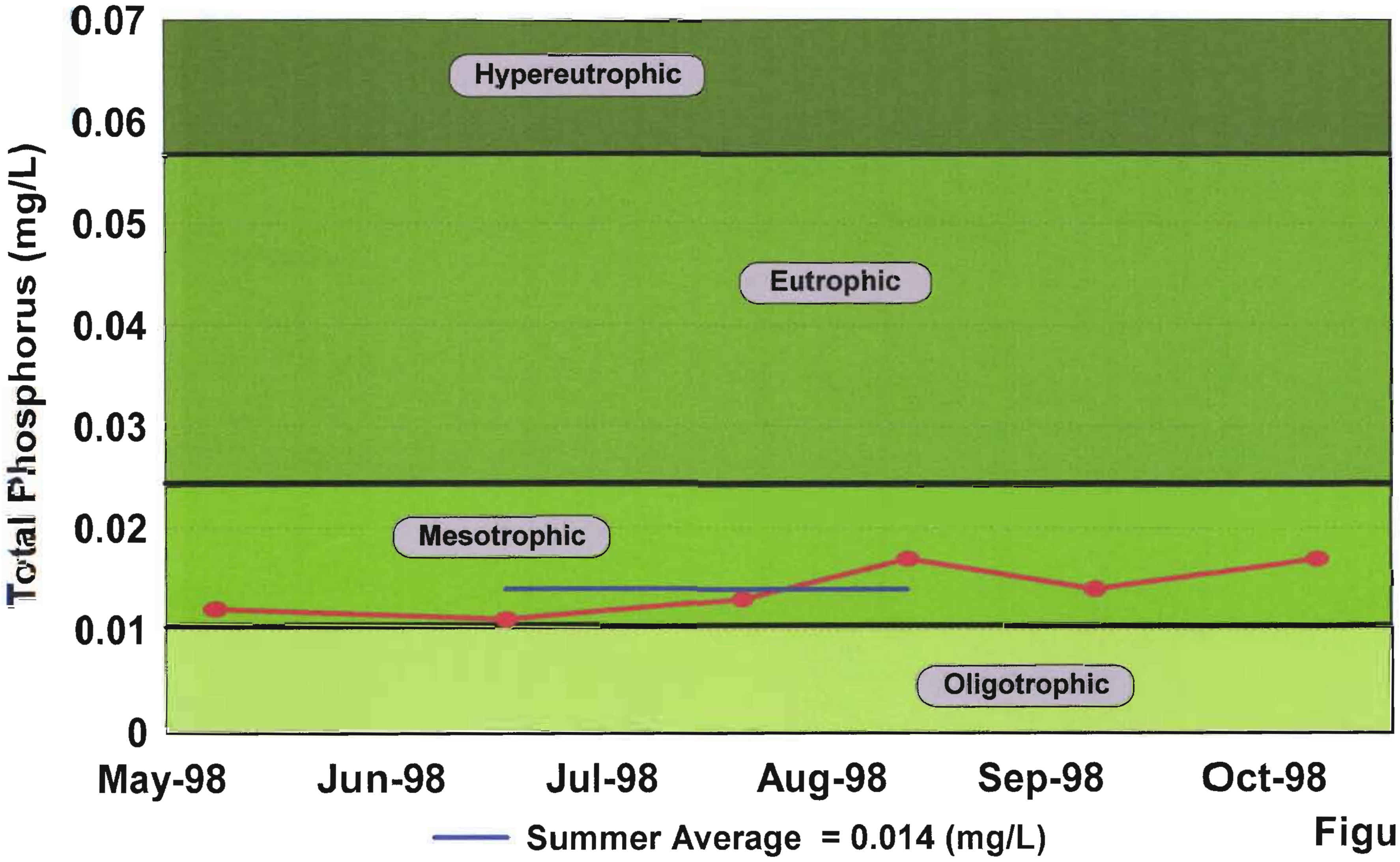


Figure 9

Grindstone Lake: 1998 Total Phosphorus
Station 4

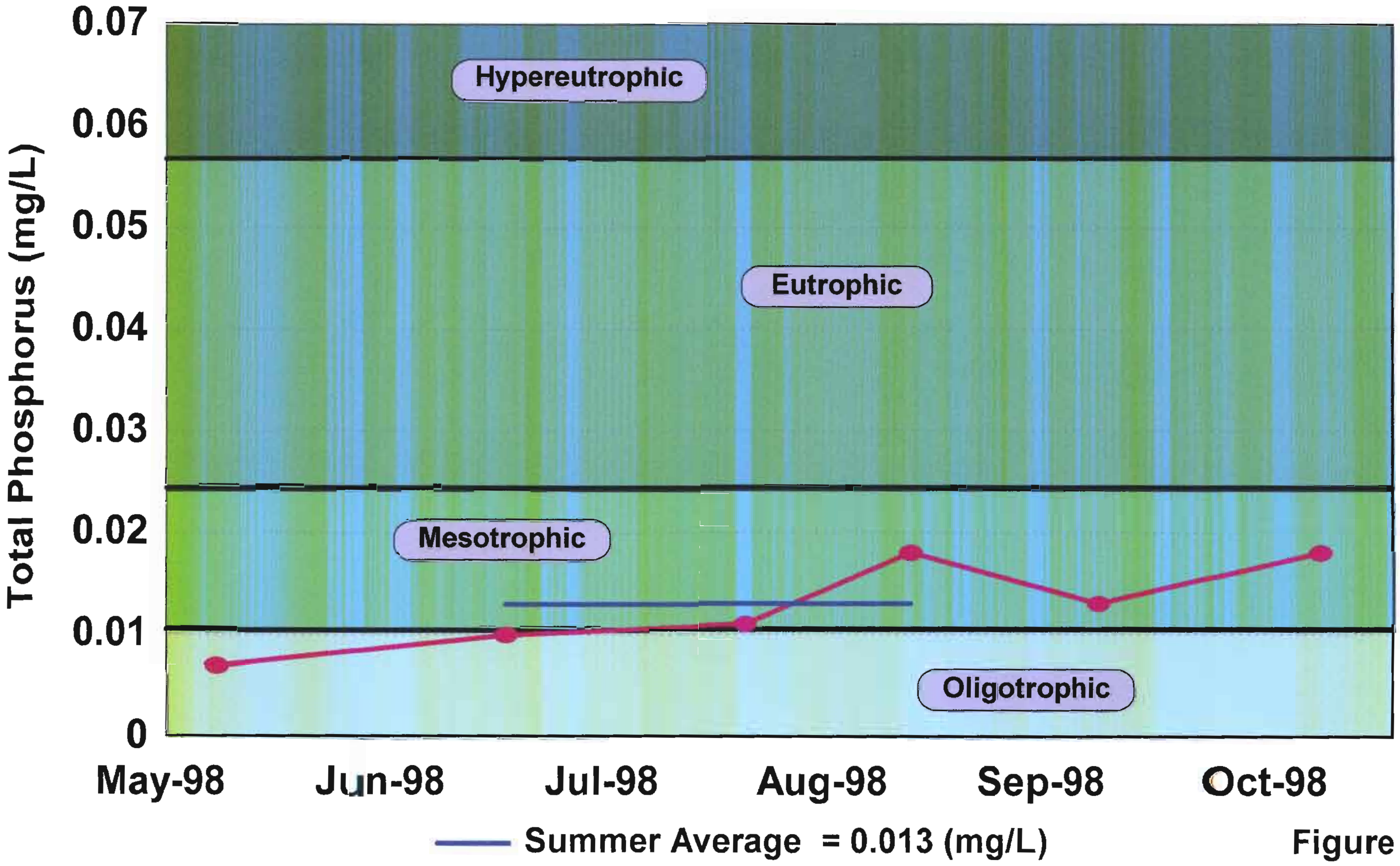


Figure 10

4.2.2 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 1998 Grindstone Lake chlorophyll-a data show that the average summer concentrations for Stations 1 and 3 were within the oligotrophic category while stations 2 and 4 were just within the mesotrophic category (see Figure 9). October chlorophyll-a samples were within the eutrophic category (i.e. nutrient rich or well fertilized). The October sample corresponds to the fall turnover of the lake. The turnover period appears to have resuspended the phosphorus from the internal loading throughout the water column and thus provided the additional nutrients needed for the algae to grow. Individuals on the lake may have noticed a slight algae bloom during this time period. Figures 10 - 13 show how the chlorophyll-a concentrations changed throughout the sampling period. Notice the sharp increase in the chlorophyll-a concentration from September to October. The seasonal pattern of chlorophyll-a was similar to the total phosphorus concentrations further indicating that the lake's algal growth is directly related to the phosphorus levels in the lake.

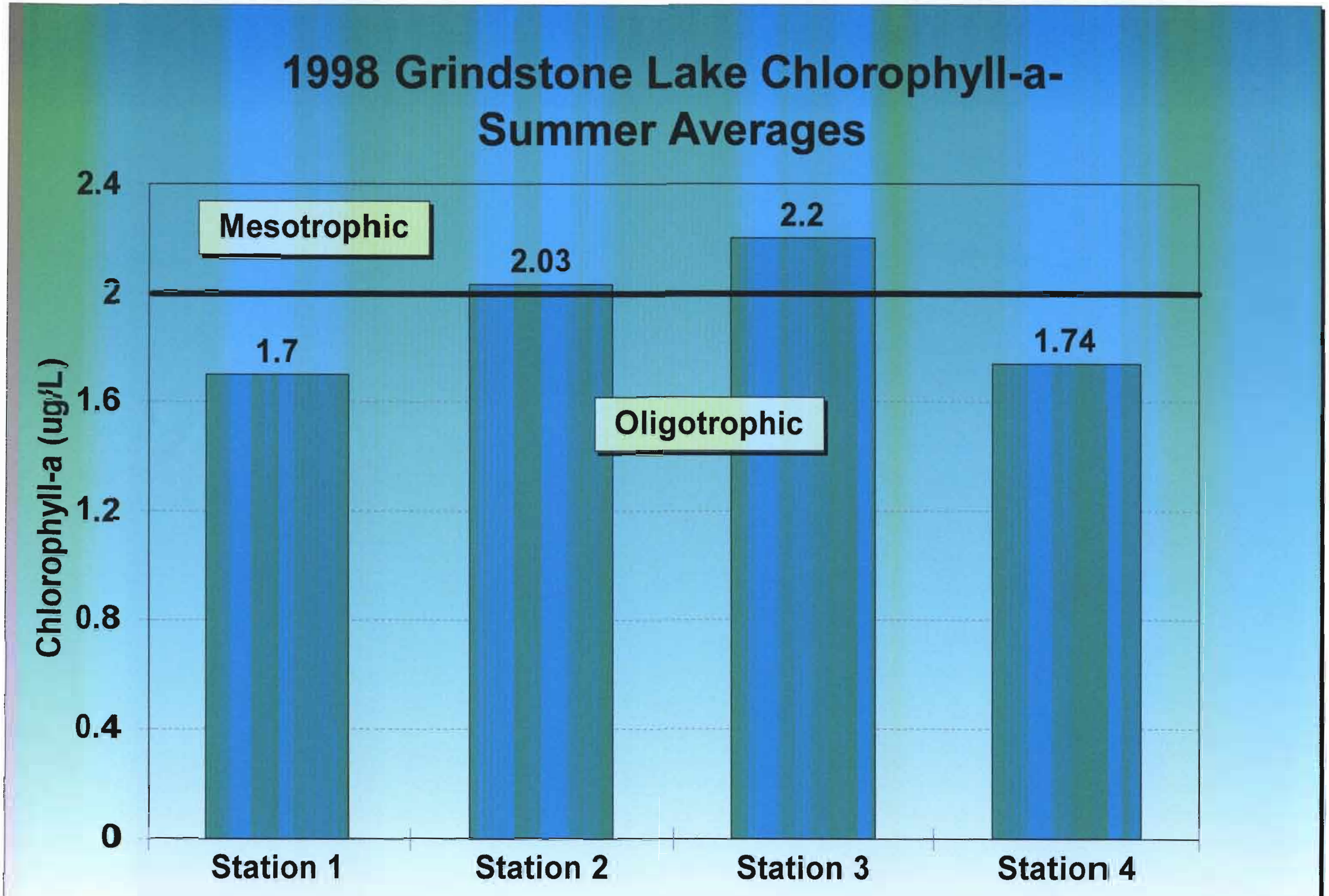
1998 Grindstone Lake Chlorophyll-a-
Summer Averages
Chlorophyll-a (ug/L)
2.4
2
1.6
1.2
0.8
0.4
0
Mesotrophic
Oligotrophic
1.7
2.03
2.2
1.74
Station 1
Station 2
Station 3
Station 4

Figure 11

Grindstone Lake: 1998 Epilimnetic Chlorophyll Concentration (Station 1)

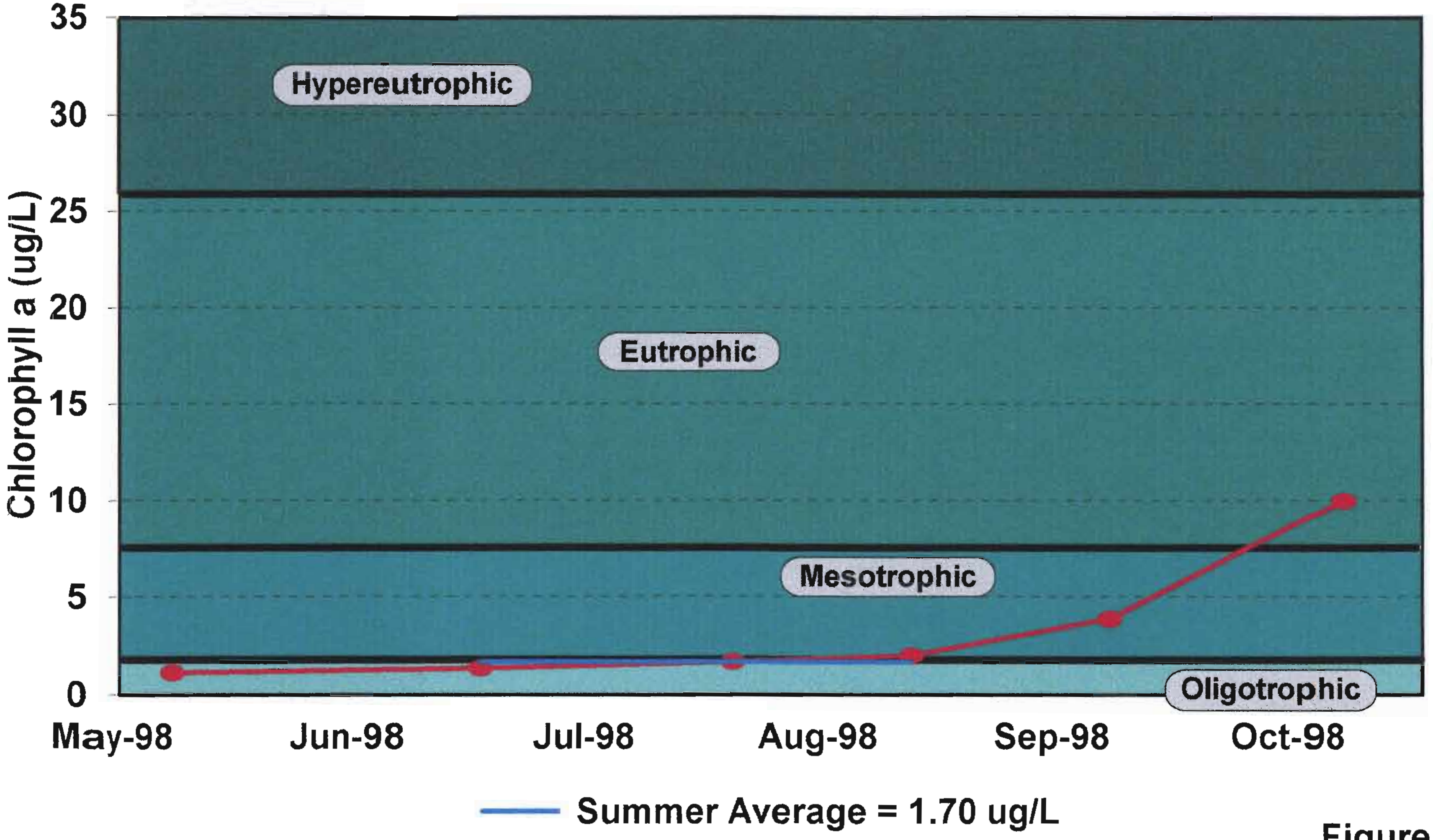
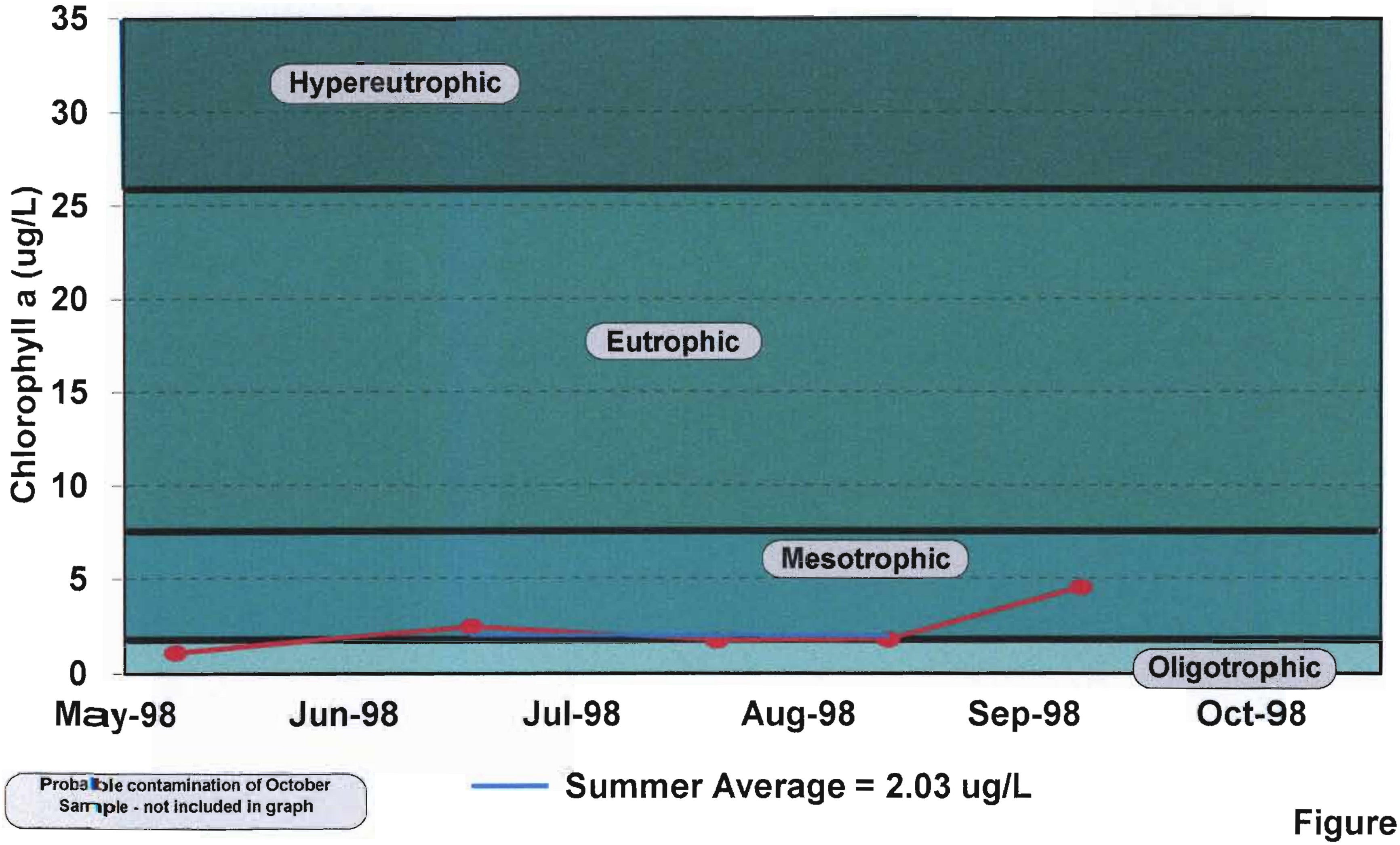


Figure 12

Grindstone Lake: 1998 Epilimnetic Chlorophyll Concentration (Station 2)



Probable contamination of October Sample - not included in graph

Figure 13

Grindstone Lake: 1998 Epilimnetic Chlorophyll Concentration (Station 3)

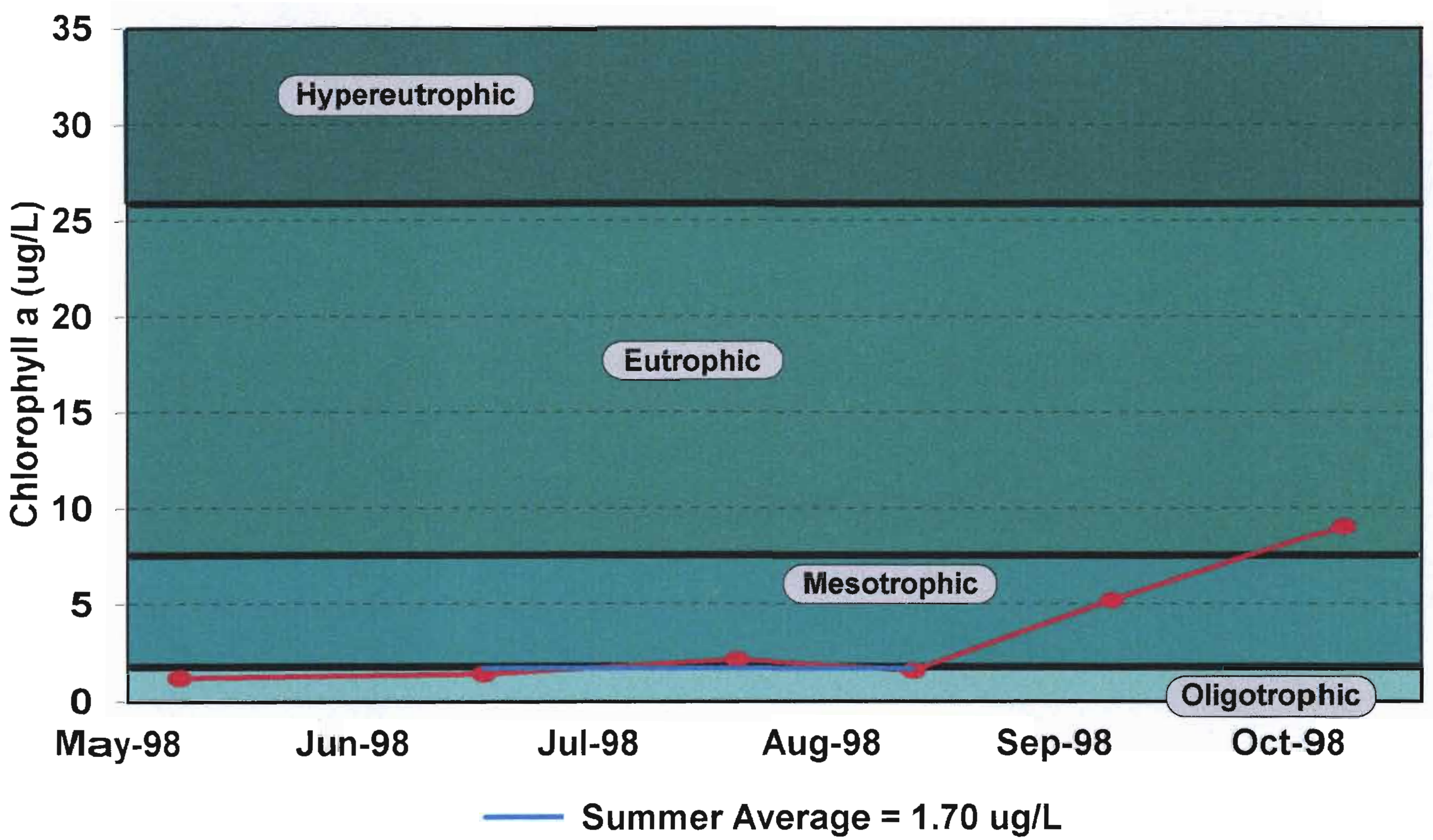


Figure 14

Grindstone Lake: 1998 Epilimnetic Chlorophyll Concentration (Station 4)

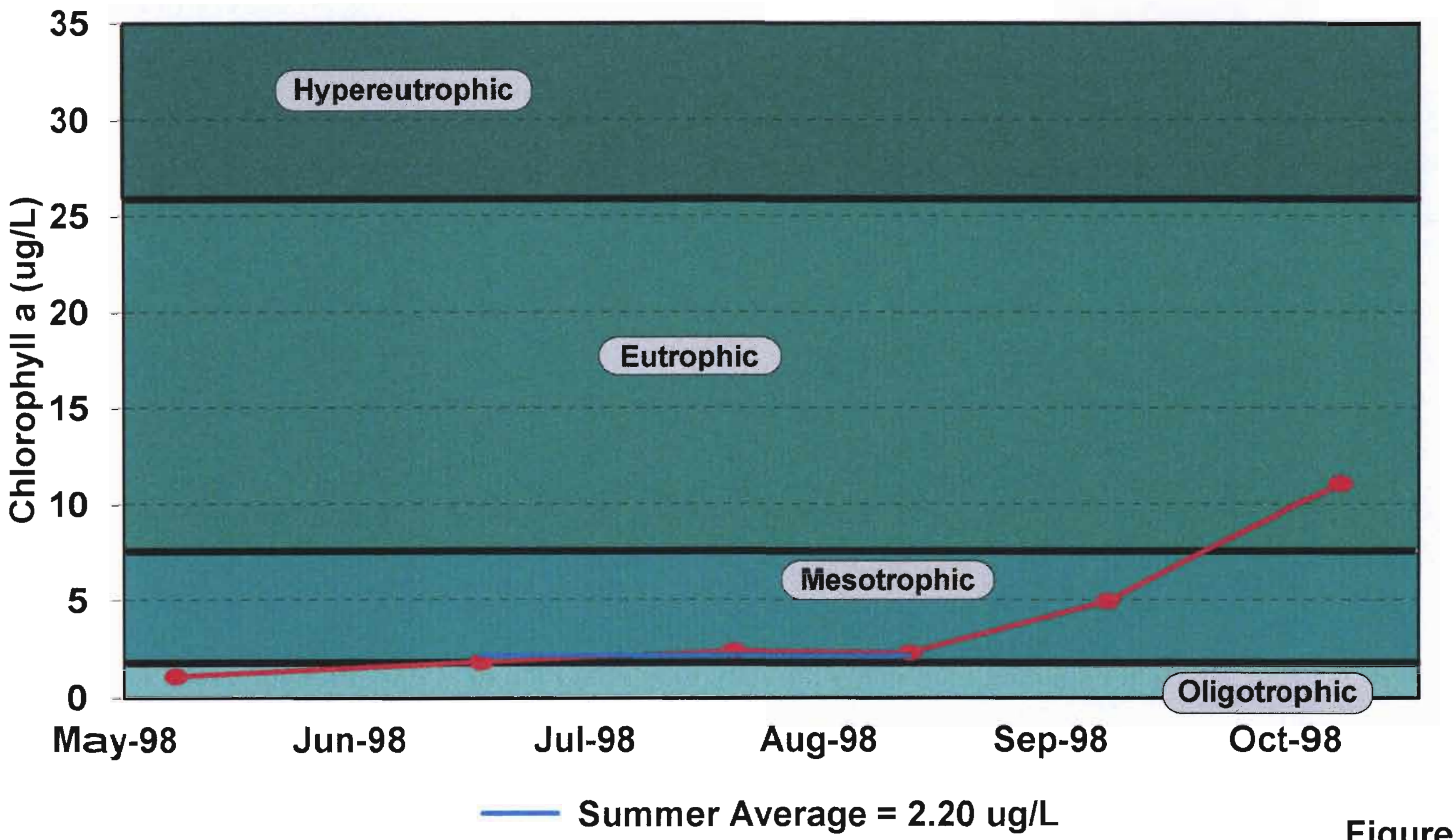


Figure 15

4.2.3 Secchi Disk Transparency

Secchi disk transparency is a measure of water clarity. Perceptions and expectations of people using a lake are generally correlated with water clarity. The results of a survey completed by the Metropolitan Council (Osgood, 1989) indicated that the following relationships can generally be perceived between a lake's recreational use impairment and Secchi disk transparencies:

- *No impairment occurs at Secchi disk transparencies greater than 4 meters (13 feet).*
- *Minimal impairment occurs at Secchi disk transparencies of 2 to 4 meters (6.5 - 13 feet).*
- *Moderate impairment occurs at Secchi disk transparencies of 1 to 2 meters (3.3 - 6.5 feet).*
- *Moderate to severe use-impairment occurs at Secchi disk transparencies less than 1 meter (3.3 feet).*

The Secchi disk measurements in Grindstone lake generally mirrored the total phosphorus and chlorophyll-a concentrations. The average Secchi disk transparency readings for all four stations were within the oligotrophic range throughout the summer months (see figure 14). Figures 15 - 18 show the pattern of the Secchi disk reading throughout the monitoring period for each station. Starting in the fall, the Secchi values decreased to the mesotrophic range. The seasonal patterns suggest that the lake's water transparency is largely determined by the algal abundance.

1998 Grindstone Lake Secchi Disk
Summer Averages

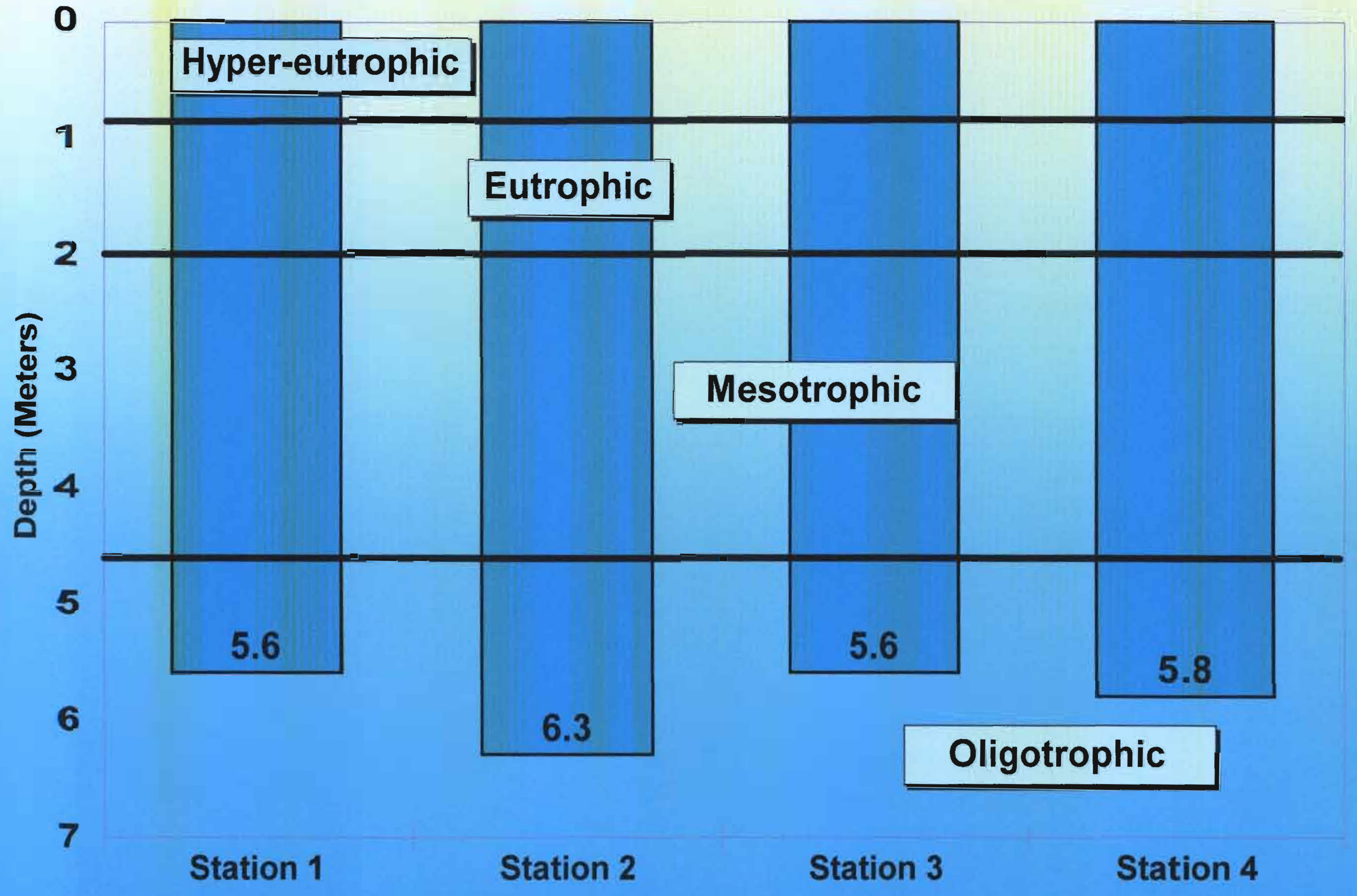
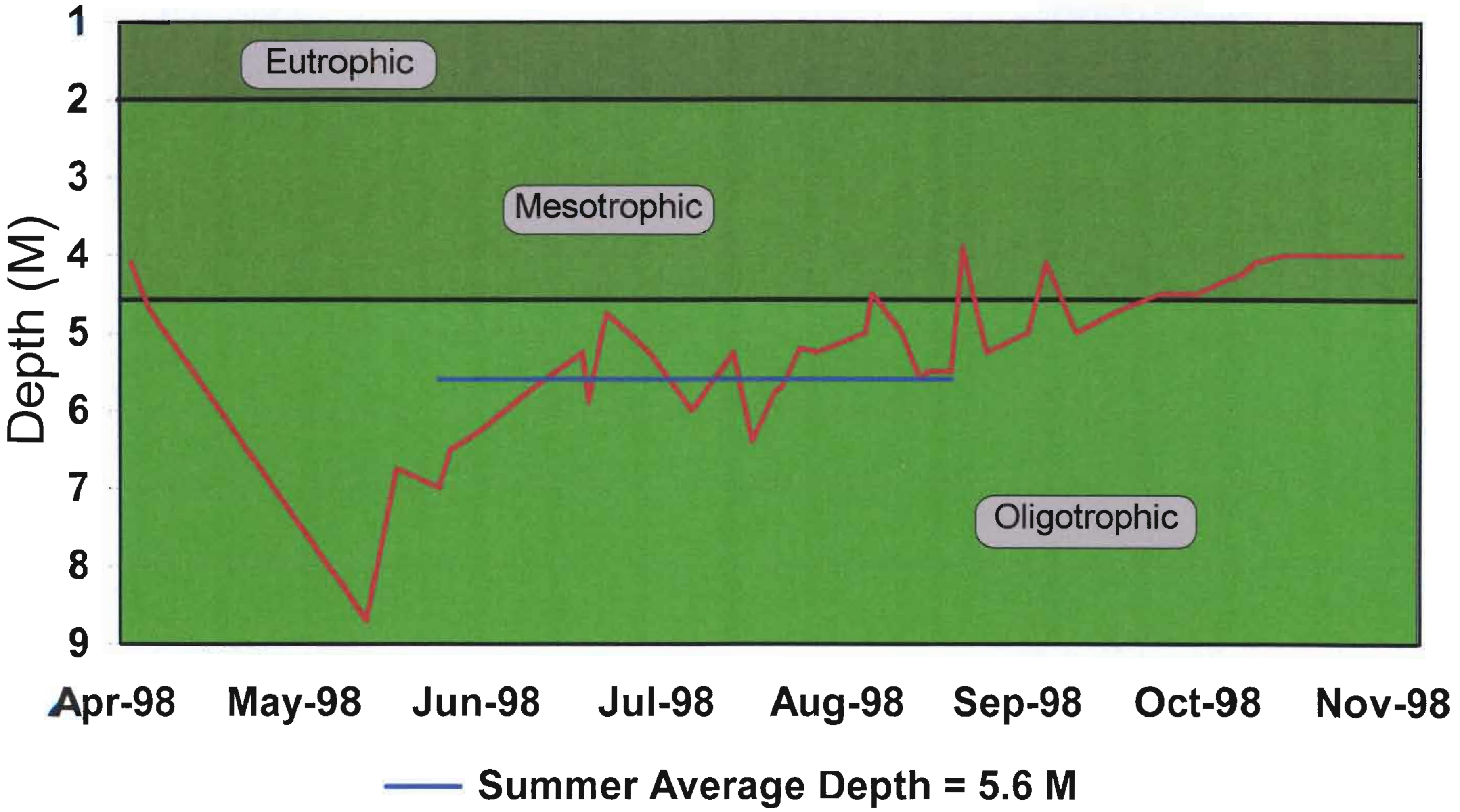


Figure 16

Grindstone Lake: 1998 Secchi Readings
Station 1



Grindstone Lake: 1998 Secchi Readings
Station 2

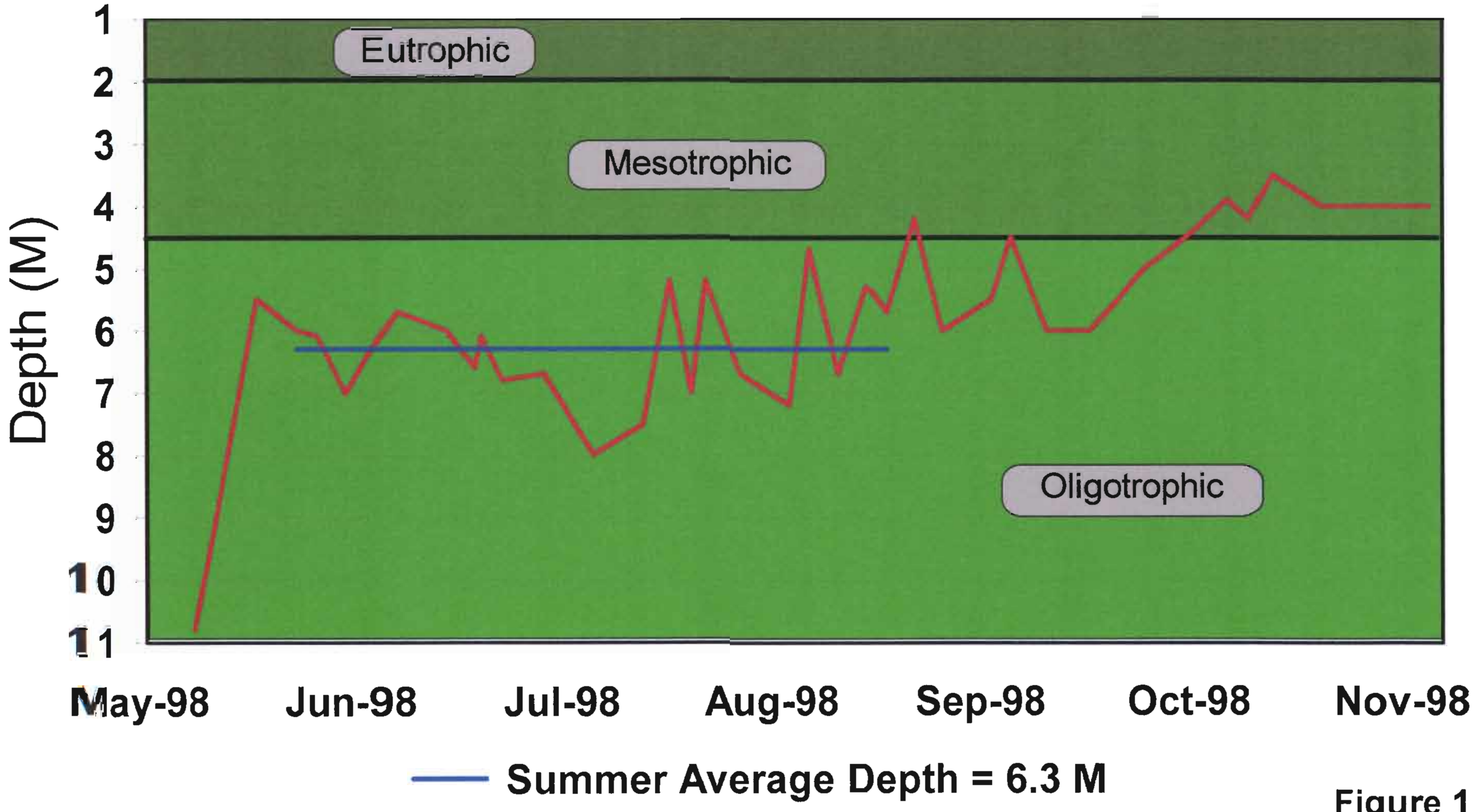


Figure 18

Grindstone Lake: 1998 Secchi Readings
Station 3

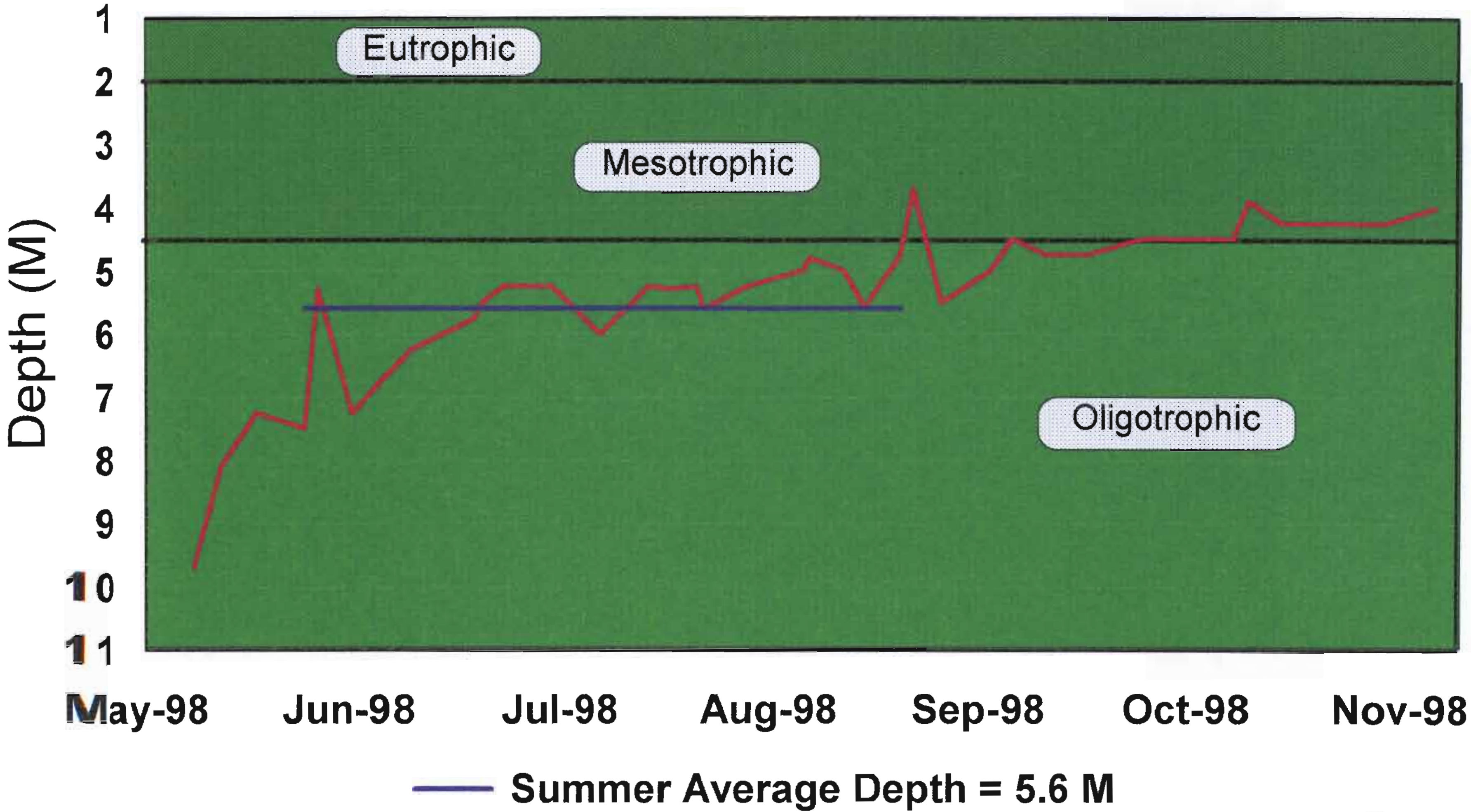
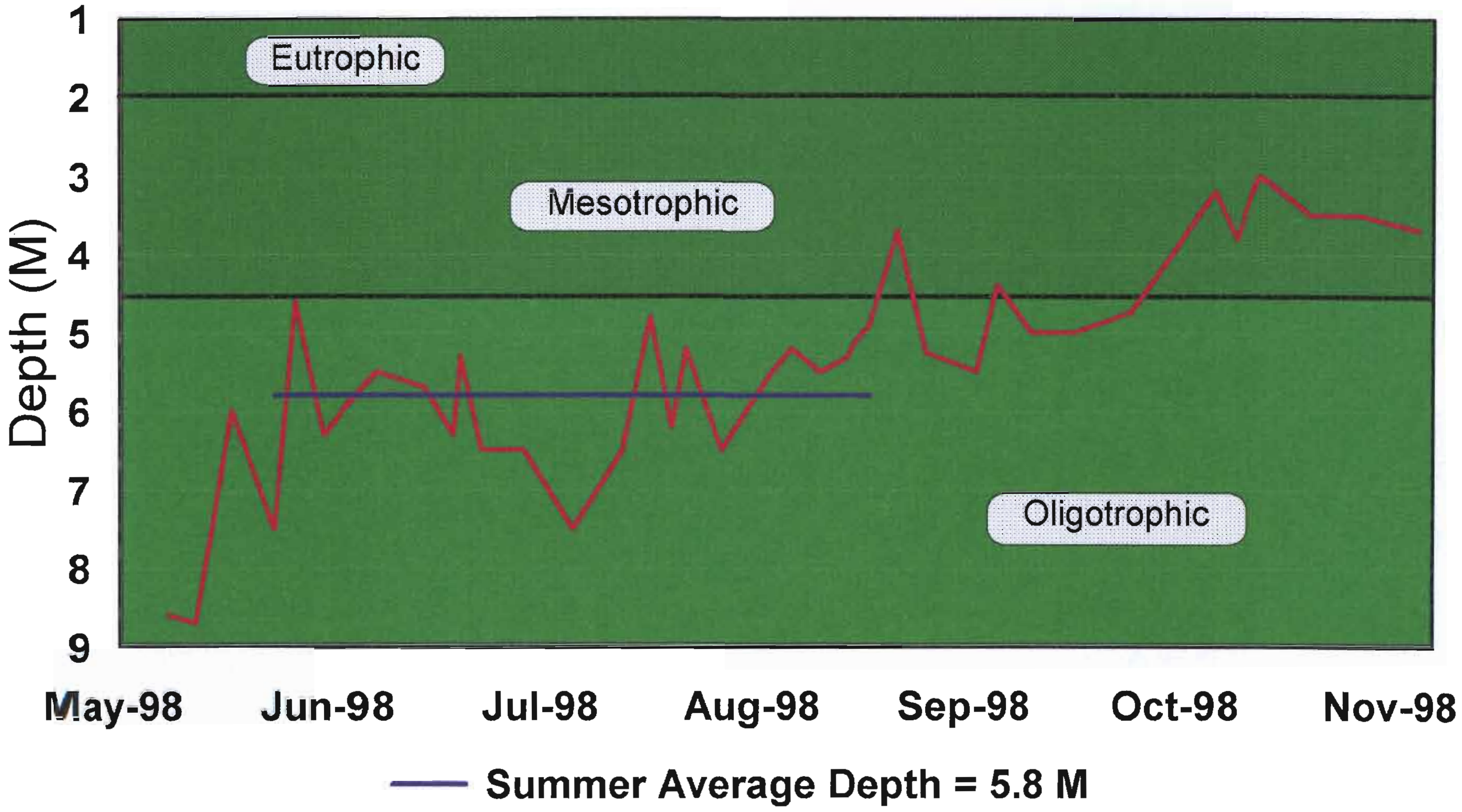


Figure 19

Grindstone Lake: 1998 Secchi Readings
Station 4



4.2.4 Temperature, Dissolved Oxygen, total Dissolved Solids, and Specific Conductance 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 dissolved solids and specific conductance were prepared for Grindstone Lake. The temperature isopleth diagrams (Figures 19 - 22) show that Grindstone Lake mixed completely during the spring and fall (i.e. same temperature from top to bottom) and was generally stratified from mid-June through early September depending on the location.

The dissolved oxygen isopleth diagrams (Figures 23 - 26) indicate that most of the lake had stratified dissolved oxygen concentrations during the monitoring period. The lowest dissolved oxygen concentrations were observed at the deepest portion of the lake (Station 2). The low dissolved oxygen concentrations were observed for a brief period from the end of September through approximately the middle of September. Oxygen depletion of the bottom waters reduces the available habitat for organisms (i.e. fish and zooplankton). A dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish. Oxygen concentrations of at least 5.0 mg/L were noted throughout the entire monitoring period down to a depth of 6 meters (20 feet). If dissolved oxygen concentrations fall below 0.5 mg/L, the water is considered anoxic (i.e. without oxygen) and phosphorus can redissolve into the anoxic waters from the sediment. This is termed internal loading. Internal loading within Grindstone Lake was considered to be minor since only a small area of the bottom waters became anoxic and were anoxic for only a relatively short amount of time.

Specific conductance is directly related to the amount of dissolved inorganic chemicals (minerals, nutrients, metals, and other inorganic chemicals) in the water. Total dissolved solids provides another measurement of materials dissolved in the lake. They both are a reflection of the soils and bedrock in the lake's watershed and they also indicate the level of internal loading occurring within the lake. Figures 27 - 30 represent the specific conductance isopleths and figures 31 - 34 represent the total dissolved solids isopleths for the four monitoring stations. The total dissolved solids and specific conductance isopleths do show an increase for a brief period during the middle of September for Station 2, thus indicating that some internal loading did occur. Lakes with higher specific conductance and total dissolved solids are more productive waters, capable of supporting more aquatic plants and animals. Higher levels can also indicate a poorer water quality among lakes.

Grindstone Lake: 1998 Temperature Isopleths (C)
Station 1

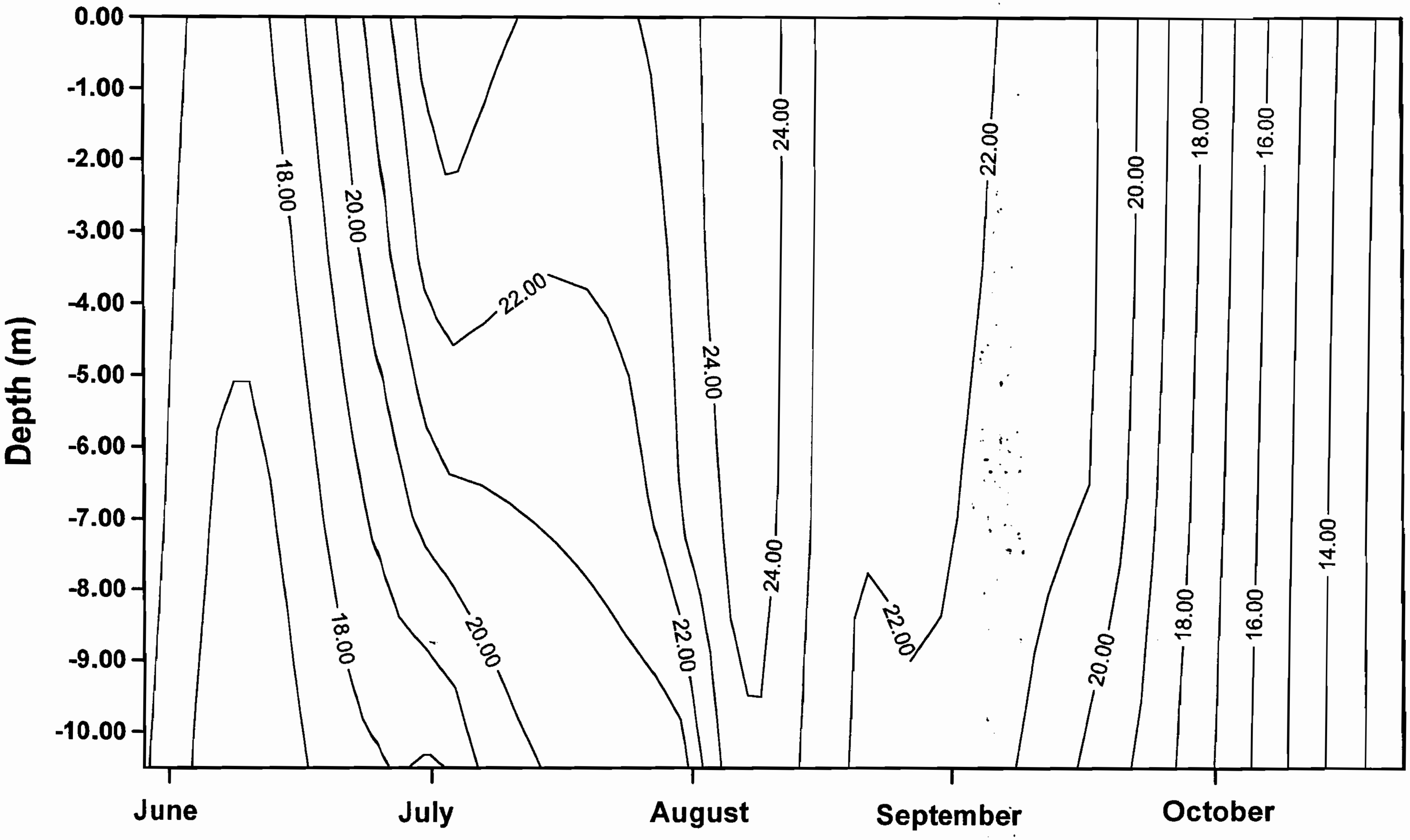


Figure 21

Grindstone Lake: 1998 Temperature Isopleths (C)
Station 2

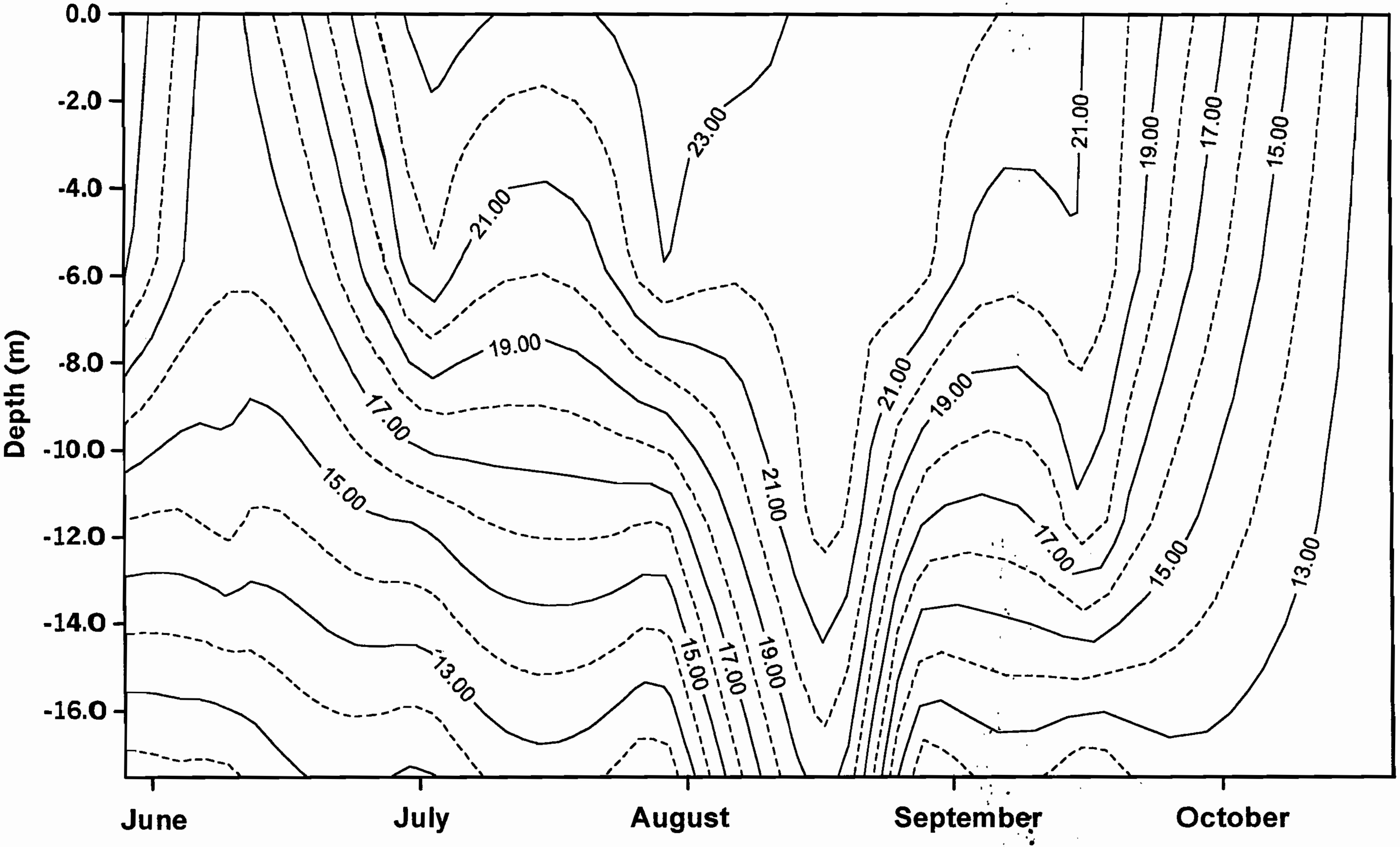


Figure 22

Grindstone Lake: 1998 Temperature Isopleths (C)
Station 3

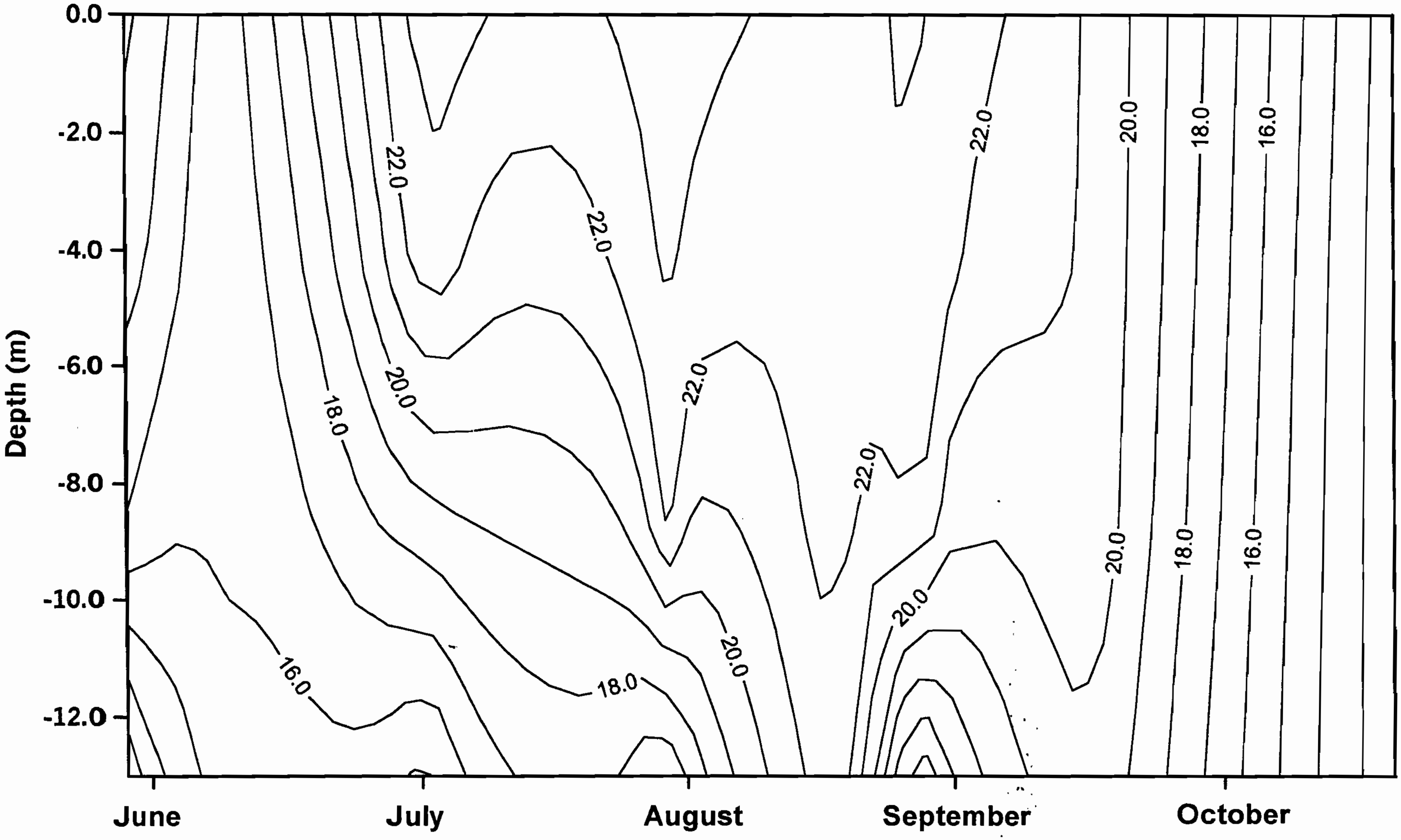


Figure 23

Grindstone Lake: 1998 Temperature Isopleths (C)
Station 4

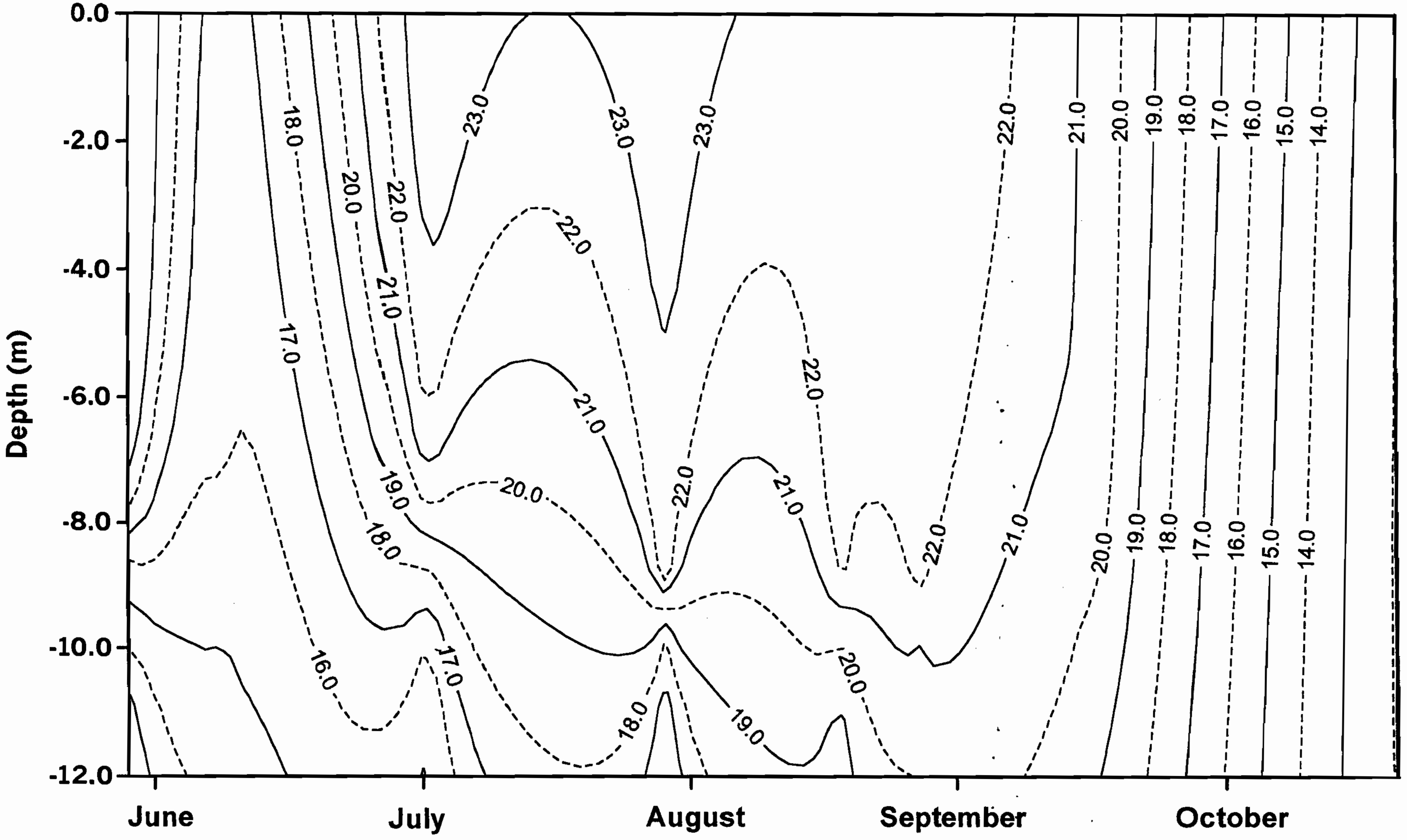


Figure 24

Grindstone Lake: 1998 Dissolved Oxygen Isopleths (mg/L)
Station 1

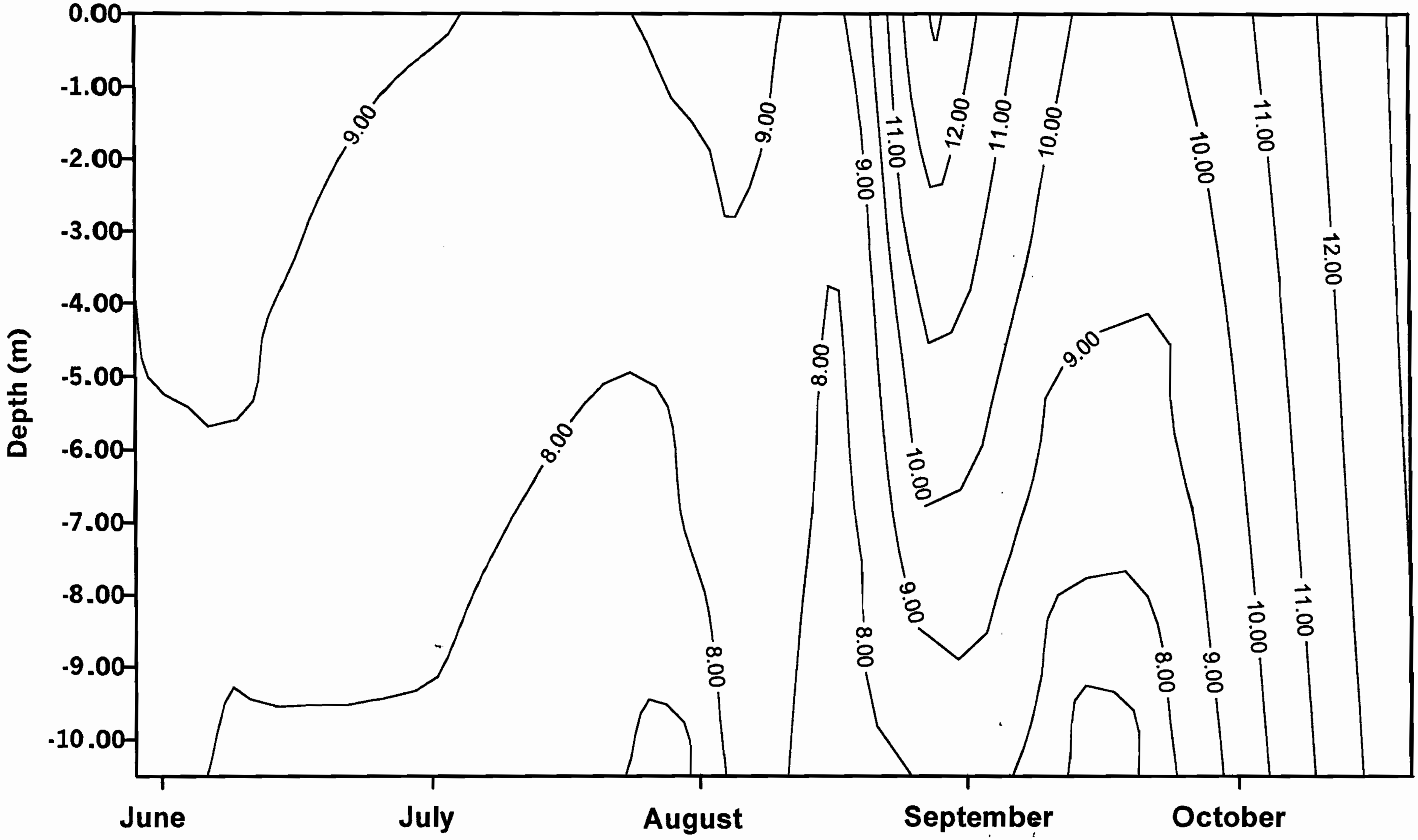
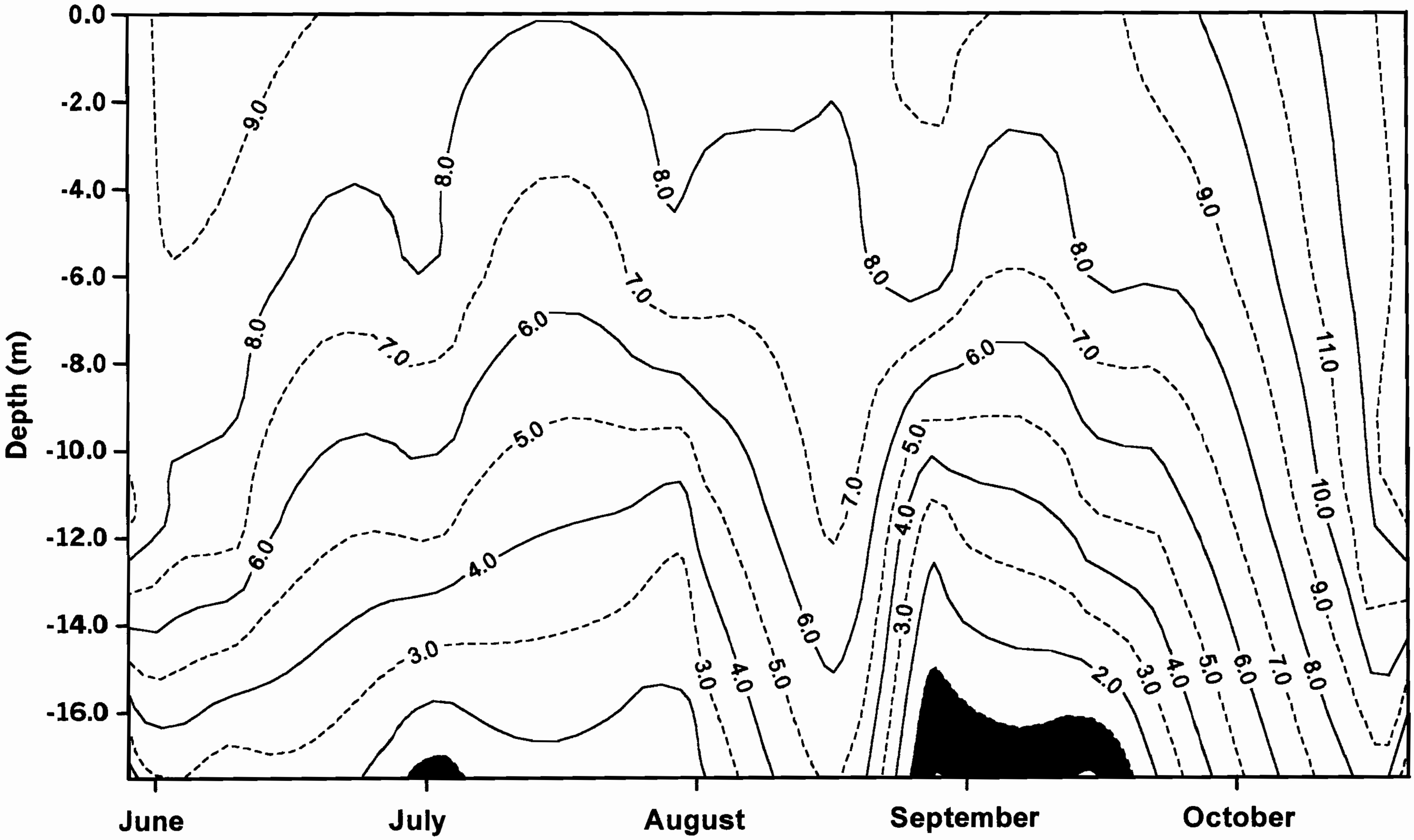


Figure 25

Grindstone Lake: 1998 Dissolved Oxygen Isopleths (mg/L)
Station 2



Shaded area represents period of likely internal loading

Figure 26

Grindstone Lake: 1998 Dissolved Oxygen Isopleths (mg/L)
Station 3

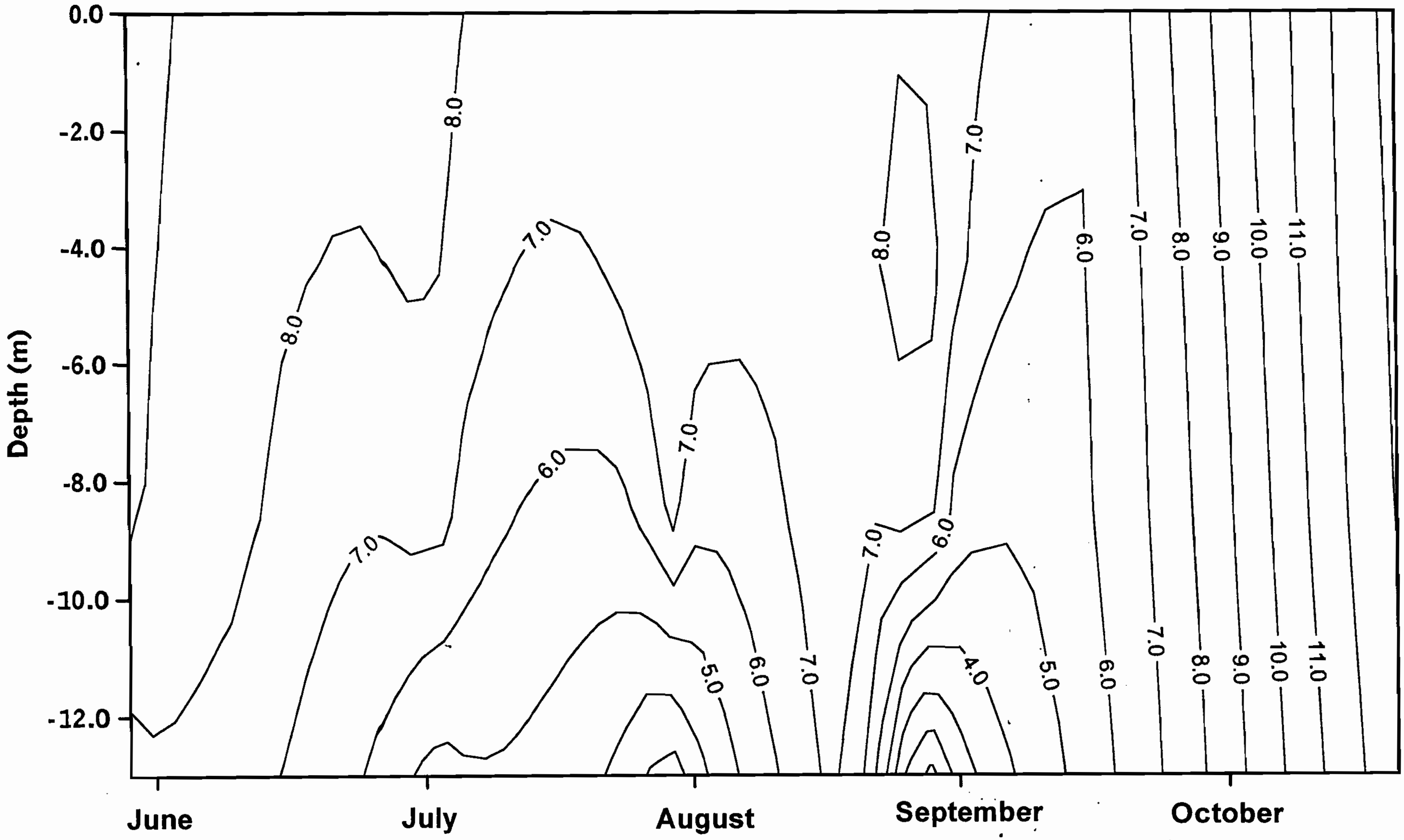


Figure 27

Grindstone Lake: 1998 Dissolved Oxygen Isopleths (mg/L)
Station 4

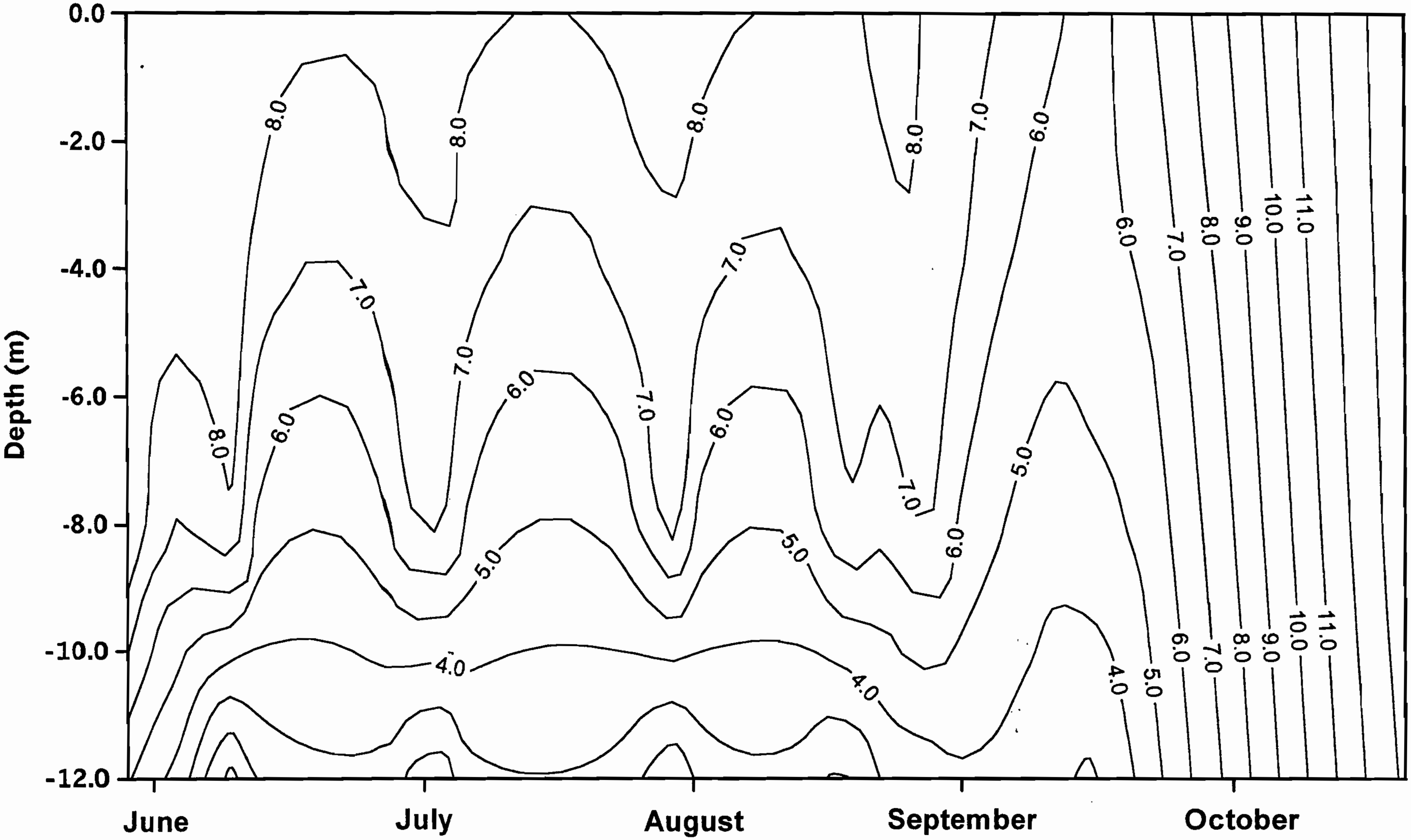


Figure 28

Grindstone Lake: 1998 Total Dissolved Solids Isopleths (g/L)
Station 1

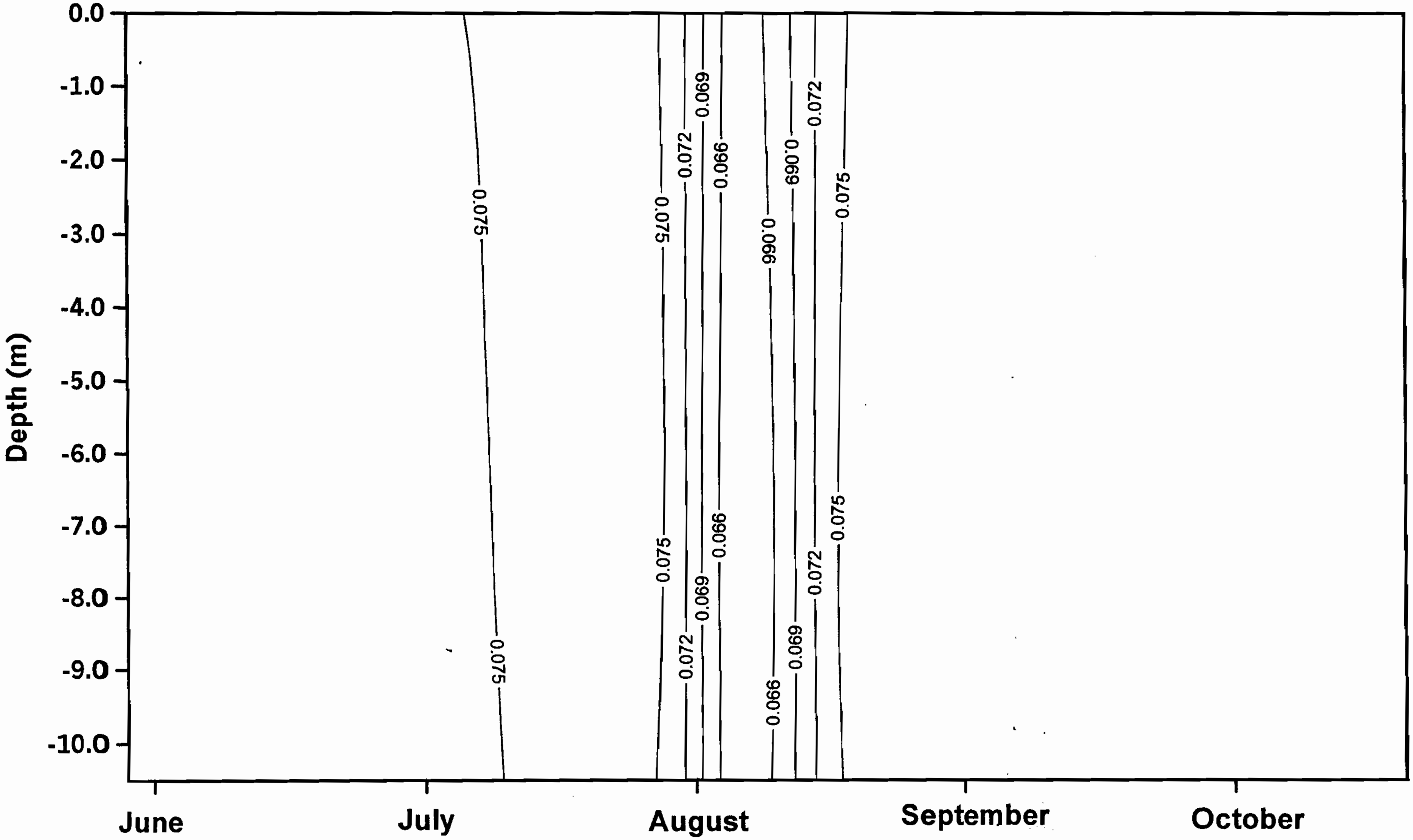


Figure 29

Grindstone Lake: 1998 Total Dissolved Solids Isopleths (g/L)
Station 2

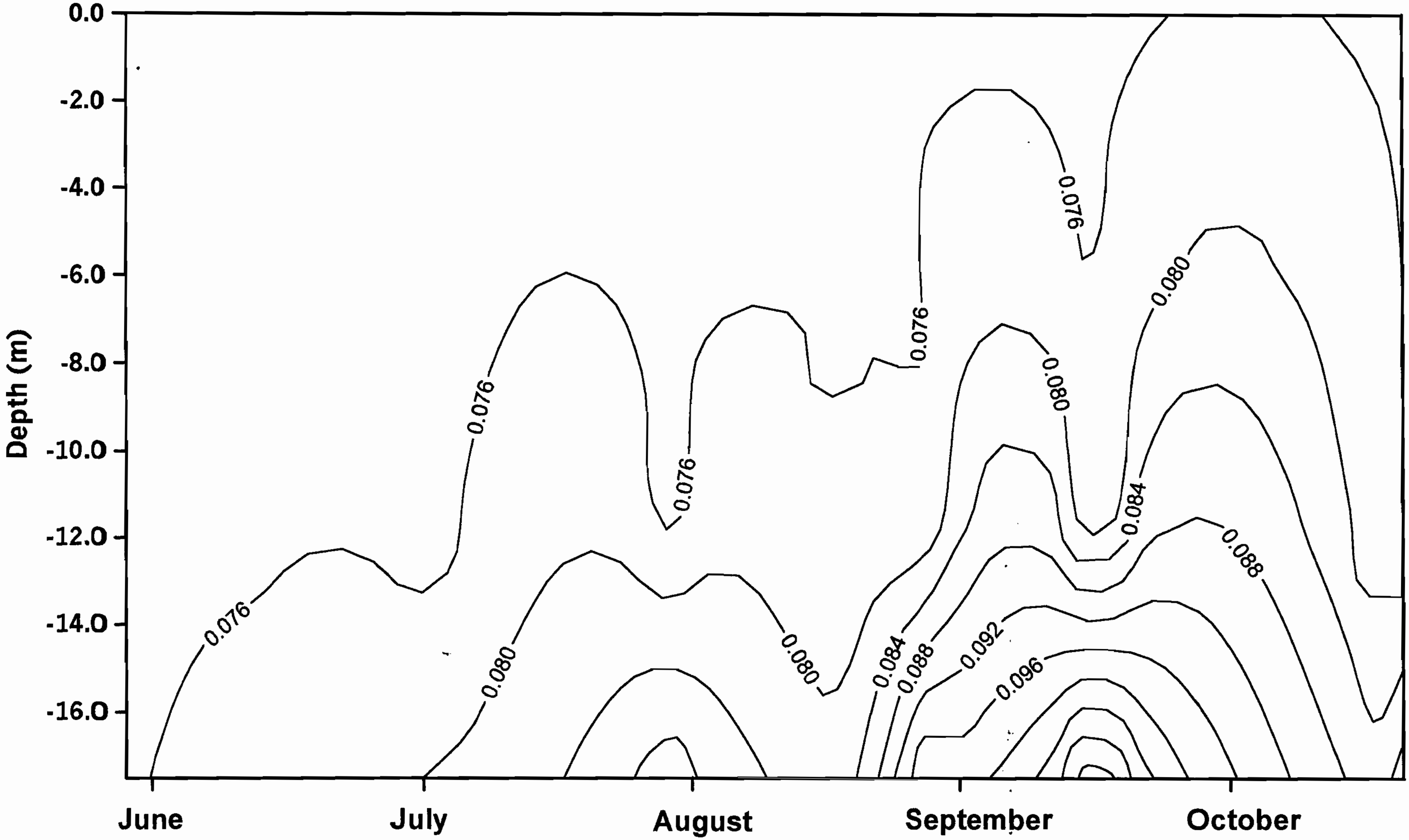


Figure 30

Grindstone Lake: 1998 Total Dissolved Solids Isopleths (g/L)
Station 3

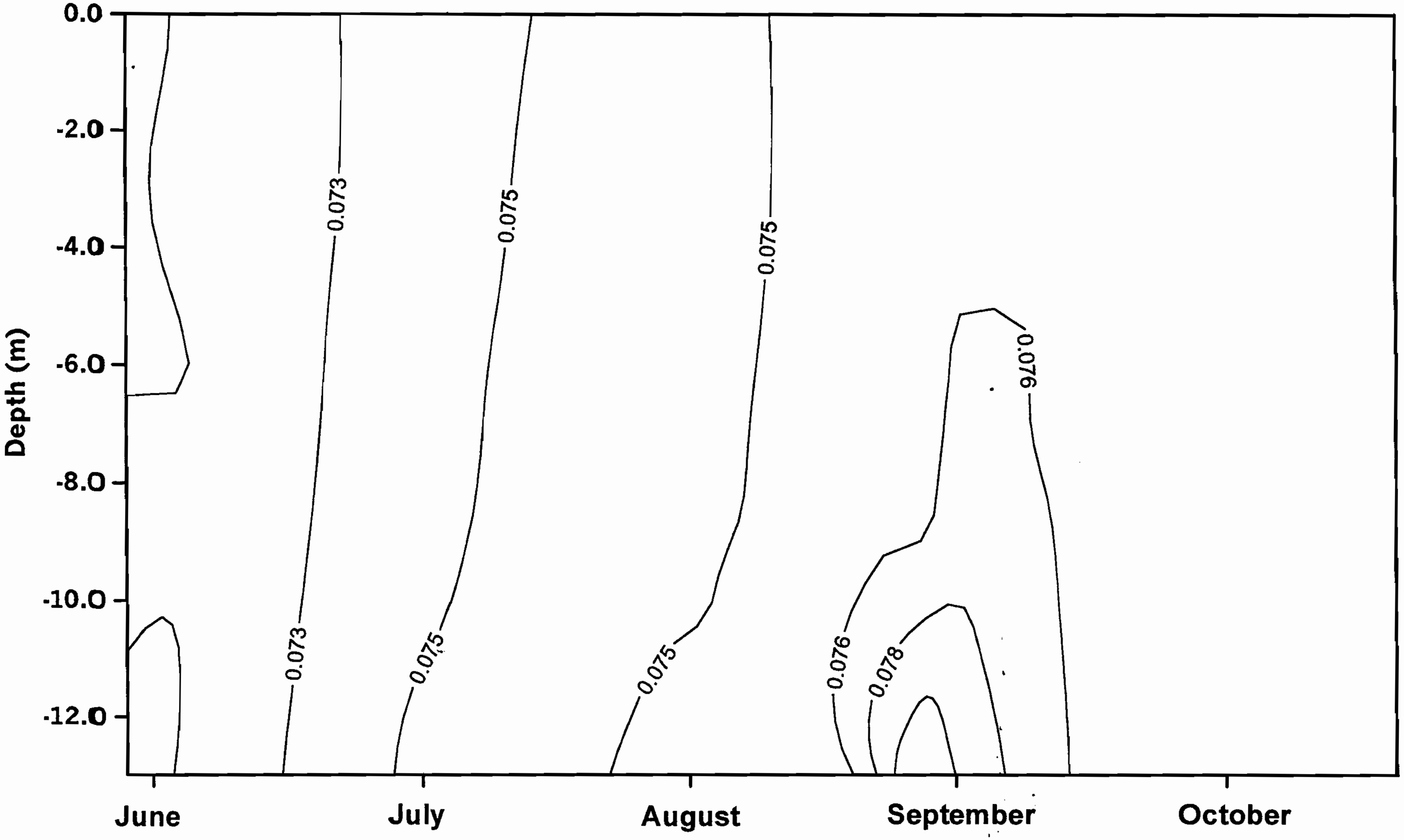


Figure 31

Grindstone Lake: 1998 Total Dissolved Solids Isopleths (g/L)
Station 4

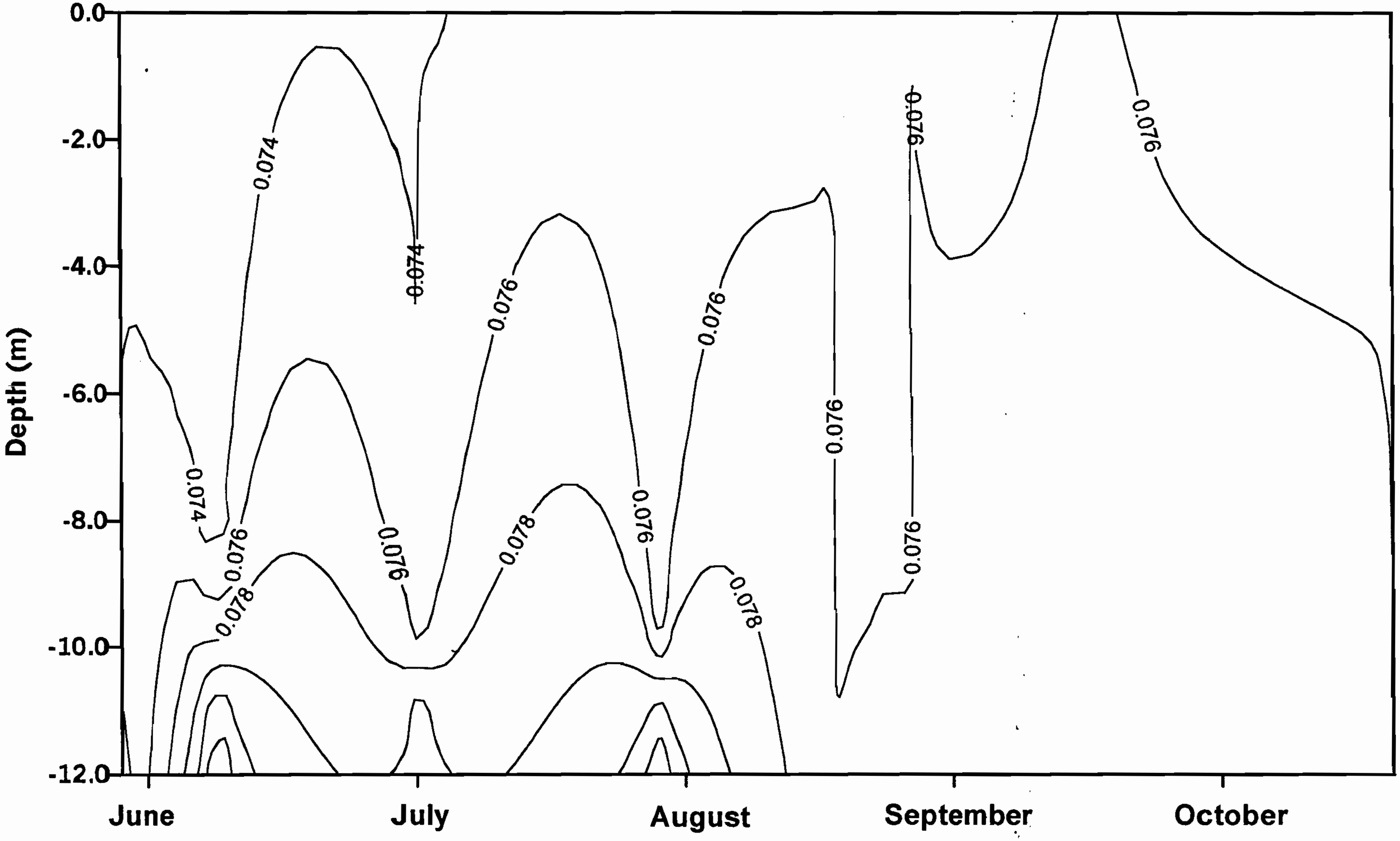


Figure 32

Grindstone Lake: 1998 Specific Conductance Isopleths (uS/cm)
Station 1

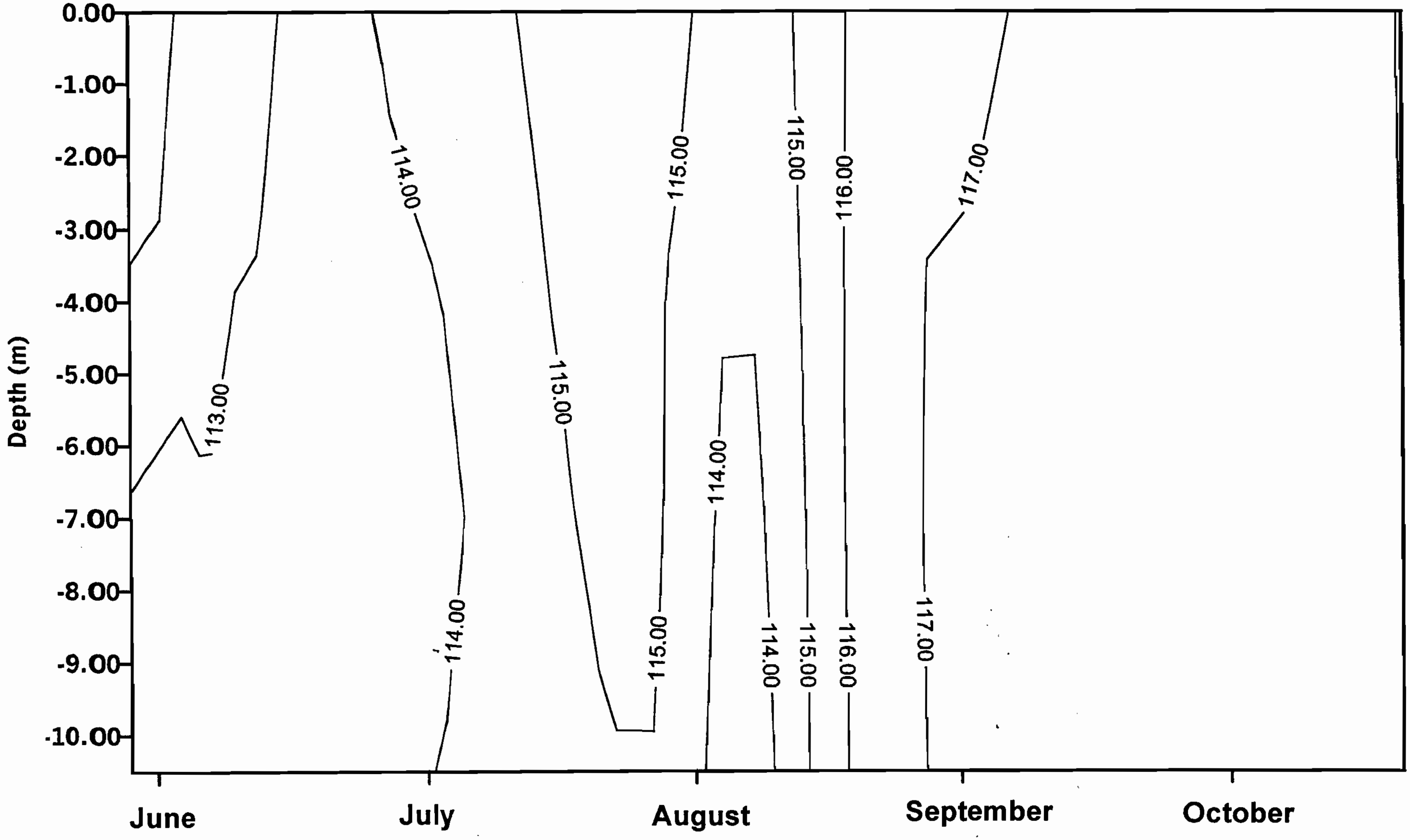


Figure 33

Grindstone Lake: 1998 Specific Conductance Isopleths (uS/cm)
Station 2

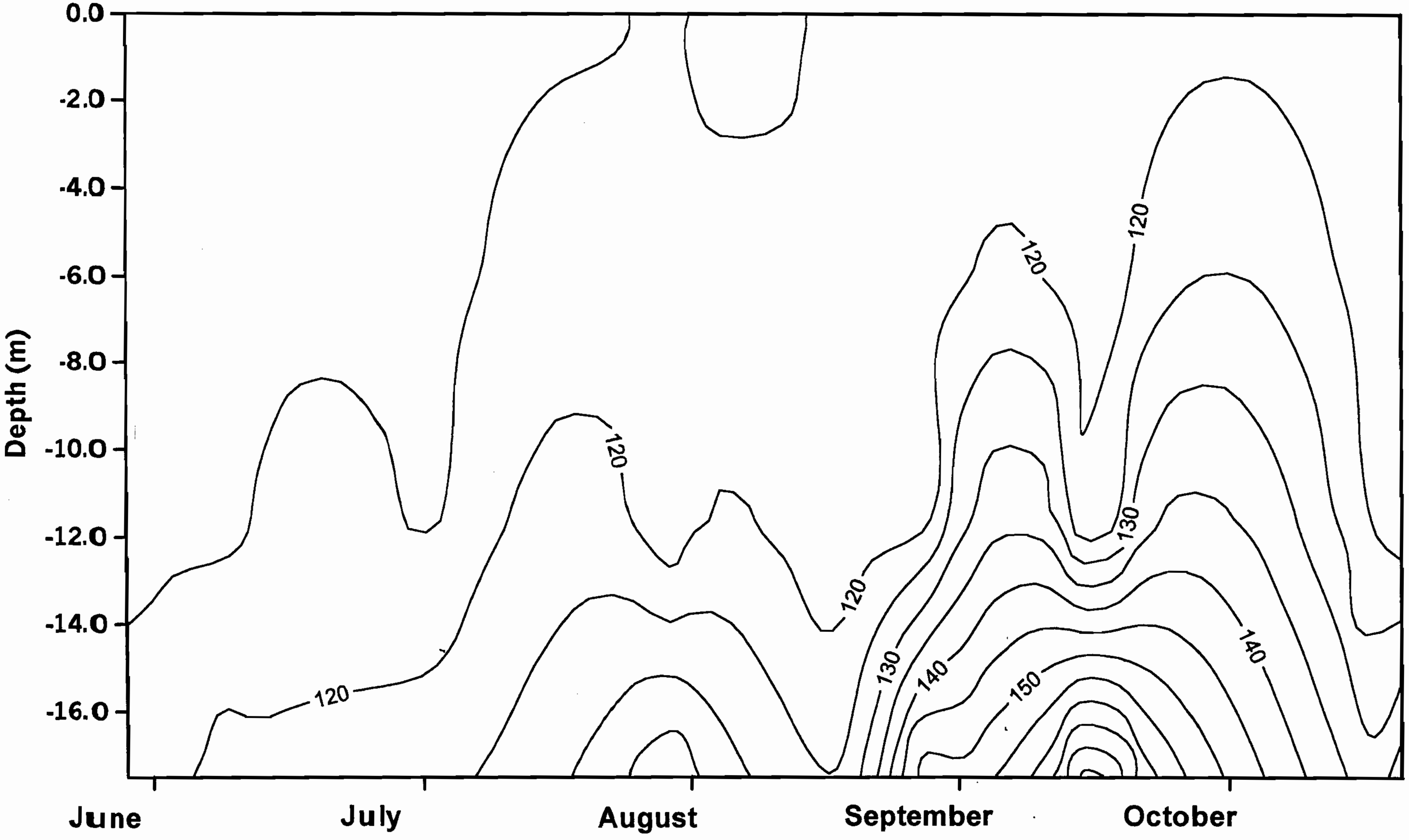


Figure 34

Grindstone Lake: 1998 Specific Conductance Isopleths (uS/cm)
Station 3

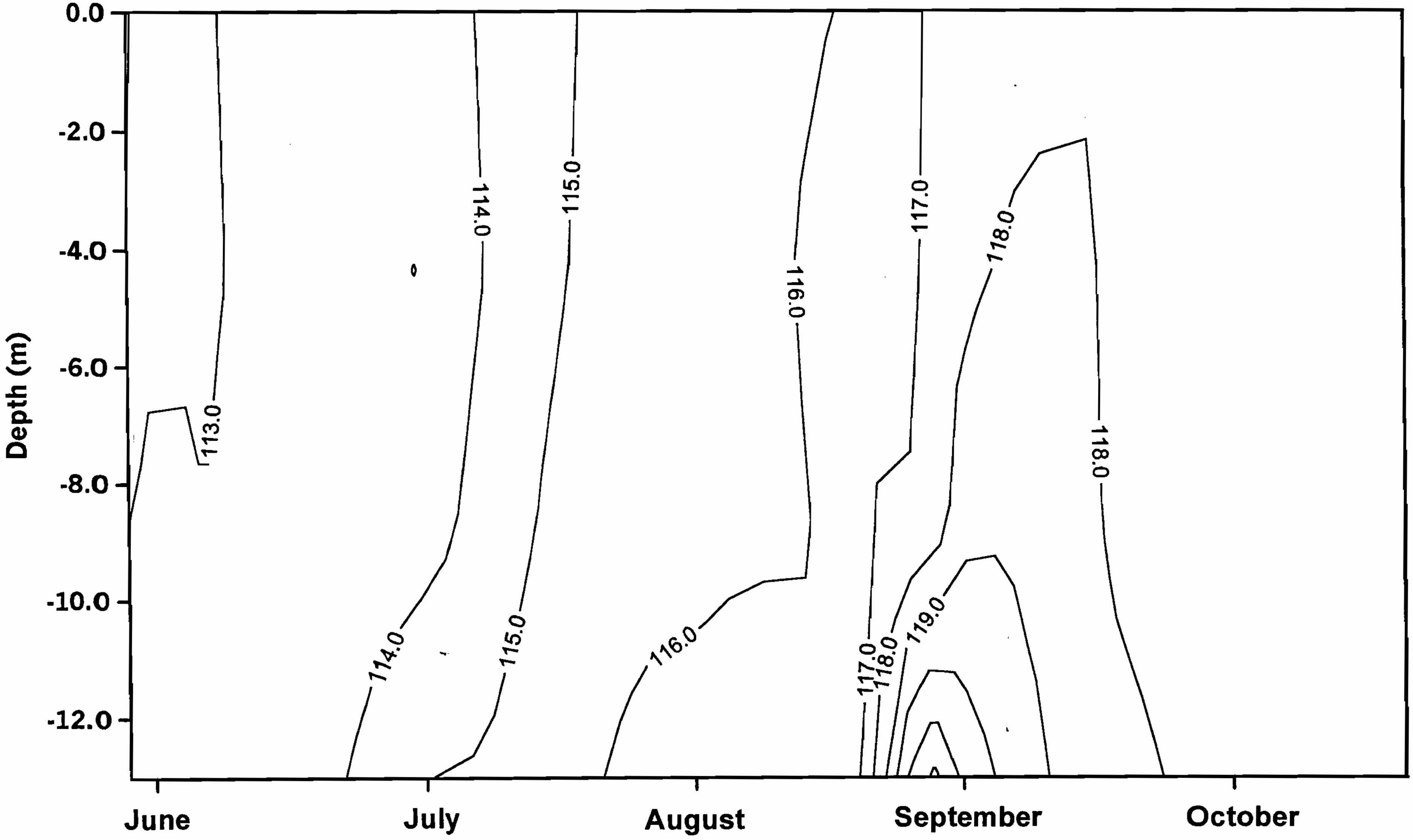


Figure 35

Grindstone Lake: 1998 Specific Conductance Isopleths (uS/cm)
Station 4

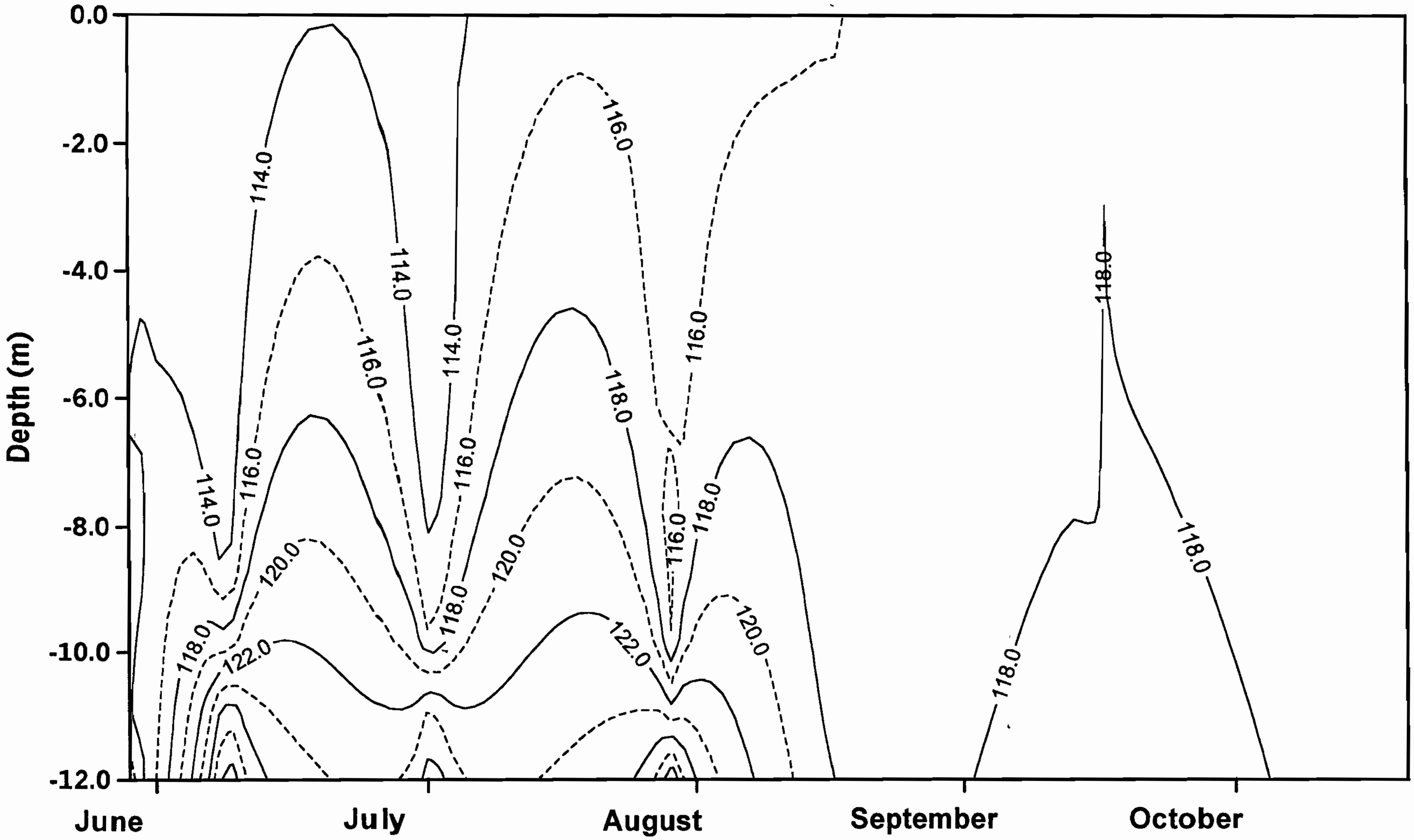


Figure 36

4.2.5 pH Isopleth Diagrams

pH defines the acid or alkaline status of the water. A pH of 7.0 is neutral, while waters above 7.0 are alkaline, and waters below 7.0 are acidic. Rainwater is naturally slightly acidic. Lakes that receive most of their water from precipitation, such as seepage lakes, will be acidic. Drainage lakes receive most of their water from streams and rivers and will tend to be more alkaline.

The acidity or alkalinity of a lake directly influences the aquatic life in the lake. For example, if a lake has a pH of 6.5 or lower (acidic), walleye spawning is inhibited. At a pH of 5.2 or lower, walleyes cannot survive. Acidic conditions may result in higher mercury levels and may pose health problems to wildlife and humans consuming fish.

The pH isopleth diagrams for Grindstone Lake indicate that alkaline conditions occurred throughout the lake (see Figures 37 - 40). The lake's surface waters tended to be more alkaline than the deeper water, as is indicated by the higher pH levels. Photosynthesis causes the addition of hydroxide ions to the water, resulting in higher pH levels. Photosynthesis by algae in the lake's surface waters likely caused the increased pH levels, thereby resulting in higher levels than the lake's bottom waters. All of the pH levels measured in Grindstone Lake are within the range of values considered safe for fish and aquatic animals. The pH values in Grindstone Lake ranged from a high of 9.1 to a low of 6.9.

Grindstone Lake: 1998 pH Isopleths
Station 1

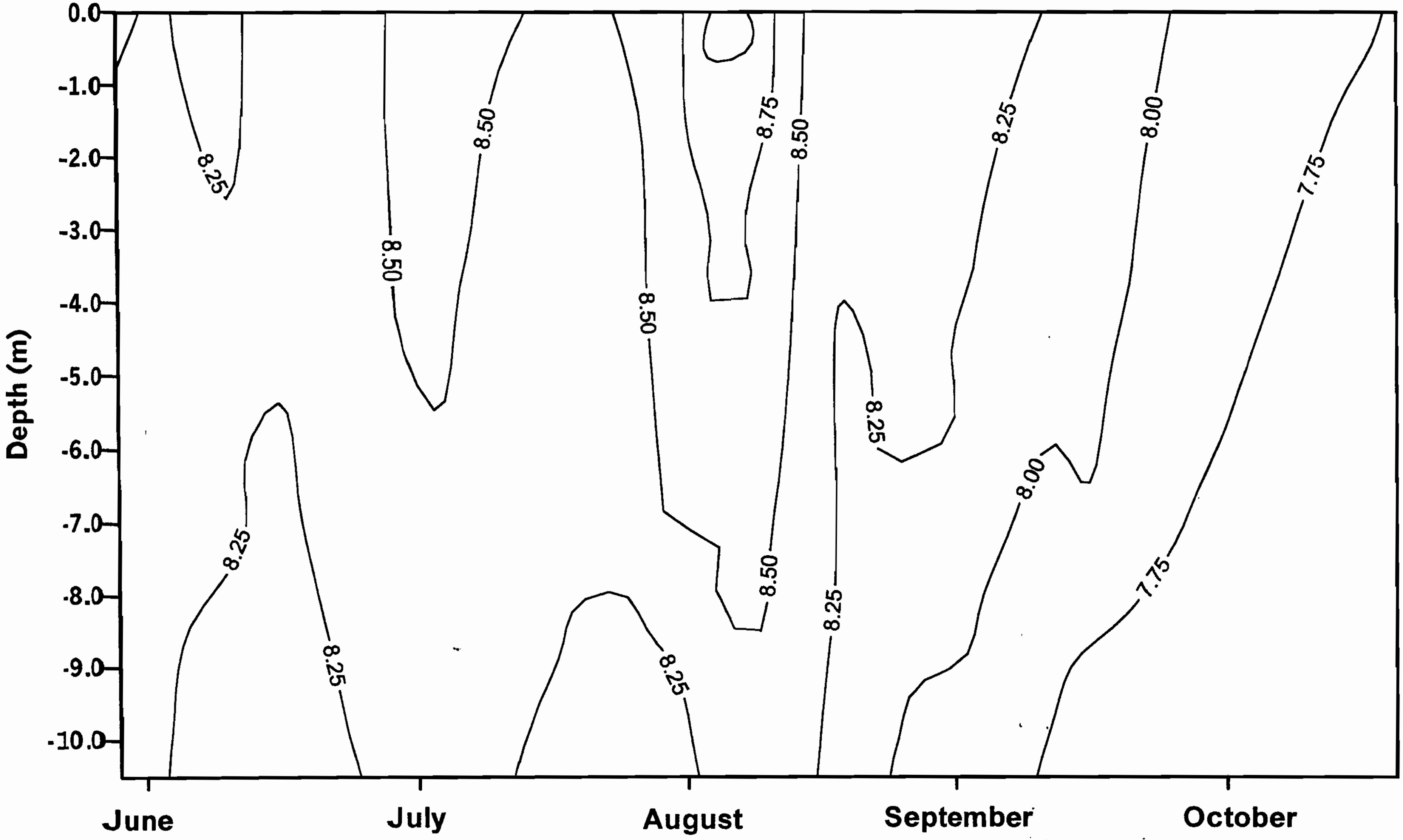


Figure 37

Grindstone Lake: 1998 pH Isopleths
Station 2

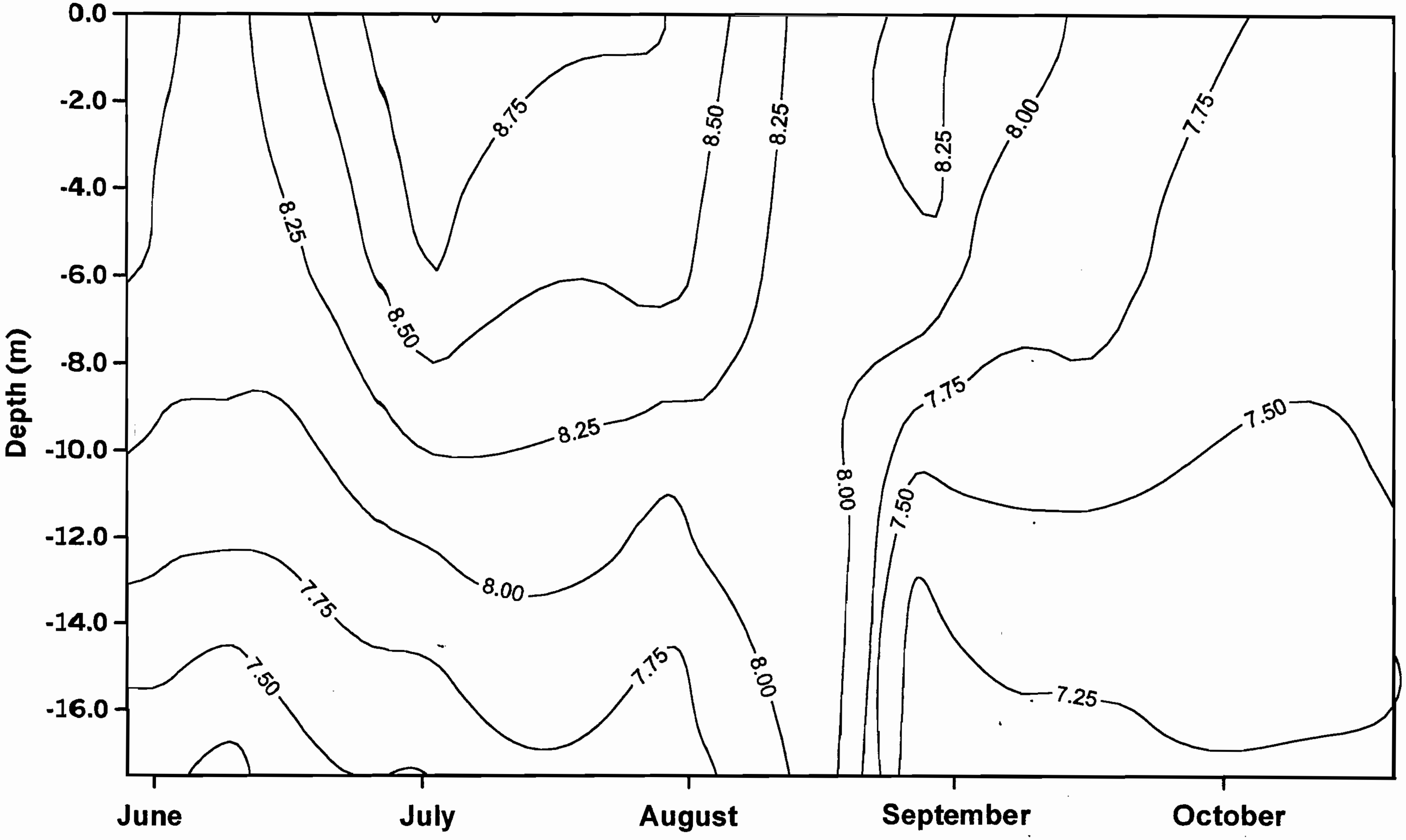


Figure 38

Grindstone Lake: 1998 pH Isopleths
Station 3

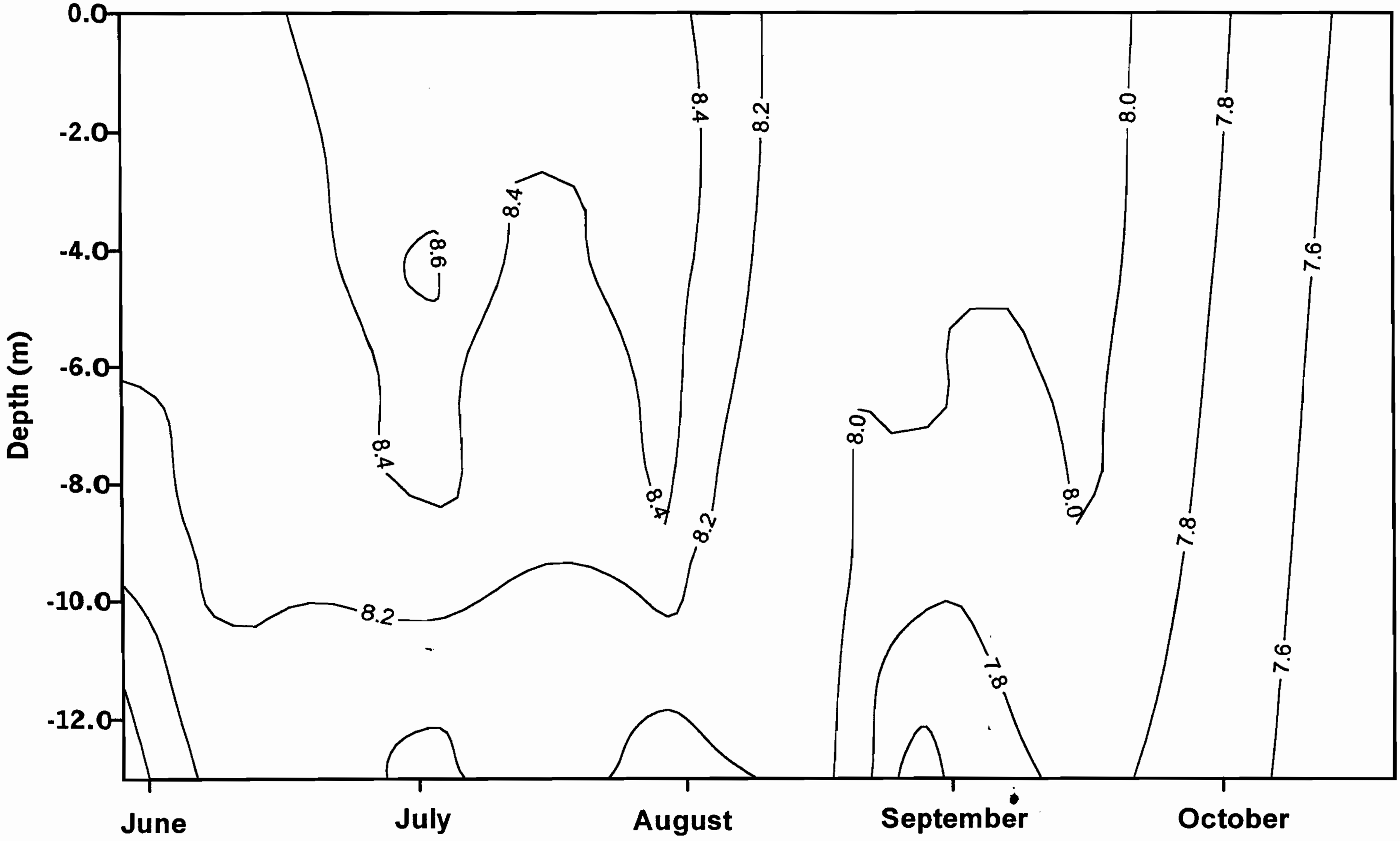


Figure 39

Grindstone Lake: 1998 pH Isopleths
Station 4

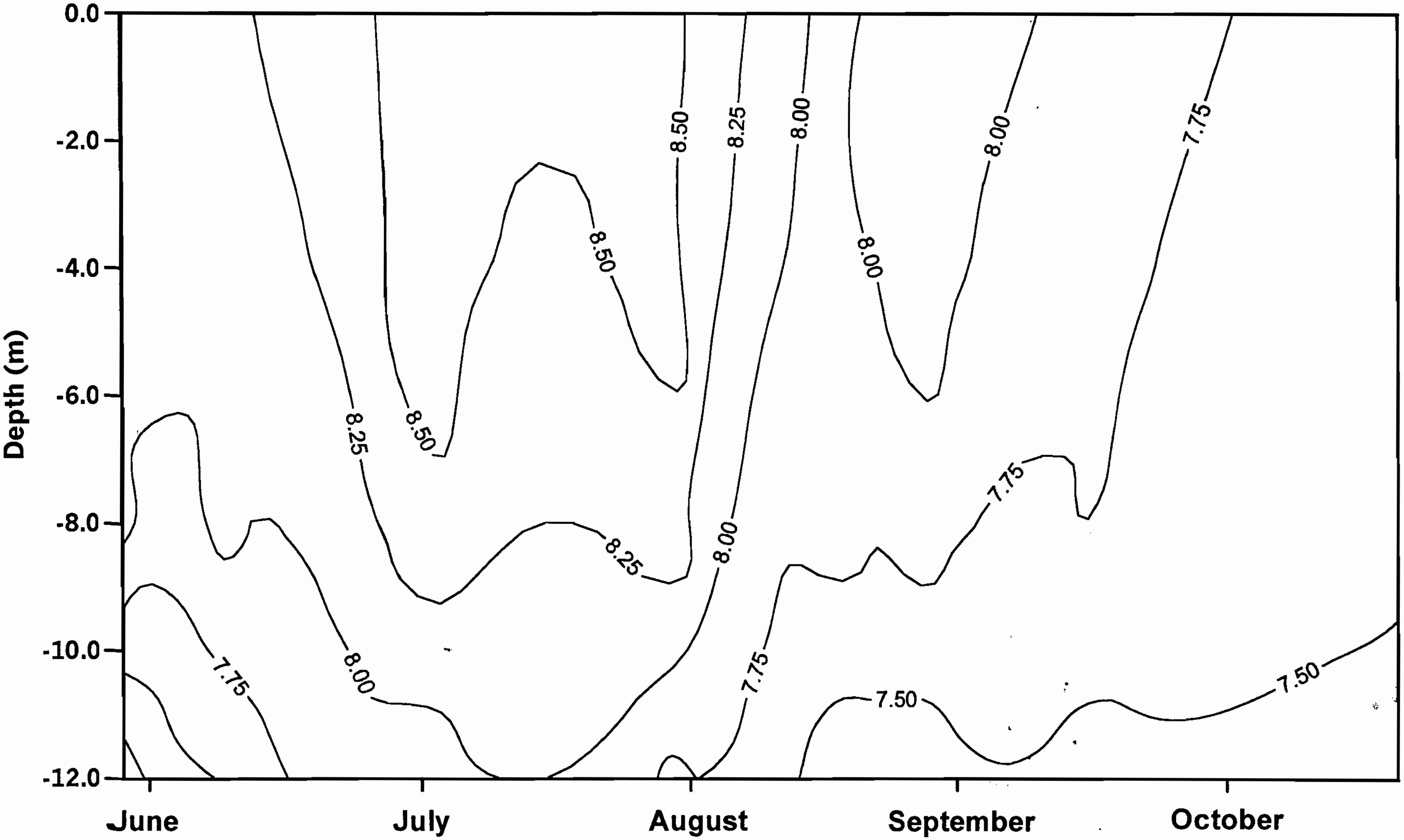


Figure 40

4.2.6 Alkalinity Data

Alkalinity is associated with the carbon system in the lake. Another term used to indicate a lake's alkalinity is hardness. Hard water lakes (greater than 60 mg/L calcium carbonate) tend to be better producers of aquatic life, including both plants and animals. Soft water lakes (less than 60 mg/L calcium carbonate) are not as productive. Extremely low alkalinities (less than 5 mg/L calcium carbonate) are more likely to be impacted by acidification resulting from acid rain. Alkalinities above 5 mg/L calcium carbonate have enough buffering to counteract the effects of acid rain.

The average alkalinity for Grindstone lake during 1998 was 54 mg/L calcium carbonate. Grindstone Lake would therefore be classified as a soft water lake. Alkalinity values ranged from 52 - 55 mg/L.

4.2.7 Current Trophic State Indices

Table 6 indicates the trophic state index (TSI) based on the given parameter.

Table 6: Grindstone Lake Trophic State Indices

Parameter	Value	Trophic State Index
Total Phosphorus	13.3 ug/L	41
Chlorophyll-a-	1.92 ug/L	37
Secchi disk depth	5.8 meters	35

The Carlson TSI values used for Grindstone Lake are the averages of all four stations which correspond to the parameter readings taken between Memorial Day and Labor Day, or the dates closest to these when samples were taken. The span of these dates corresponds with typical summer conditions and peak recreational use of the lake and therefore should most closely correlate with user perceptions of the lake. The TSI values indicate that Grindstone Lake is generally Oligotrophic bordering on Mesotrophic (refer to Figure 1 and Table 1).

The TSI values indicate that water clarity is better than what would be expected based upon the total phosphorus and chlorophyll-a readings. It also appears that the total phosphorus was not utilized completely by the algae (i.e. the chlorophyll-a is predicted to be greater than what was observed based upon the amount of nutrients available for growth).

4.3 Rainfall, Evaporation and Lake Level Data

As was previously mentioned, four rain gauges were installed around Grindstone Lake and read on a daily basis by a volunteer throughout the ice-free period to determine daily precipitation amounts. The total average precipitation during the 1998 water year was 26.62 inches. This is nearly 13% below the normal Wisconsin average precipitation of 30.49 inches determined by the Spooner Experimental Farm.

Pan evaporation rates from the Marshfield Agricultural Experimental Research Station were used to determine the surface evaporation from Grindstone Lake. Since pan evaporation rates are higher than actual lake evaporation, they must be adjusted to account for variances such as radiation and heat exchange effects. The adjustment factor, termed the pan coefficient, ranges from 0.64 to 0.81 and averages 0.70 for the United States (Bedient and Huber, 1992). A pan coefficient of 0.7 was used for this study. The pan evaporation data did not cover the winter months i.e. (November - April). Therefore, winter evaporation rates used by Barr Engineering for a similar study on Lac Courte Oreilles Lake were used (Barr, 1998). Evaporation ranged from a high of 7.15 inches in May to a low of 0.12 inches for each month in December, January, and February. The total estimated lake surface evaporation during 1997-98 was 33.19 inches. The average annual evaporation rate for northwestern Wisconsin is 28 inches (Linsley, Jr. et al., 1982). The annual evaporation rate for 1997-98 was nearly 19% above normal.

A staff gauge was installed in the lake to determine changes in storage. The gauge was read on a daily basis from May 29, 1998 through November 21, 1998. The monitored lake surface elevations had a range of approximately 11.75 inches. The highest lake levels observed during the monitoring period were in June and the lowest levels were observed in September and October.

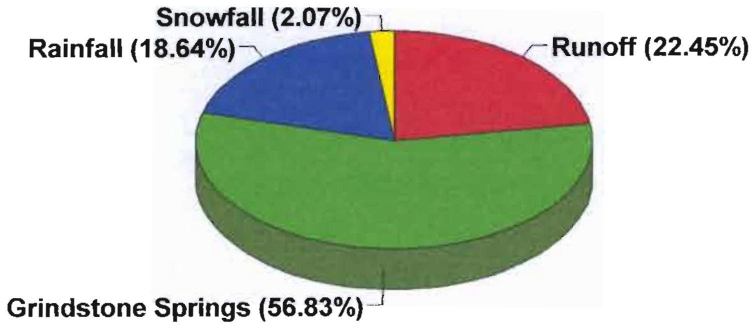
4.4 Inlet Data

Discharge and total phosphorus concentration data were collected from Grindstone Creek which is the inlet to Grindstone Lake. This data was used to determine the annual phosphorus input from Grindstone Creek. The total flow from Grindstone Creek into the lake was estimated to be 18,963 acre-feet. This results in an estimated annual phosphorus loading to the lake of 526.5 kg/yr (1,161 lb/year).

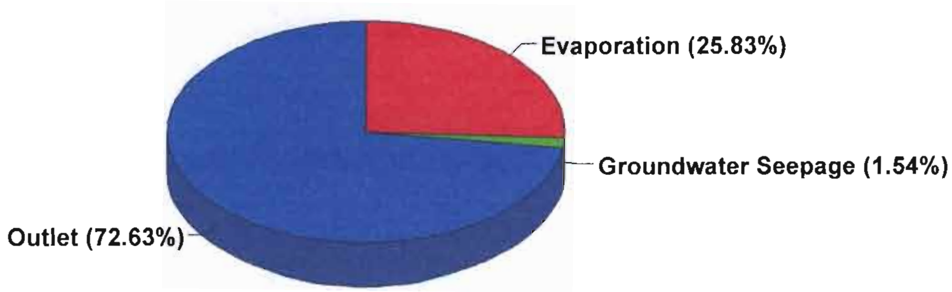
4.5 Hydrologic Budget Calculations

The 1997-98 water year (October 1, 1997 through September 30, 1998) estimated hydrologic budget for Grindstone Lake is presented in Figure 41. As the budget indicates, the inlet from Grindstone Creek supplied over half of the estimated annual water load to the lake. Direct precipitation on the lake's surface and runoff comprised the remainder of the annual water load. Runoff includes both the overland and groundwater flow to the lake. The watershed runoff volume represents an annual water yield of approximately 10.6 inches from the Grindstone Lake watershed. This runoff yield, divided by the 26.62 inches of total precipitation for the water year, results in a runoff coefficient of 0.397 (39.7% of the total precipitation is estimated to runoff the watershed and reach the lake). The large amount of watershed runoff to reach the lake indicates that watershed runoff can have a significant impact on the water quality of Grindstone Lake.

The majority of the water (72.6%) exited Grindstone Lake via the outlet. Evaporation and groundwater seepage accounted for the remainder. Groundwater seepage (1.5%) was determined to be a minor source of outflow.



Grindstone Lake Estimated Inflow
'97 - '98 Water Year



Grindstone Lake Estimated Outflow
'97 '98 Water Year

Figure 41

Estimated Grindstone Lake Hydrologic Budget

4.6 Phosphorus Budget and Lake Water Quality Mass Balance Model

The phosphorus budget modeling indicated that the total annual phosphorus loading to Grindstone Lake was 3,758 pounds per year, based on 1997-98 data. The results of the phosphorus loading budget are presented in Figures 40 and 41. Grindstone Creek contributed the largest amount of phosphorus (1,161 lbs or 30.9%). A high volume of low phosphorus water is discharged from the creek on a year round basis, which results in the significant loading to the lake. The next largest phosphorus source to the lake is from atmospheric (aerial) deposition. By applying a wet and dry atmospheric deposition rate of 0.25 lbs/acre/yr to the surface of Grindstone Lake, the atmospheric component of the phosphorus loading is computed to be nearly 778 lbs or 20.7%. Agricultural land uses which include row crop, mixed agriculture, and pasture/grassland comprise the next largest loading to the lake of 598 lbs or 15.9%. The computations reveal that septic systems and residential use comprise nearly three percent (120 lbs) and thirteen percent (494 pounds) of the annual load respectively. Wetlands are estimated to comprise 1.8% (68 lbs) and the forested portion of the watershed contributes nearly 500 lbs of phosphorus which is 13.3% of the loading. Cranberry bogs are estimated to contribute approximately 13 pounds (0.4%) and internal loading comprises 0.7% or 26 lbs.

Grindstone Lake 1998 Phosphorus Loading (lbs)

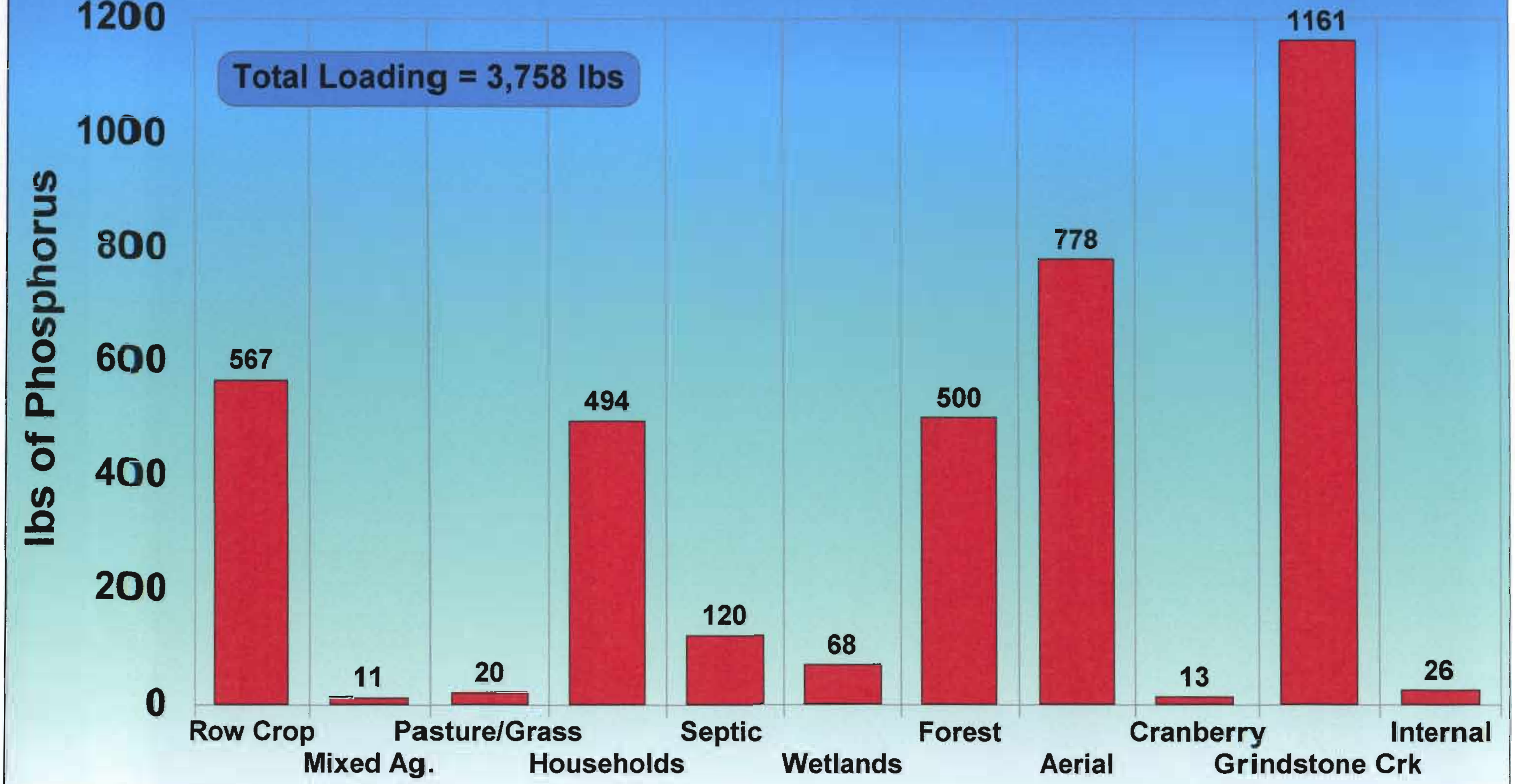


Figure 42

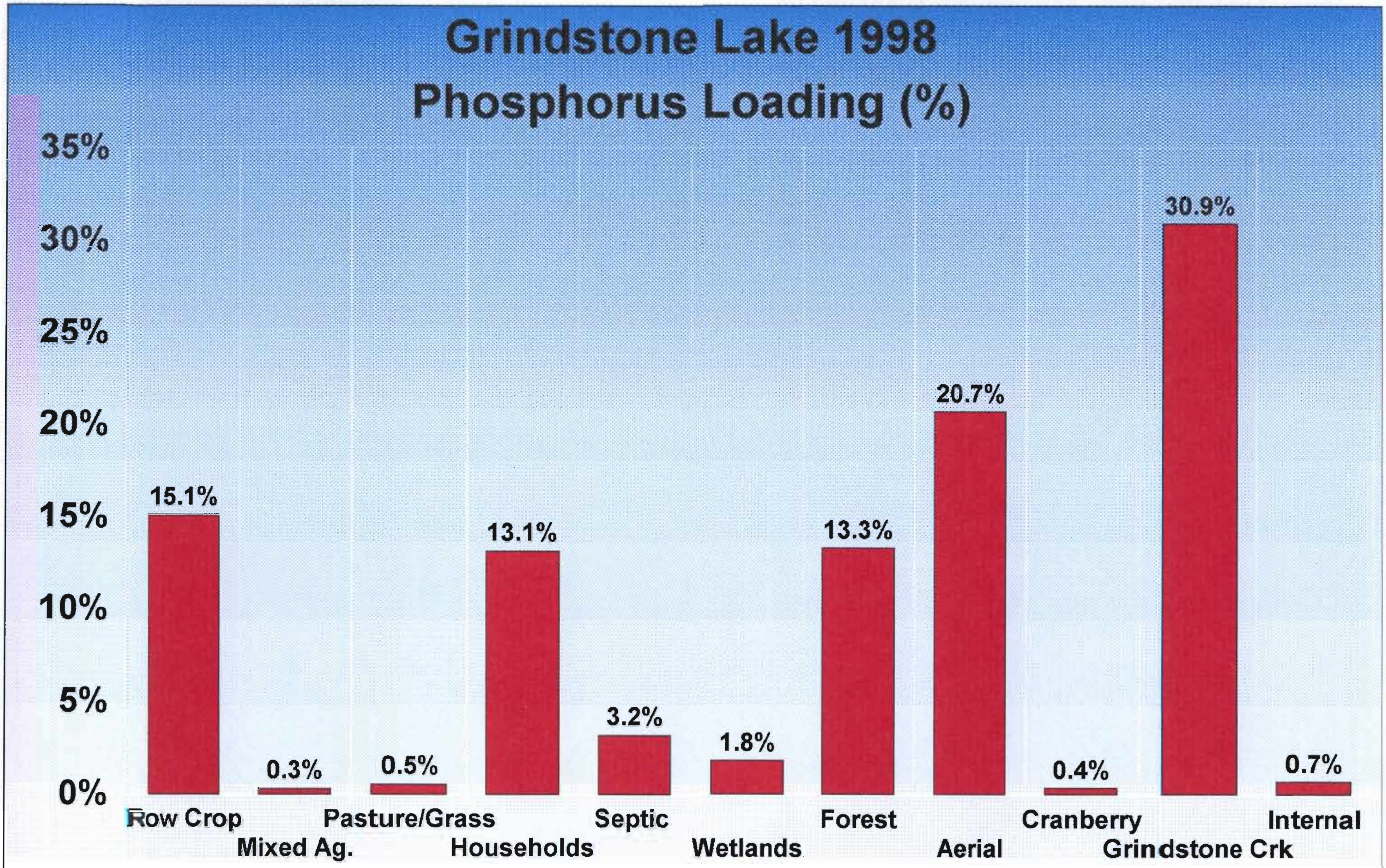

Grindstone Lake 1998
Phosphorus Loading (%)
35%
30%
25%
20%
15%
10%
5%
0%
15.1%
0.3%
0.5%
13.1%
3.2%
1.8%
13.3%
20.7%
0.4%
30.9%
0.7%
Row Crop
Mixed Ag.
Pasture/Grass
Households
Septic
Wetlands
Forest
Aerial
Cranberry
Grindstone Crk
Internal

Figure 43

4.7 Cultural Eutrophication Impacts on Grindstone Lake

All of the land use practices within a lake's watershed impact the lake and determine its water quality. These 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, impacting the lake's water quality differently. Land uses resulting from human activity generally accelerate the natural eutrophication process of a lake. These land uses generally contribute larger quantities of phosphorus to a lake than the natural land uses occurring prior to development. Cultural eutrophication describes the acceleration of the natural eutrophication process caused by human activities. The impacts of cultural eutrophication on Grindstone Lake were evaluated in this study. An assessment of the land uses within the Grindstone Lake watershed indicated that there are three types of land uses resulting from human activity. These land uses are:

1. ***Agriculture***- the phosphorus loading from agricultural land uses includes the row crop, mixed agriculture, and the pasture/grassland land use types (does not include cranberry bogs). The total loading from agriculture is estimated to be 15.9 percent of the total loading.

2. ***Residential*** - residential land is comprised of the households within the watershed and the septic systems located around the lake shore. The total phosphorus loading from residential land use is estimated to be 16.3 percent.

3. ***Cranberry Bog*** - the phosphorus loading from the cranberry farm adjacent to the lake was estimated to comprise approximately 0.4 percent of the total loading.

The impacts of cultural eutrophication on Grindstone Lake were estimated by modeling pre-development in-lake phosphorus concentrations and comparing the estimated pre-development phosphorus concentrations with current phosphorus concentrations (i.e. post-development conditions). Four modeling scenarios were completed to assess the impacts of cultural eutrophication. The four scenarios consisted of the following:

1. Estimating the in-lake phosphorus concentration assuming forested land use (i.e. pre-development condition) instead of agricultural land use (i.e. current or post-development condition).

2. Estimating the in-lake phosphorus concentration assuming forested land use (i.e. pre-development condition) instead of residential land use (i.e. current or post-development condition).

3. Estimating the in-lake phosphorus concentration assuming natural wetlands (i.e. pre-development condition) instead of cranberry farm land use (i.e. current or post-development condition).

4. Estimating the in-lake phosphorus concentration assuming forested land use and natural wetlands (i.e. pre-development conditions) instead of agricultural, residential, and cranberry farm land uses (i.e. current or post-development conditions).

The model indicates that the assumed conversion of forested land use to agricultural land use results in a 2 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of two feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

The model indicates that the assumed conversion of forested land use to residential land use results in a 2 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of two feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

The model indicates that the assumed conversion of natural wetlands to cranberry farm land use results in no change to the total in-lake phosphorus concentration, and consequently there would be no noticeable water quality change.

The model indicates that the assumed conversion of forested land use and natural wetlands to agricultural, residential, and cranberry farm land uses results in a 4 ug/L increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a very noticeable water quality change. The estimated 4 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of 4.6 feet. This is based upon the regression relationship between phosphorus and chlorophyll and the regression relationship between chlorophyll and Secchi disk developed by the Minnesota Pollution Control Agency for phosphorus-limited lakes (Heiskary et al. 1990).

5.0 Recommendations and Management Actions

The development of a comprehensive lake management plan for Grindstone Lake is recommended in order to prevent further degradation of the water quality. This plan should include:

1. The development of a long-term water quality goal for the lake;
2. An evaluation of different watershed development scenarios to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options;
3. Recommendations for ultimate watershed development relative to achieving the lake's water quality goal (i.e. minimum lot size, maximum area of impervious surface, etc.);
4. Recommendations for watershed best management practices under future development conditions;
5. Recommendations for ordinances to control watershed development;
6. Recommendations for the riparian owner management practices;
7. Recommendations for best management plans to protect sensitive lands including wetlands, steep slopes, undeveloped land, shoreline, etc.;
8. Algal study to determine species abundance and distribution;
9. A macrophyte study to determine the spatial coverage, density, and species composition of the macrophyte community. A special area of concern would be identification of Eurasian Water Milfoil;
10. Volunteer monitoring program to record long-term water quality database.

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