1991 Water Quality Study of Nugget Lake (Pierce County, Wisconsin) Wisconsin Lake Management Project

Prepared for
Nugget Lake County Park
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Plum City, WI

With Assistance from:
Nugget Lake County Park
Wisconsin Department of Natural Resources
Pierce County Soil Conservation Service
Pierce County Land Conservation Department

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EXECUTIVE SUMMARY

Nugget Lake was created in 1972 as a flood control structure for Plum Creek. Soon thereafter, the development of a park around the lake made it a popular recreational attraction. However, subsequent sedimentation and water quality problems have changed the lake from an attraction to park visitors to a detriment, turning some visitors away. A 1991 study was completed to define the lake's problems, determine the relative sources of its problems, and provide recommendations to solve its problems.

Study results indicate the water volume of the northern portion of Nugget Lake has been reduced by nearly 40 percent since 1972. Sediment deposition has occurred in this portion of the lake at an annual rate of about 1.76 acre-feet per year. The major portion of this area of the lake is now less than two feet deep.

A water quality assessment of Nugget Lake indicates it is a eutrophic lake. This classification is consistent with its current water quality problems. These include frequent algal blooms, dense weed growths in shallow waters, and a lack of oxygen in the deeper bottom waters. Study results indicate the lake's algal growth is limited by its phosphorus concentration. The primary source of phosphorus during the summer months appears to be runoff from the lake's tributary watershed. However, some recycling of phosphorus from bottom sediments may be occurring in the shallow northern portion of the lake. The water quality study indicates a reduction of phosphorus in stormwater runoff will be necessary to improve the lake's water quality. In addition, a reduction of sediment loading will be necessary to improve the lake's transparency after rainstorms because suspended solids in runoff cause the lake waters to become turbid.

The results of a streambank erosion survey indicate approximately one-third of the lake's sedimentation problem may be due to streambank erosion. Streambank erosion currently encompasses 17 percent of the total length of Plum Creek and 9 percent of the total length of Rock Elm Creek. Sediment loads to Nugget Lake from streambank erosion total about 24,000 cubic feet per year. Comparing current data with data collected in 1978 suggests major increases in streambank erosion have occurred. The data suggest streambank erosion will continue to increase unless stabilization measures are implemented.

The remaining two thirds of the lake's sedimentation problem appears to be due to watershed erosion. Approximately half of the 11,390 acre watershed consists of cropland. Past erosion control efforts have focused on agricultural land conservation practices. At least one form of land conservation is now found in 82 percent of existing cropland. Few structural measures have been implemented. Currently, nine grade stabilization structures control drainage in 5.5 percent of the watershed drainage area.

The results of an assessment of bacteria concentrations indicate feedlots in the tributary watershed are adding animal wastes to Plum Creek and Rock Elm Creek via stormwater runoff. The bacteria are carried to Nugget Lake via the streams. High concentrations are found in the swimming beach area of the lake following rainstorms.

Recommendations to solve the lake's sedimentation and water quality problems focus on changes in the tributary watershed. They include:

- Structural measures to control the rate of runoff, reduce watershed erosion, and remove sediment and nutrients from runoff
- Additional land conservation measures to reduce watershed erosion
- Streambank stabilization measures to reduce the rate of flow and prevent streambank erosion
- Waste management systems to prevent the addition of animal wastes to Plum Creek, Rock Elm Creek, and Nugget Lake via stormwater runoff.

It is also recommended that the northern portion of Nugget Lake be dredged for navigational purposes. A plan should be prepared which details dredging methodology, costs, and funding sources.

INTRODUCTION

Nugget Lake was created in 1972 to alleviate the flooding problems in Plum Creek, located in eastern Pierce County (Wisconsin). Although the 116-acre reservoir was originally created for flood control purposes, a 752-acre park was developed around the lake to provide recreational opportunities to area residents and tourists. In addition, a swimming beach and boat ramp were developed on the lake, and canoe and boat rental provided to park attendees. The steep depth contours of most portions of the lake limited the location of the swimming beach and boat ramp to the northwestern portion of the lake, near the mouth of Plum Creek.

Sediment deposits and water quality problems have changed the lake from an attraction to park visitors to a detriment, turning some visitors away. Since the lake's creation, Plum Creek has brought massive quantities of sediment and nutrients into Nugget Lake. Sediment deposits in the northern portion of the lake have made it too shallow to be used for boating, except within the main stream channel, and have made it an undesirable place to swim. Sediment deposits have also resulted in dense growths of aquatic weeds. Nutrients cause mats of algae in this portion of the lake, and make it an even more undesirable place to swim or boat. Park visitors are unable to see beyond the problematic northern portion of the lake, and are reluctant to boat through it to reach the lake's deeper southern end. Many visitors leave the park, choosing to find recreational opportunities elsewhere.

Reservoirs, such as Nugget Lake, typically have poorer water quality than natural lakes. Their tributary watersheds are generally quite large, and include the tributary watershed of the creek upstream from the reservoir in addition to the tributary watershed of the reservoir itself. The large tributary watershed generally results in high nutrient inputs to the reservoir in relation to its volume (Wetzel, 1975). Because the water quality of a lake is related to its nutrient inputs, high nutrient inputs result in poorer water quality. Reservoirs generally have a shorter lifetime than natural lakes because of the high rates of sediment load delivered by influents (Canfield and Bachman, 1980). An understanding of a typical reservoir is important in assessing the existing water quality of Nugget Lake and in setting realistic goals for water quality improvement.

The following sections of this report discuss the methodology and results of a 1991 study to define the lake's problems, determine the relative sources of its problems, and provide recommendations to make the lake an attractant, rather than a detriment to park visitors. The report focuses on:

- The problem--The rate of sedimentation in the lake and the lake's water quality problems.
- The source of the problem--The tributary watershed and streambank erosion.
- The solution--Recommendations for changes in the lake, its tributary watershed, and streambank stabilization.

METHODS

The 1991 study of Nugget Lake involved surveys to define the lake's problems (i.e., sedimentation and water quality) and evaluations to determine the sources of the problem (i.e., streambank erosion and the tributary watershed). The methods used for the study are discussed in the following sections of this report.

Determination of the Rate of Sediment Deposition

A survey was conducted to determine the average annual sedimentation rate of Nugget Lake. The survey, completed on December 10, 1991, involved the determination of lake depths throughout the northern portion of Nugget Lake. Standard survey techniques were used to establish perpendicular transects at 100-foot intervals, thus establishing approximately 90 sample locations (Figure 1). At each location, the depth of water (including ice) was recorded. The information was then used to determine a current bathymetric map (depth contour map) of the northern portion of Nugget Lake.

A change in water volume over time was used to determine the average annual sedimentation rate of Nugget Lake. The water volumes of the northern portion of the lake during 1972 and 1991 were determined from bathymetric maps. The difference in volumes was caused by the addition of sediments to this portion of the lake. Therefore, the water volume difference was also a measurement of the volume of sediment deposited in the lake. The volume of sediment was divided by the 19 years over which deposition occurred to obtain the average annual sedimentation rate of Nugget Lake.

Water Quality Survey of Nugget Lake

A water quality survey of Nugget Lake was completed during the summer of 1991 to evaluate its water quality problems. Summer data were collected because the lake's summer water quality is typically poorest, while public use of the park and lake are highest. The collection of summer samples was scheduled to coincide with the lake's period of elevated biological activity (i.e., heaviest algal blooms). Collection occurred twice each month at Station 4 (the south end of the lake) and once a month at Station 3 (the north end of the lake). Station locations are shown in Figure 2.

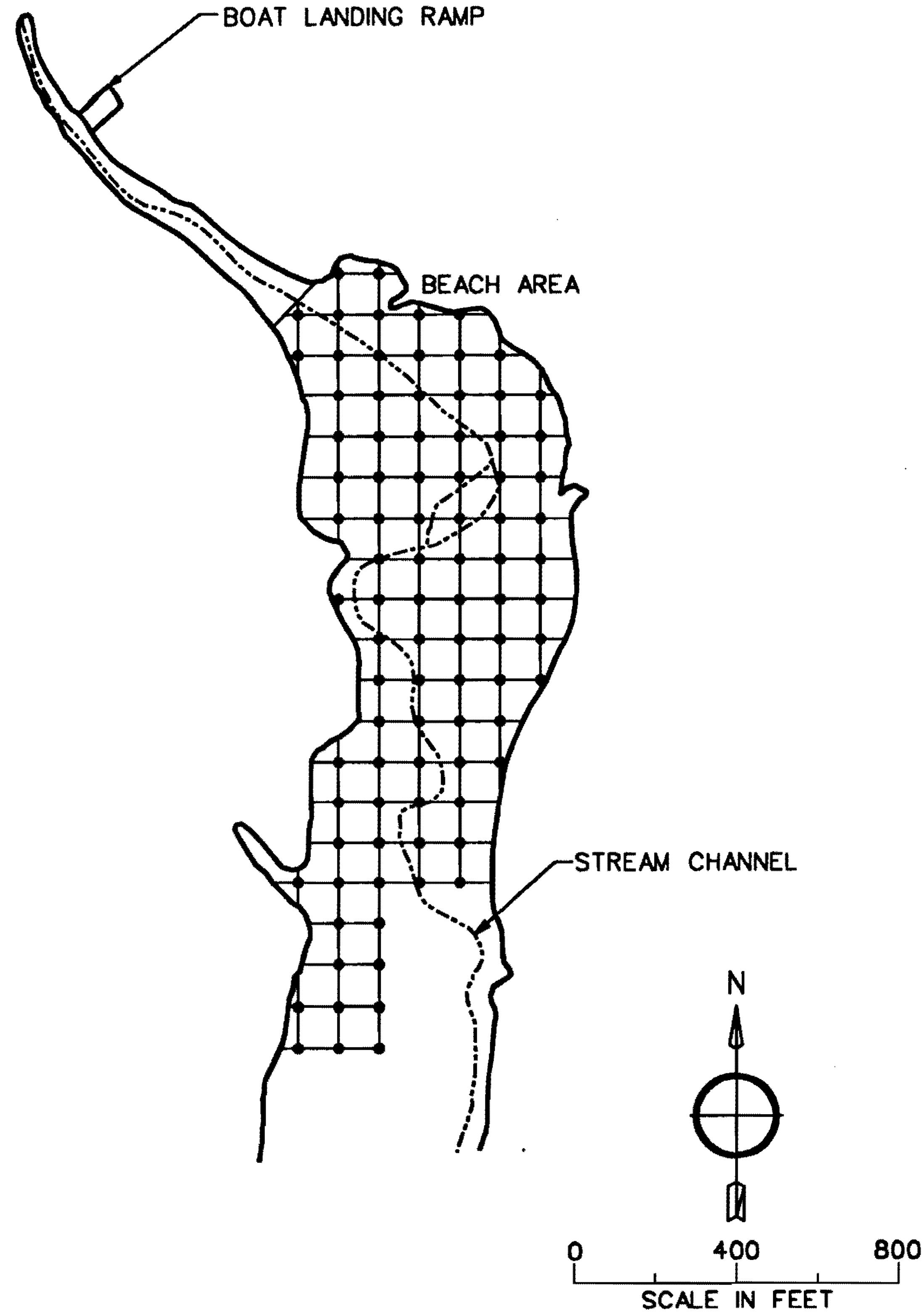

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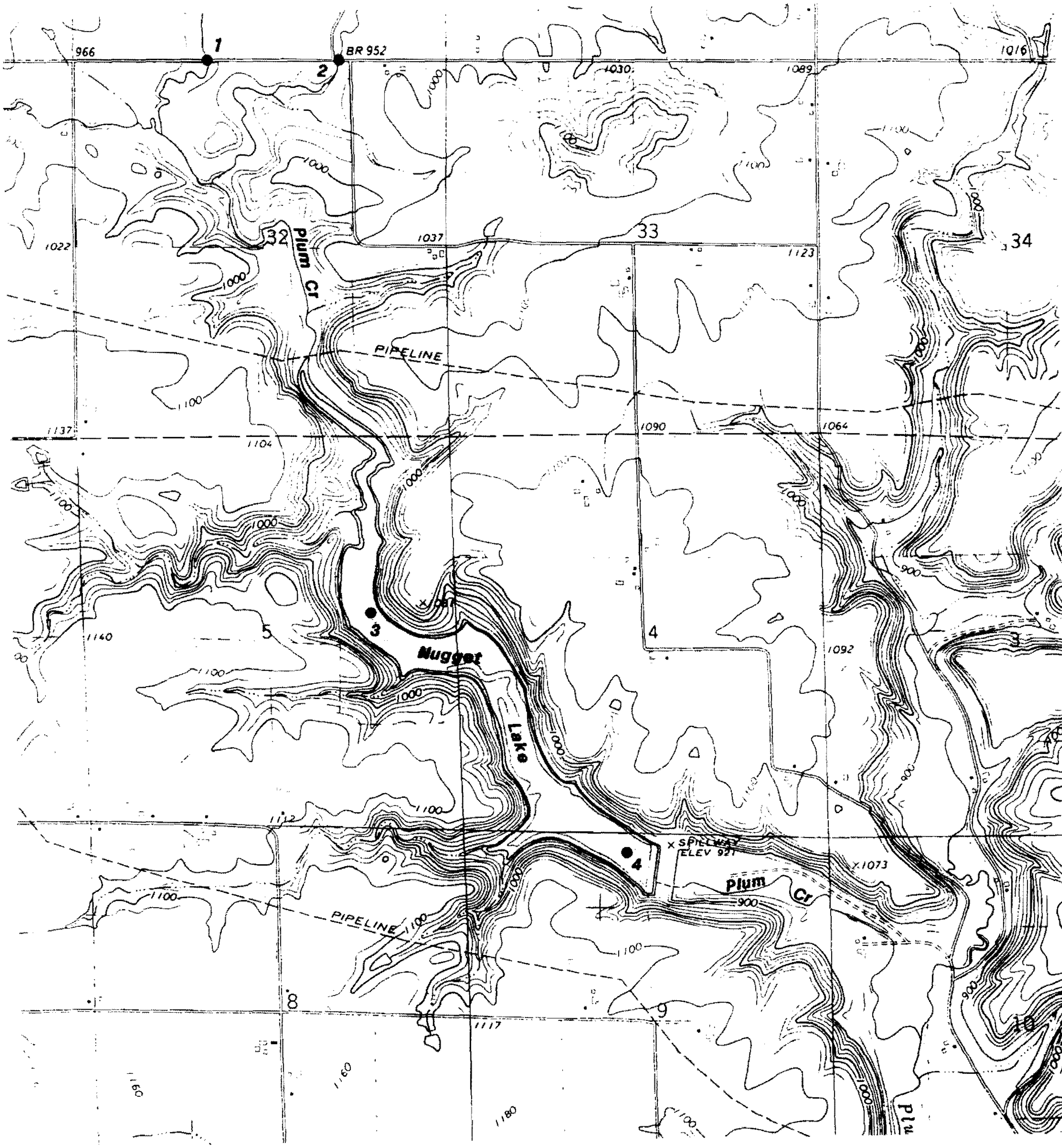
FIGURE 1
1991 SAMPLE LOCATIONS TO DETERMINE RATE OF SEDIMENT DEPOSITION IN NUGGET LAKE.



N

0 2000 4000

Scale in Feet

Figure 2

WATER QUALITY STATION LOCATIONS FOR
NUGGET LAKE MANAGEMENT PLANNING PROJECT

During June through August, the following monthly samples were collected from Station 4.

- A 0 to 2-meter integrated, epilimnetic (surface) composite sample was collected and analyzed for total and soluble reactive phosphorus.
- The surface sample was also analyzed for nitrite + nitrate, ammonia, and total Kjeldahl nitrogen; and pH.
- Lake samples collected from the upper mixing zone were also analyzed for chlorophyll a.
- On one sample occasion, samples were analyzed for total alkalinity.
- A near-bottom sample (one-half meter off the bottom) and samples from the thermocline (whenever/wherever it existed) were collected and analyzed for total phosphorus concentrations only.
- A near-bottom sample was also collected and analyzed for ammonia and pH.
- Water temperature, specific conductance, and dissolved oxygen concentrations were determined in the field along a profile at depth intervals of 1 meter.
- The limits of Secchi disc visibility were measured on each sampling date as an indicator of water transparency.

Additional samples were collected from Stations 3 and 4 approximately monthly during July through October. Sample collection from Station 4 was coordinated with the above program to insure twice a month collection during the summer. Samples were analyzed for the following parameters:

- Water temperature, pH, and dissolved oxygen concentrations were measured along a profile at depth intervals of 3 feet (0.9 meters)
- Surface and near bottom samples were analyzed for phosphorus

- Surface samples were also analyzed for chlorophyll a

- Secchi disc was measured to indicate water transparency

These samples were collected by the Nugget Lake County Park staff as a part of the 1991 Wisconsin Self Help Lake Monitoring Program. A similar collection program occurred in 1990.

During both 1990 and 1991, Secchi disc measurements were made more often than the above sampling frequency to more closely monitor changes in the water transparency of Nugget Lake. 1990 measurements occurred biweekly from early May through early November. 1991 measurements were more frequent, occurring monthly during April and May, and weekly during June through mid-October.

Evaluation of the Tributary Watershed

The watershed tributary to Nugget Lake was evaluated to determine the relative source of the lake's sediment and water quality problems. The evaluation consisted of the following components:

- Streambank Erosion Evaluation
- Watershed Evaluation
- Bacteria Assessment

Streambank Erosion Evaluation

An evaluation of streambank erosion was completed to determine the relative source of the sediment yield problem to Nugget Lake. The major areas of streambank erosion were identified during a walk along the entire length of Plum Creek (from its source to Nugget Lake) and Rock Elm Creek (from its source to its junction with Plum Creek). The survey was completed during the fall of 1991 (late September through early October).

The method used for the streambank erosion evaluation was developed by the Wisconsin Department of Natural Resources, and is very similar to the method used by the Soil Conservation Service. Briefly, each major erosion area was identified and the following information determined:

- Its location on the stream--left bank, right bank, or both
- Whether the site was eroding, trampled, or slumping
- The length of the site
- The average height of the bank
- The lateral recession rate
- The land use within 1 to 2 rods of the stream
- Whether cattle have access to the stream
- Identification of two practices to reduce erosion at the site (i.e., streambank fencing, shaping and seeding, riprapping, and cattle or machine stream crossing)

The above information was recorded on field sheets and the location of each major erosion area was indicated on an air photo of the stream.

The data from the survey were then used to determine the percent of the total stream length experiencing major erosion problems. The annual sediment yield from streambank erosion was also determined. This yield was compared to the lake's average annual sedimentation rate to determine the role of streambank erosion in the lake's sedimentation problem.

Watershed Evaluation

Land use, cropping information, and current conservation measures were evaluated by the Pierce County Soil Conservation Service and the Pierce County Land Conservation Department. A variety of sources were used to obtain information for the evaluation, including:

- Aerial photos
- Plat book information
- CRP plans
- Farm conservation plans
- The use of a planimeter

Bacteria Assessment

A bacteria assessment of Plum Creek, Rock Elm Creek, and Nugget Lake was completed to evaluate runoff contributions of feedlots in the watershed tributary to Nugget Lake. 1991 stream samples were collected from Station 1, located on Plum Creek and from Station 2, located on Rock Elm Creek. Both locations were located approximately ½ mile upstream from Nugget Lake (Figure 2). Samples were collected by Nugget Lake County Park staff during the summer months. Sample collection occurred on five occasions:

- Two occasions shortly after rainstorms
- Three occasions during base flow conditions

All samples were shipped to the Wisconsin State Lab of Hygiene and analyzed for fecal coliform bacteria and fecal streptoccus bacteria.

Samples were also collected from the swimming beach portion of Nugget Lake to evaluate the effect of watershed feedlot contributions on the lake's water quality. Summer samples were collected by Nugget Lake County Park staff during 1990 and 1991. Collection occurred on six occasions during July through September, 1990, and on eight occasions during July through September, 1991. All samples were shipped to the Wisconsin State Lab of Hygiene and analyzed for fecal coliform bacteria.

RESULTS AND DISCUSSION

Reservoirs, such as Nugget Lake, generally have a shorter lifetime than natural lakes because of the high rates of sediment load delivered to them. They fill in gradually with sediment from upland, streambank, and stream channel erosion. Agricultural practices and numerous other land use activities in the lake's tributary watershed further accelerate this filling process.

Nugget Lake and other similar reservoirs are especially vulnerable to sedimentation because the ratio of their watershed area to their lake surface area is very large. A large ratio means nutrient and sediment loading rates from the watershed will be high relative to the size of the lake. The watershed area-to-lake surface area ratio for Nugget Lake is approximately 100:1. This ratio is much higher than those of natural lakes, which are often less than 20:1.

High nutrient and sediment loading to Nugget Lake and other impoundments result in differences in aquatic life than are typically found in natural lakes and streams. The combination of nutrient-rich sediment loading from the tributary watershed and fertile lake sediments provide the potential for nuisance-level plant growth. An overabundance of algae, duckweed, and/or macrophytes (rooted aquatic plants) are common symptoms of reservoir eutrophication. The type and abundance of plant growth is affected by water temperature, light penetration, and sediment type. The distribution of rooted plants may also be affected by water clarity and sedimentation. Excessive turbidity and/or algal growth may reduce light penetration and thereby limit macrophyte growth to the shallowest areas of the lake. Emergent and submergent rooted plants may be prolific in these areas and become more prevalent as the reservoir fills with nutrient-rich sediments.

Sedimentation not only affects a lake's plant growth, but also adversely affects the diversity and reproduction of its desirable aquatic organisms. Sediment degradation of game fish habitat and spawning areas can lead to rough or forage fish domination. Through feeding and excretory activities, large numbers of rough fish can contribute significantly to turbidity and nutrient release from soft sediments.

Nugget Lake is currently experiencing sedimentation and water quality problems similar to those described in the preceding paragraphs. The results of a 1991 study to define the lake's problems and determine the relative sources of its problems are presented in the following sections of this report.

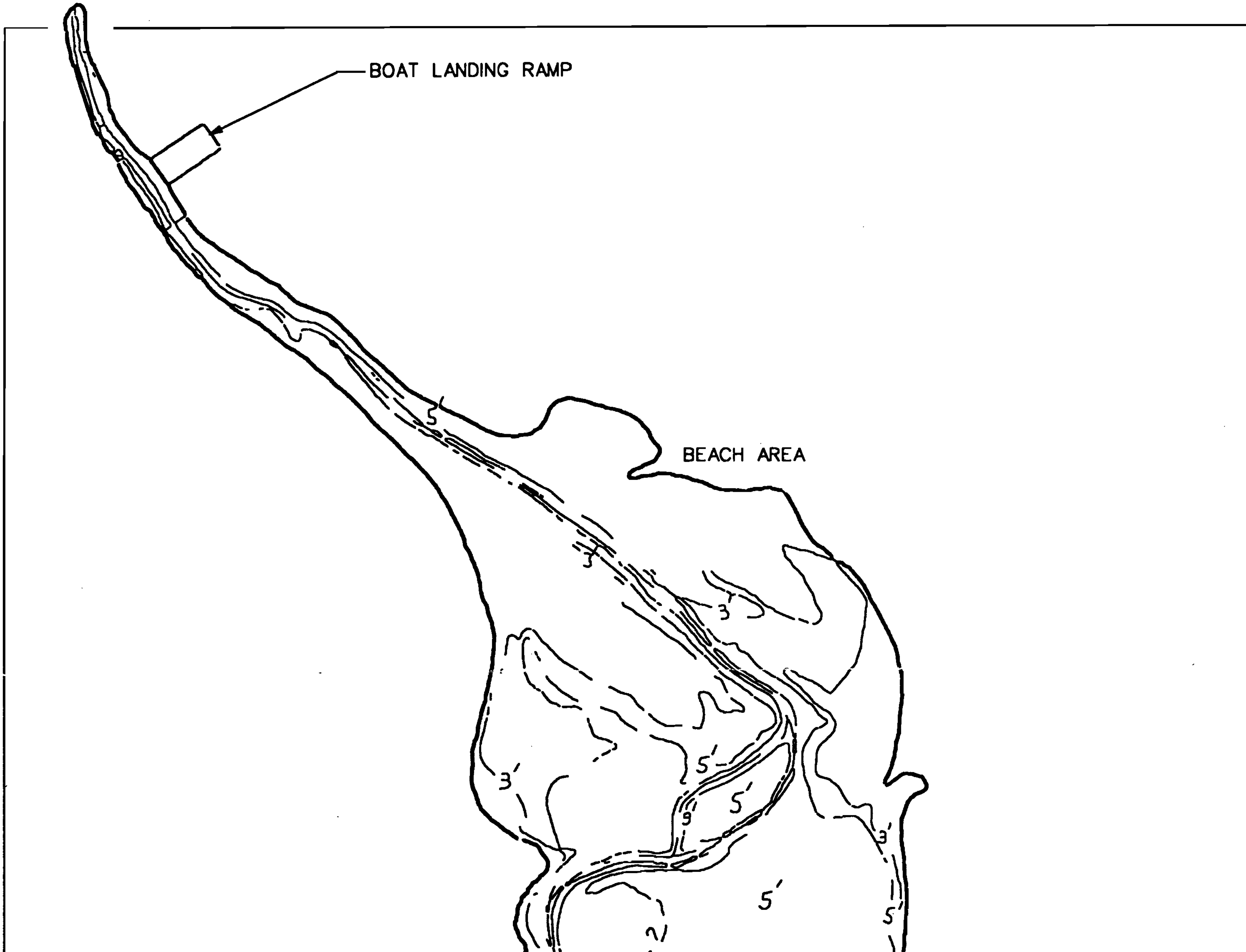
Determination of the Rate of Sediment Deposition

A survey was completed to determine the rate of sediment deposition in Nugget Lake. The results indicate massive loads of sediment have been delivered to the lake since its creation in 1972. The deposits have significantly reduced lake depths. According to a 1972 bathymetric map of the lake (Figure 3), depths in the northern portion ranged from three to seven feet. The map shows that nearly the entire northern portion was at least five feet deep in 1972. In contrast, the major portion of this area was less than two feet deep in 1991 (Figures 4 and 5).

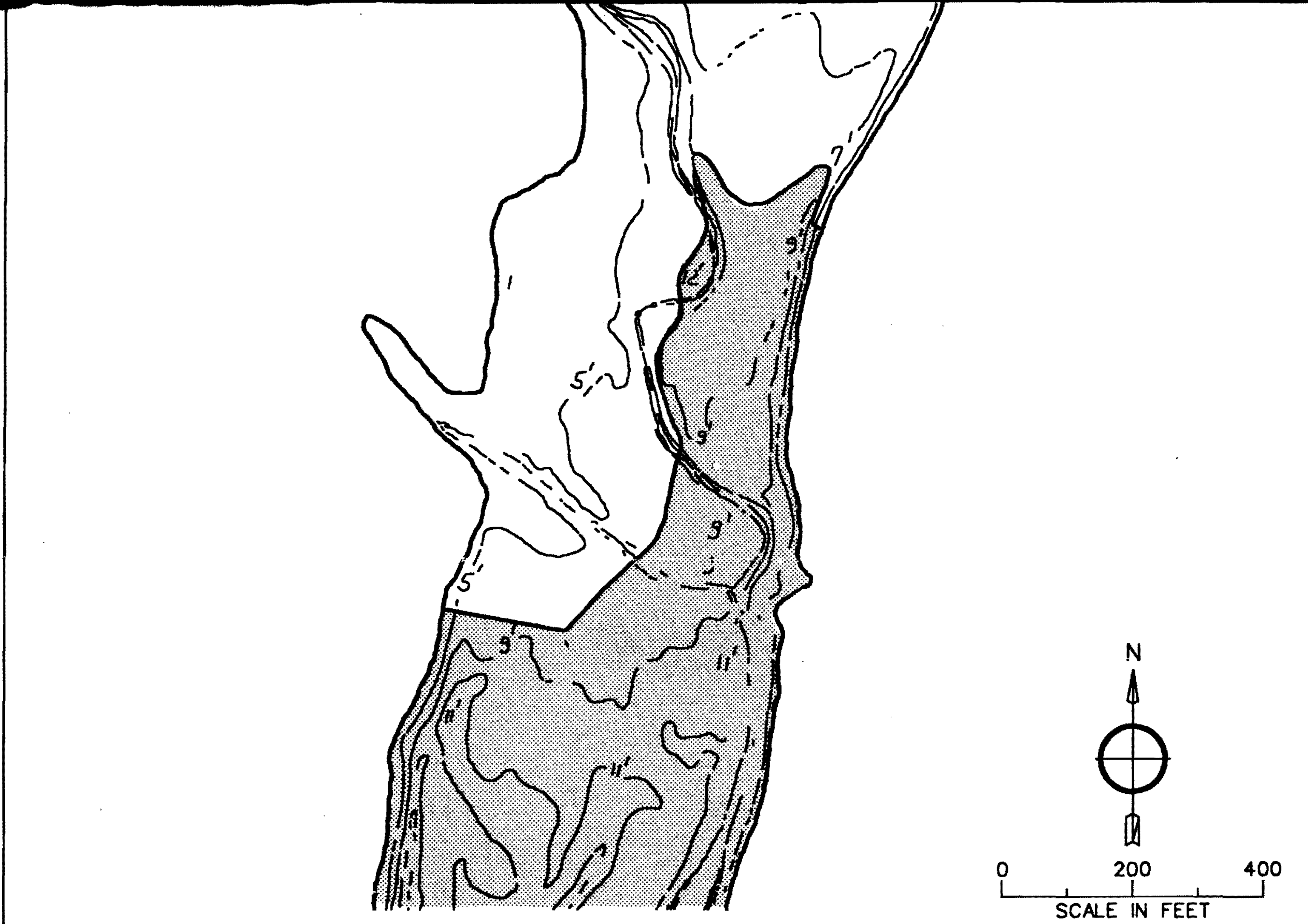
Sediment deposits in this portion of the lake have reduced its water volume by nearly 40 percent during the period 1972 through 1991. The water volume of the northern portion of the lake was 90 acre-feet in 1972 (Figure 3). By 1991, sediment deposits had reduced this volume to 57 acre-feet (Figure 5). The difference in volumes (i.e., 33 acre-feet) is the volume of sediment deposited in the lake during the 19-year period. At the time of the 1991 survey, the lake level was normal and similar to the 1972 level. Data from 1972 and 1991 are, therefore, directly comparable.

Sediment has been deposited in the northern portion of Nugget Lake at a rate of approximately 1.76 acre-feet per year since the lake's creation in 1972 (Figure 6). The rate was determined from the difference in water volumes during 1972 and 1991 (i.e., 33 acre-feet). This difference was divided by the time period in which deposition occurred (i.e., 19 years). This rate is approximately 4 times higher than the sedimentation rate of Neshonoc Lake, a reservoir in La Crosse County (Wisconsin). If this high rate of sediment deposition continues, the northern portion of Nugget Lake will be completely filled with sediment in approximately 32 years.

The shallow depths throughout the northern portion of Nugget Lake currently prevent boating in this portion of the lake, except within the narrow stream channel. In addition, swimming is undesirable because of the shallow depths and sediment deposits. Current conditions, therefore, make this area of the lake undesirable to park visitors. As a result, many visitors leave the park to find recreational opportunities elsewhere. The additional sediment deposits occurring in subsequent years will exacerbate the lake's existing problems, and further reduce park attendance.



BOAT LANDING RAMP
BEACH AREA
5'
3'
3'
3'
5'
5'
3'
5'
5'



SURFACE AREA: 20.70 Acres
LAKE VOLUME: 90 ACRE - FEET

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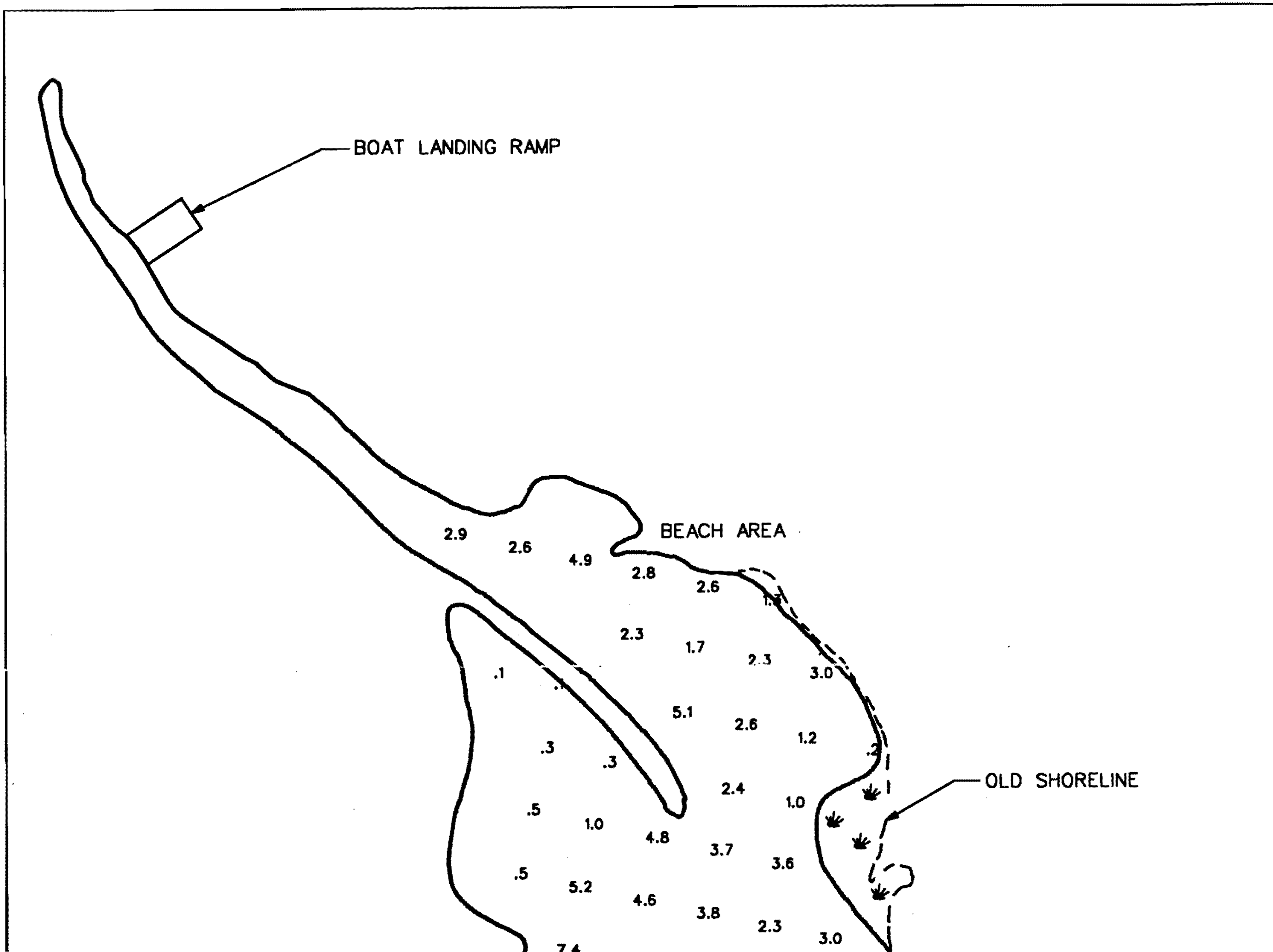
FIGURE 3
1972 NUGGET LAKE BATHYMETRIC MAP
OF SURVEYED AREA


BOAT LANDING RAMP
BEACH AREA
OLD SHORELINE
2.9
2.6
4.9
2.8
2.6
2.3
1.7
2.3
3.0
.1
5.1
2.6
1.2
.3
.3
2.4
1.0
.5
1.0
4.8
3.7
3.6
.5
5.2
4.6
3.8
2.3
3.0

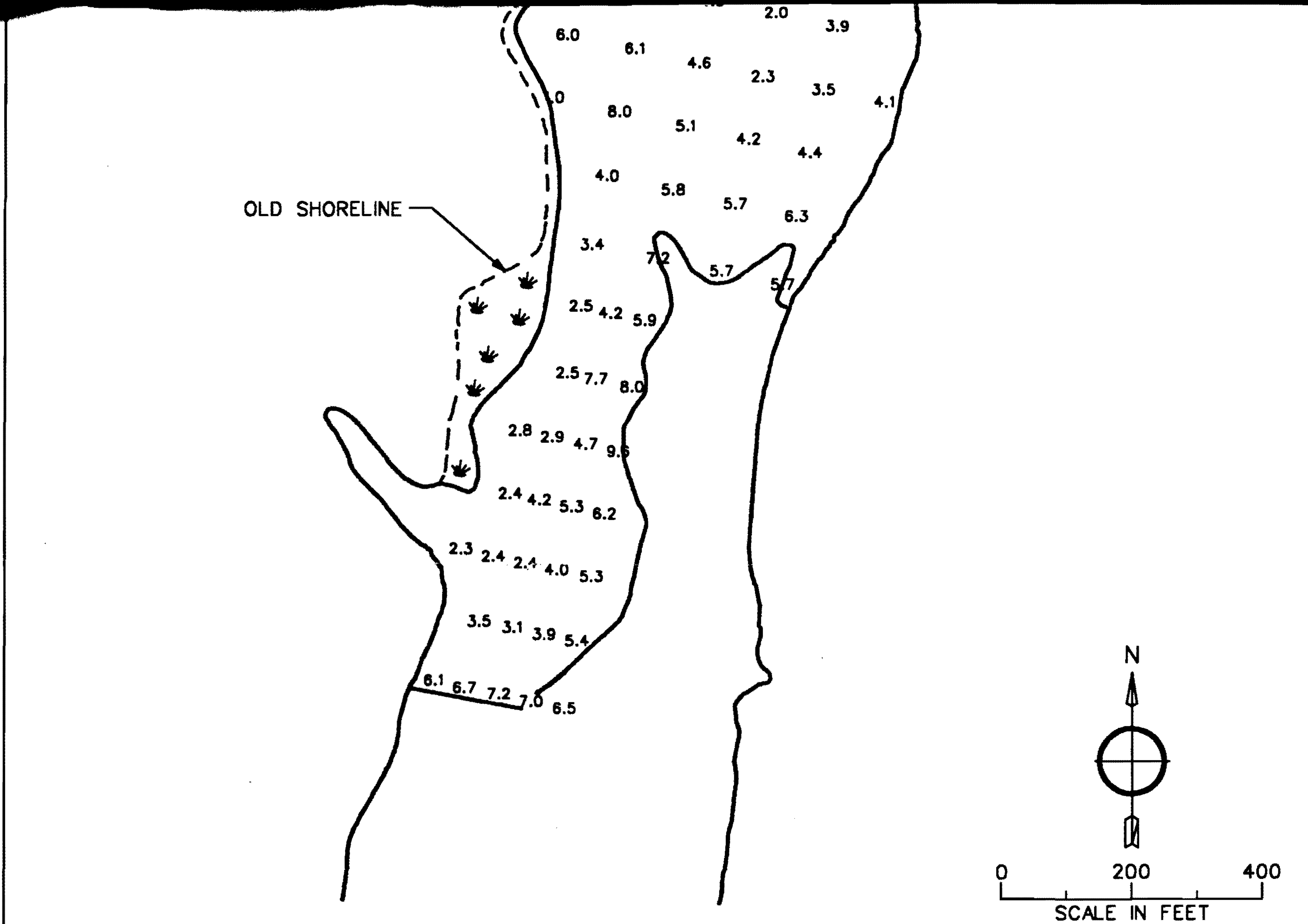


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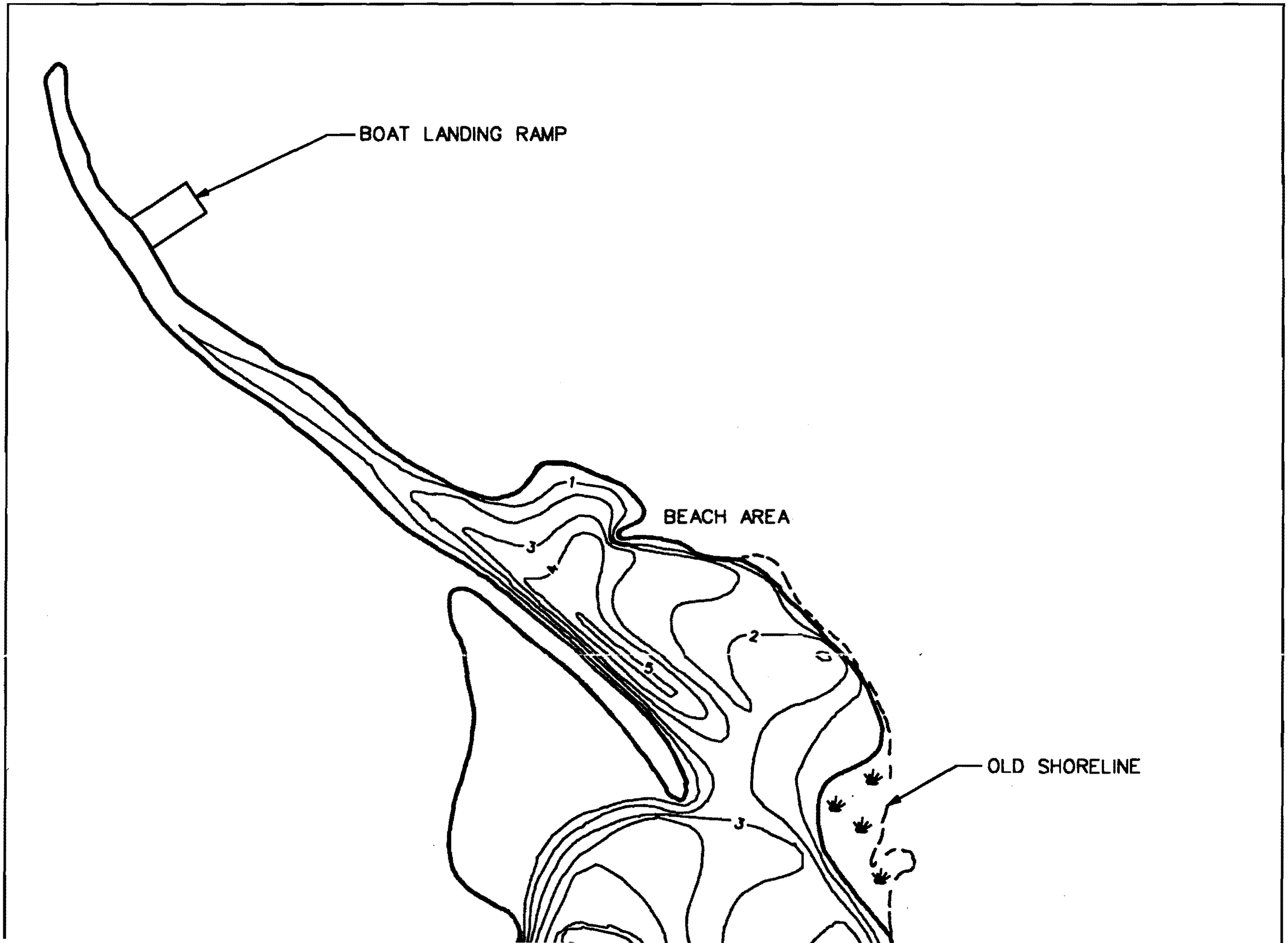
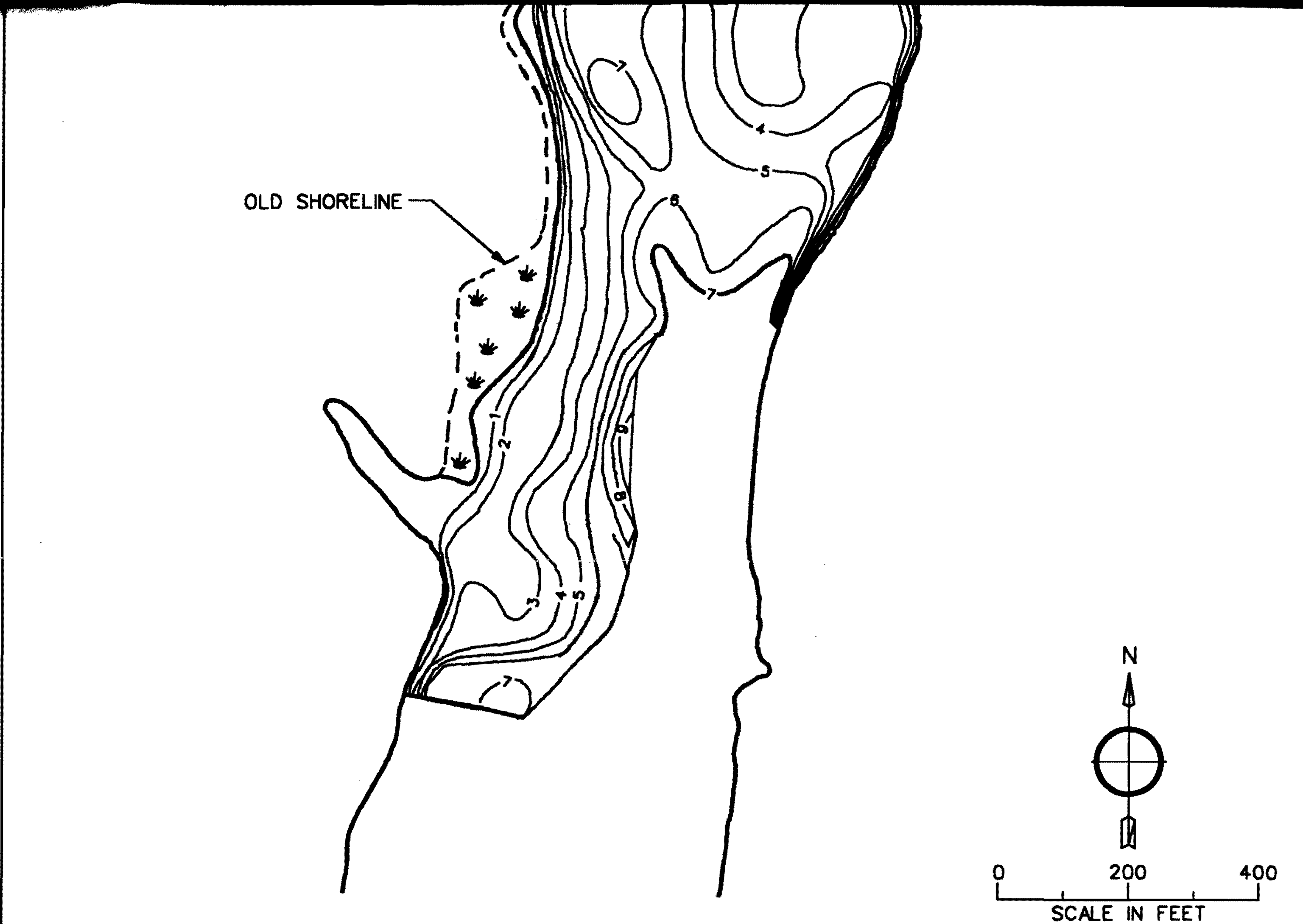
FIGURE 4

1991 LAKE DEPTH MEASUREMENTS


BOAT LANDING RAMP
BEACH AREA
OLD SHORELINE
1
2
3
4
5
3



SURFACE AREA: 18.88 Acres
LAKE VOLUME: 57 ACRE - FEET

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FIGURE 5
1991 NUGGET LAKE BATHYMETRIC MAP
OF SURVEYED AREA

AVERAGE ANNUAL SEDIMENT DEPOSITION RATE IN THE NORTHERN PORTION OF NUGGET LAKE

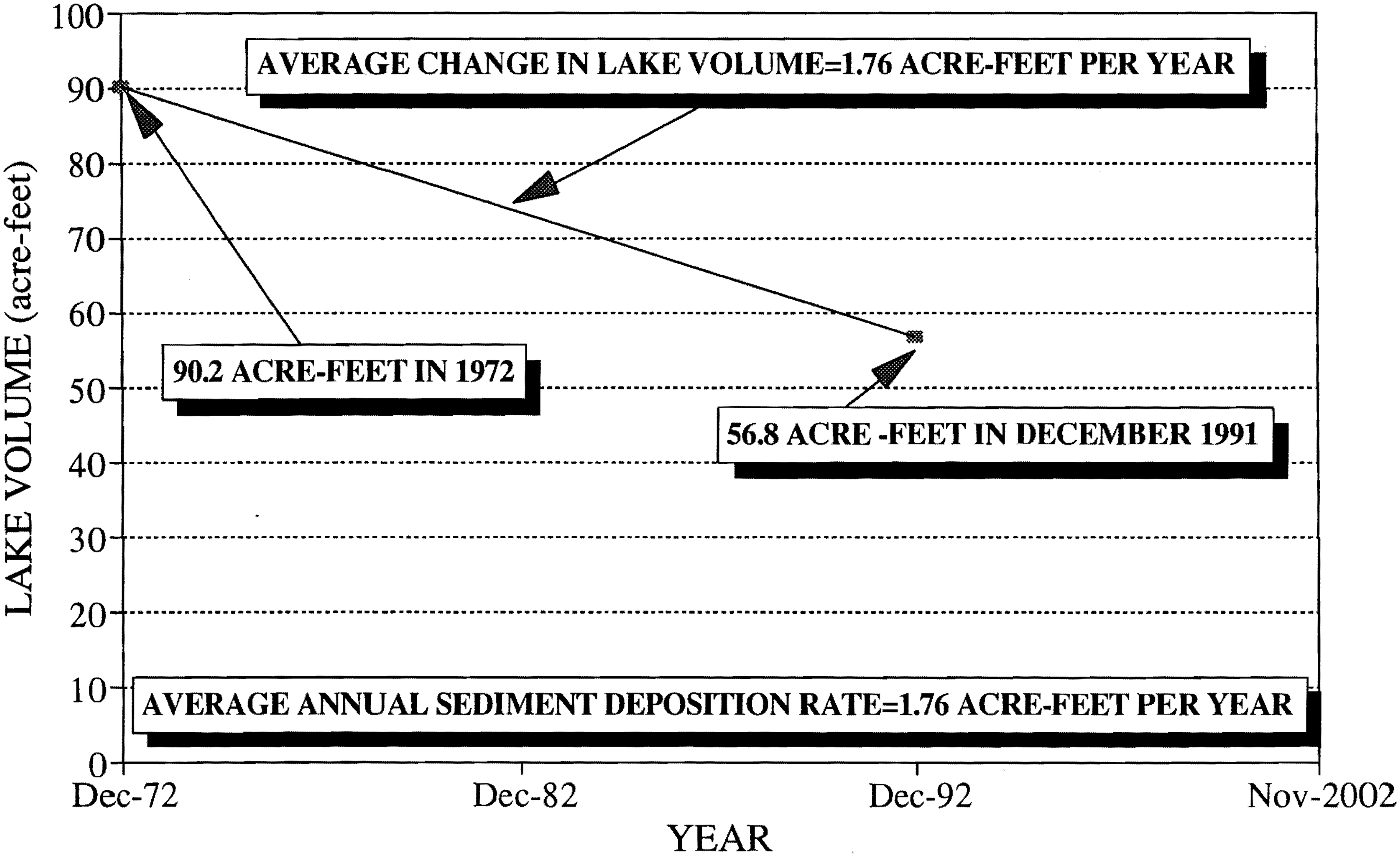

FIGURE 6

Water Quality Survey of Nugget Lake

A summer survey was completed in 1991 to evaluate the water quality problems of Nugget Lake. The lake's water quality problems were defined by evaluating its level of eutrophication (i.e., degradation). The structure of the lake was then evaluated to determine the primary source of the lake's nutrient load.

The study results are detailed in the following sections of this report:

- Eutrophication
- The Limiting Nutrient
- Structure of Lakes and Ponds
- Nugget Lake Water Quality

Eutrophication

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

The process of eutrophication is natural and results from the environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. This acceleration may result from point-source nutrient loadings, such as effluent from wastewater treatment plants and septic tanks. It may also be caused by diffuse (i.e., non-point) sources of nutrients and sediments, such as stormwater runoff. Eutrophication in Nugget Lake is caused by non-point source pollutants. Nutrients and sediments are added to the lake via runoff from its agricultural watershed. The accelerated rate of water quality degradation caused by these pollutants has resulted in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or rooted aquatic weeds (macrophytes).

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

1. Oligotrophic
2. Mesotrophic
3. Eutrophic
4. Hypertrophic

Oligotrophic (Greek for "food-poor") describes a water body with few nutrients, and a clear or pristine appearance. Mesotrophic describes a water body that is moderately nourished, and has an appearance midway between an oligotrophic and eutrophic lake. Eutrophic (Greek for "food-rich") describes a water body, such as Nugget Lake, that is rich in nutrients. Significant weed growth and green and/or murky colored water from algal blooms and sediment are generally found in eutrophic water bodies. Hypertrophic describes a water body extremely rich in nutrients. Such water bodies experience heavy algal blooms and/or very dense weed growths all summer.

The Limiting Nutrient

The determination of the eutrophication stage of Nugget lake (i.e., its stage of degradation) is an important aspect of the diagnosis of its problem. Eutrophication indicates the severity of its algal problems and the degree of change needed to meet its recreational goals. However, it does not indicate the cause of algal growth, or a means of reducing such growth.

The quantity or biomass of algae in a lake or pond is usually limited by the concentration of an essential element or nutrient (the "limiting nutrient" concept). Aquatic weeds, on the other hand, derive most of their nutrients from lake or pond sediments. The limiting nutrient concept is a widely applied principle in the study of eutrophication. It is based on the concept that, in considering all of the substances needed for biological growth, one will be present in limited quantity and will be the "limiting" nutrient, thereby controlling the rate of biological growth. This is an oversimplification, but serves to point out the importance of nutrient concentrations in determining biological growth. The identification of a lake's limiting nutrient will point the way toward a solution to its algal problems.

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content of both water and algae provides ratios of N:P that tend to indicate whether one or the other of these elements is growth-limiting. These ratios are based on the average elemental composition of algae. An average stoichiometric formula for algae is $C_{106}H_{181}O_{16}P$. By comparing the tissue concentrations of important nutrients in algae to the concentrations of the same nutrients in the ambient waters, one can estimate whether a particular nutrient may be limiting.

Algal growth is generally phosphorus-limited in waters with N:P ratios greater than 12. It has been amply demonstrated, in experiments ranging from laboratory bioassays to fertilization of in-situ enclosures to whole-lake experiments, that most often phosphorus is the nutrient that limits algal growth. Nugget Lake N:P ratios ranged from 15 to 35 during the 1991 summer sampling dates (summer average of 28). Therefore, algal abundance is phosphorus-dependent. Reductions of phosphorus concentrations in Nugget Lake will be necessary 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.

Structure of Lakes and Ponds

The realization that the solution to Nugget Lake's eutrophication problems must focus on phosphorus reduction is but the first step in the problem solving process. Phosphorus enters lakes and ponds from internal and/or external sources. An understanding of the structure of Nugget Lake helps one determine whether the solution should focus on internal and/or external sources.

Certain physical phenomena occur in Nugget Lake that can profoundly influence its chemistry and biology. Probably the most important phenomenon is thermal stratification. Because water varies in density according to its temperature, lakes and ponds in temperate regions tend to stratify, or form temperature layers, especially during the summer.

Immediately after the ice melts in the spring, the water temperature throughout Nugget Lake is 4°C (~39°F). At this temperature, water is most dense (heaviest). During the spring and summer months, the sun warms the surface layer of the lake causing it to become warmer and less dense (lighter). The warm surface layer of the lake is called the epilimnion. The northern portion of Nugget Lake is very shallow (Figure 7), and the suns rays are able to reach the lake's bottom in most places. During the summer, the water temperature in this portion of the lake is warm, from the lake's surface to its bottom (Figures A-1 to A-7, Appendix A).

The deeper southern portion of Nugget lake (Figure 7) has a structure that differs from its shallow north end. Because sunlight does not reach the bottom of the deeper portions of the lake, these waters remain cool and generally remain around 6°C (~43°F). The cool bottom waters of the lake are heavier than its warm surface waters. Therefore, the warmer, lighter water lays near the surface and the cooler, heavier water lays at the bottom of the lake. The cool water layer of the lake is called the hypolimnion. Between the warm epilimnion and the cool hypolimnion is a transitional layer of water known as the metalimnion. This layer of the lake is characterized by a rapidly-declining temperature. The variation in the water temperature of the south (deep) end of Nugget Lake is known as summer thermal stratification.

The significance of summer thermal stratification in lakes is that the density change in the metalimnion often provides a real physical barrier to water circulation. While water above the metalimnion may circulate as a result of wind action, hypolimnetic waters at the bottom are isolated and do not mix. Consequently, very little transfer of oxygen occurs from the atmosphere to the hypolimnion during the summer. If the lake or pond sediments are rich in organic matter, microbial decomposition and respiration can deplete hypolimnetic waters of their dissolved oxygen. Phosphorus contained in the sediment may then be released into the water column as a result of changes in the oxidation-reduction (REDOX) potential of the system caused by oxygen depletion. Phosphorus will contribute to the growth of algae in surface waters when the lake or pond mixes.

The shallow northern portion of Nugget Lake and other shallow water bodies (generally $\leq$10-foot depth) stratify weakly and may circulate may times during the summer as a result of wind mixing. This frequent mixing is known as polymictic (multiple-mixing). In contrast, the deeper southern end of Nugget Lake and other deep lakes generally circulate only twice each year. This occurs in the spring and fall. Air temperatures during these seasons cause surface waters to warm or cool sufficiently to allow wind-driven circulation to occur, and the lakes mix. Such lakes are designated dimictic (twice mixing). The water columns of all lakes and ponds become isothermal (same temperature) whenever they circulate, and phosphorus is mixed throughout the water column.

Recycling of nutrients from anoxic (devoid of oxygen) sediments to the surface waters of a lake or pond is most often a problem in highly-fertile water bodies. Nugget Lake is a fertile water body and is subject to hypolimnetic oxygen depletion and recycling of phosphorus from its sediments.

The data indicate phosphorus recycled from bottom sediments was added to the surface waters in the shallow (north) end of Nugget Lake. Summer thermal stratification (temperature layers) and anoxic conditions (devoid of oxygen) were not observed in this portion of the lake during 1990 and 1991 sampling events (Figures A-1 to A-7). However, bottom phosphorus concentrations were higher than surface phosphorus concentrations during June and August, 1991 (Table A-1, Appendix A). The data suggest that still conditions (lack of wind) result in brief periods of ephemeral stratification. The bottom waters become anoxic during these periods, and are enriched with phosphorus released from bottom sediments. These waters are then mixed by the wind into the overlying epilimnetic strata, causing their phosphorus concentrations to increase.

This portion of the lake is particularly sensitive to phosphorus additions from its tributary watershed. Phosphorus added to the lake's surface water from external sources is only part of its problem. In addition, watershed sediments deposited in this portion of the lake recycle phosphorus to the surface waters. The combination of external and internal phosphorus additions causes nuisance algal growth. Measures to reduce both internal and external phosphorus loading may be necessary to reduce algal growth in this portion of the lake.

Phosphorus loading in the deep (south) end of Nugget Lake appears to be due to external sources during the summer months. Summer thermal stratification in this portion of the lake isolates its bottom waters from its surface waters (Figures A-8 to A-18, Appendix A). A lack of oxygen exchange between the atmosphere and the bottom waters results in anoxic conditions (devoid of oxygen) in all but the top three meters of the lake throughout the summer. These conditions facilitate phosphorus recycling from bottom sediments, which causes the occurrence of high phosphorus concentrations in its bottom waters. However, because mixing of the bottom and surface waters does not occur until fall, phosphorus rich bottom waters are isolated from the surface during the summer months (Tables A-2 and A-4, Appendix A). Therefore, summer additions of phosphorus to the lake's surface waters appear to be due to phosphorus loading from the tributary watershed. Consequently, efforts to improve the summer water quality of this portion of the lake should be directed toward the reduction of phosphorus loading from the watershed.

The structure of Nugget Lake not only affects the sources of phosphorus loading to its surface waters, but also affects the lake's fish population. Oxygen depletion in the bottom waters of the south (deep) end of Nugget Lake restricts the lake's fish population to its surface waters (upper 10 feet). Game fish require at least 3.5 mg/L dissolved oxygen, and rough fish require at least 2.0 mg/L dissolved oxygen. The lack of oxygen in the bottom portion of Nugget Lake prevents the survival of fish, and restricts them to the surface waters. Cold water fish are unable to tolerate the warm temperature of the surface waters. Therefore, only warm water fish are able to survive in Nugget Lake.

Nugget Lake Water Quality

The North American Lake Management Society (NALMS, 1988) has used Carlson's Trophic State Index to relate the "nutrient status" of a water body to total phosphorus concentrations, chlorophyll a, concentrations, and Secchi disc transparency. The "nutrient status" of a water body indicates its stage of eutrophication (i.e., degradation). Phosphorus is the nutrient that determines algal growth in Nugget Lake, and is considered a key factor in its rate of eutrophication. Chlorophyll a is a measurement of the quantity of algae present in the lake, and Secchi disc transparency is a measurement of water clarity.

Phosphorus, chlorophyll a, and Secchi disc data from Nugget Lake indicate it is a eutrophic lake. Figures 8 to 16 compare the 1990 and 1991 total phosphorus, chlorophyll a, and Secchi disc data from the lake to levels characteristic of each of the trophic status categories. The summer average values were generally within the bounds of the eutrophic category. Based on this comparison, it would be assigned a nutrient status of eutrophic. As discussed earlier, this classification describes a water body that is rich in nutrients and has summer algal blooms. Nugget Lake experiences frequent algal blooms throughout the summer months. Pictures of algal blooms occurring in the northern portion of Nugget Lake during August of 1991 are shown in Figure 17. A eutrophic classification means the lake has undergone significant degradation, and is aging quickly.

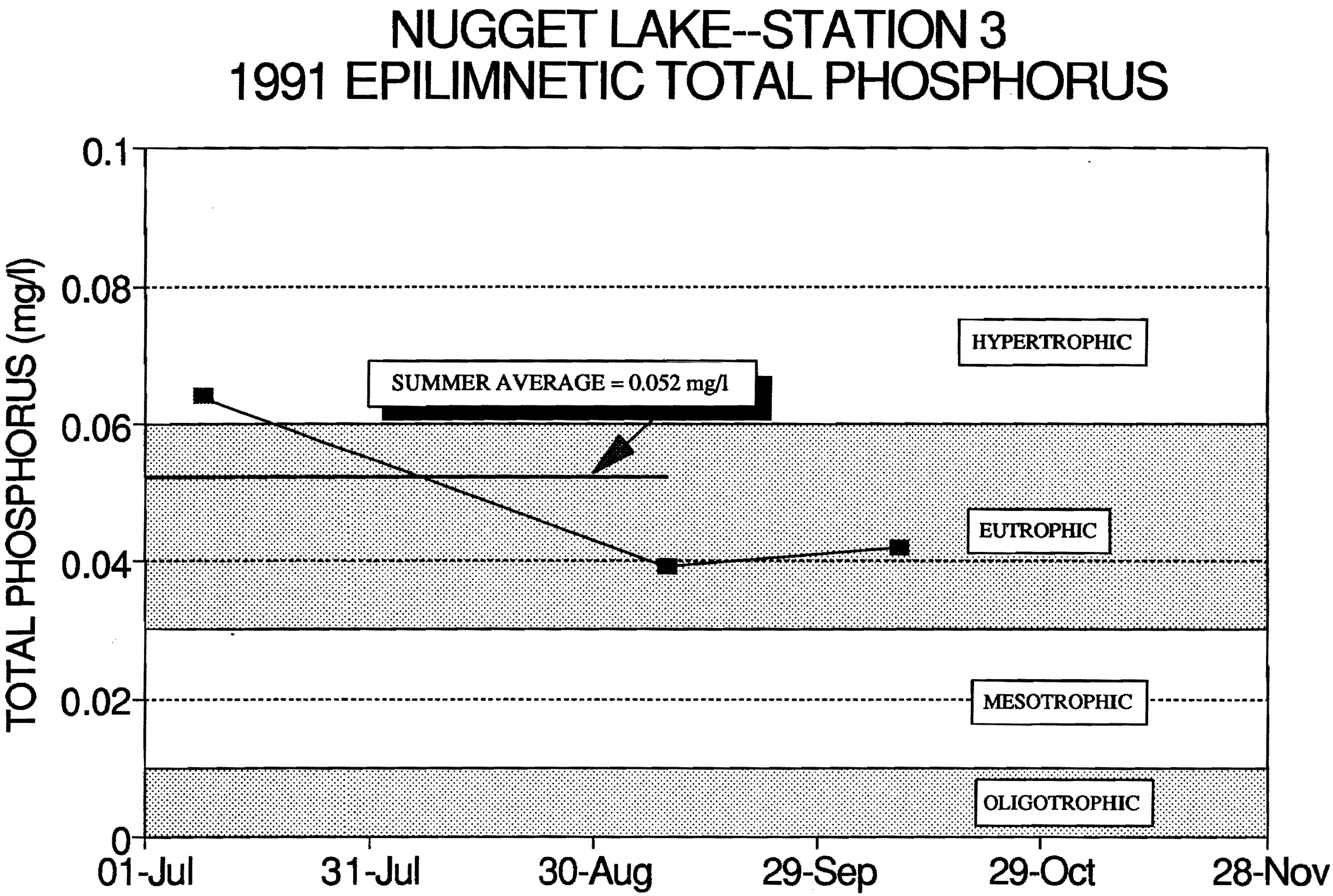
NUGGET LAKE--STATION 3
1991 EPILIMNETIC TOTAL PHOSPHORUS
TOTAL PHOSPHORUS (mg/l)
0.1
0.08
0.06
0.04
0.02
0
01-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov
SUMMER AVERAGE = 0.052 mg/l
HYPERTROPHIC
EUTROPHIC
MESOTROPHIC
OLIGOTROPHIC

Figure 8

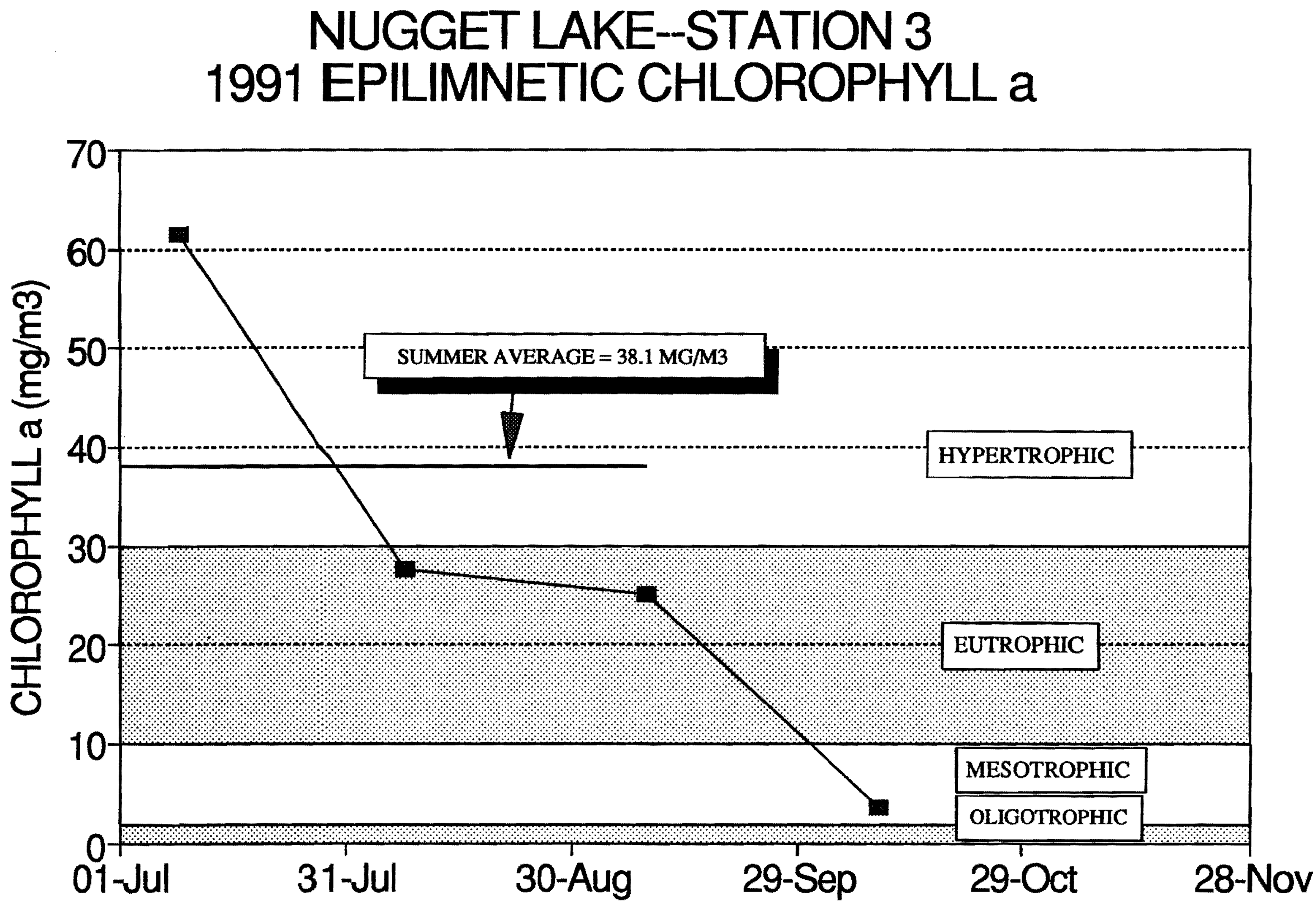
NUGGET LAKE--STATION 3
1991 EPILIMNETIC CHLOROPHYLL a
CHLOROPHYLL a (mg/m3)
70
60
50
40
30
20
10
0
01-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov
SUMMER AVERAGE = 38.1 MG/M3
HYPERTROPHIC
EUTROPHIC
MESOTROPHIC
OLIGOTROPHIC

Figure 9

NUGGET LAKE--STATION 3

1991 SECCHI DISC TRANSPARENCIES

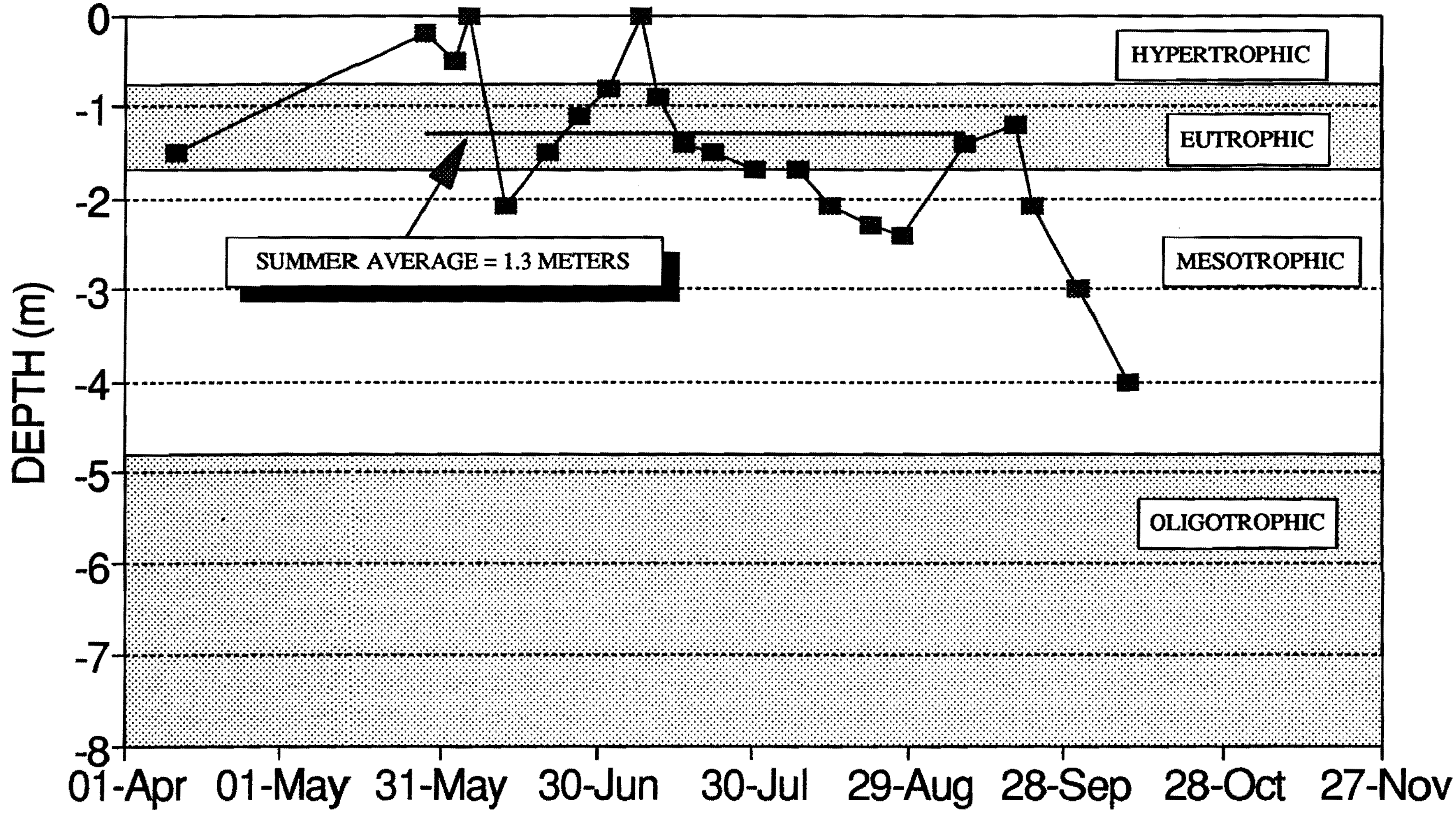

Figure 10

NUGGET LAKE--STATION 3
1990 SECCHI DISC TRANSPARENCIES

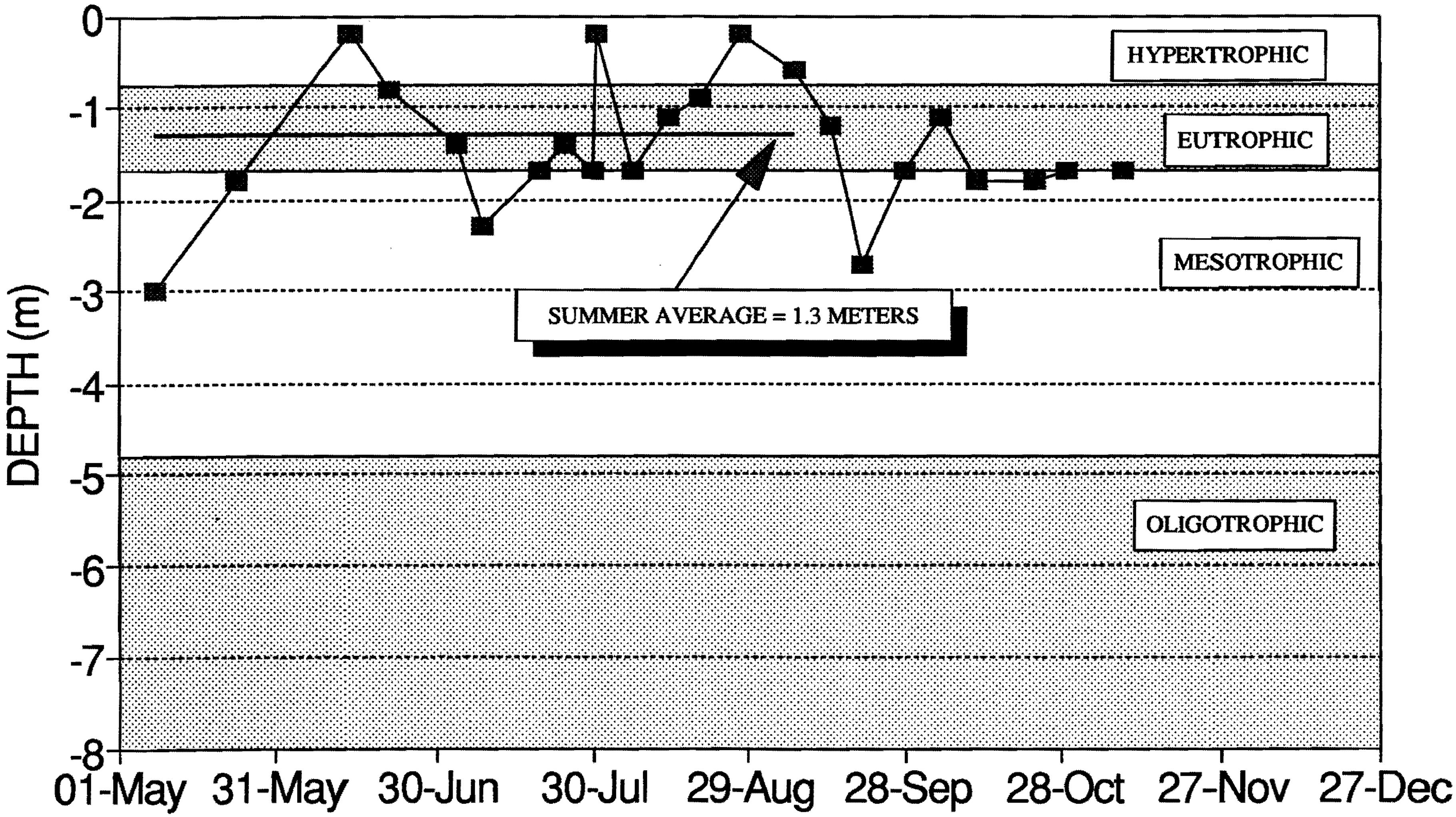

Figure 11

NUGGET LAKE--STATION 4
1991 EPILIMNETIC TOTAL PHOSPHORUS

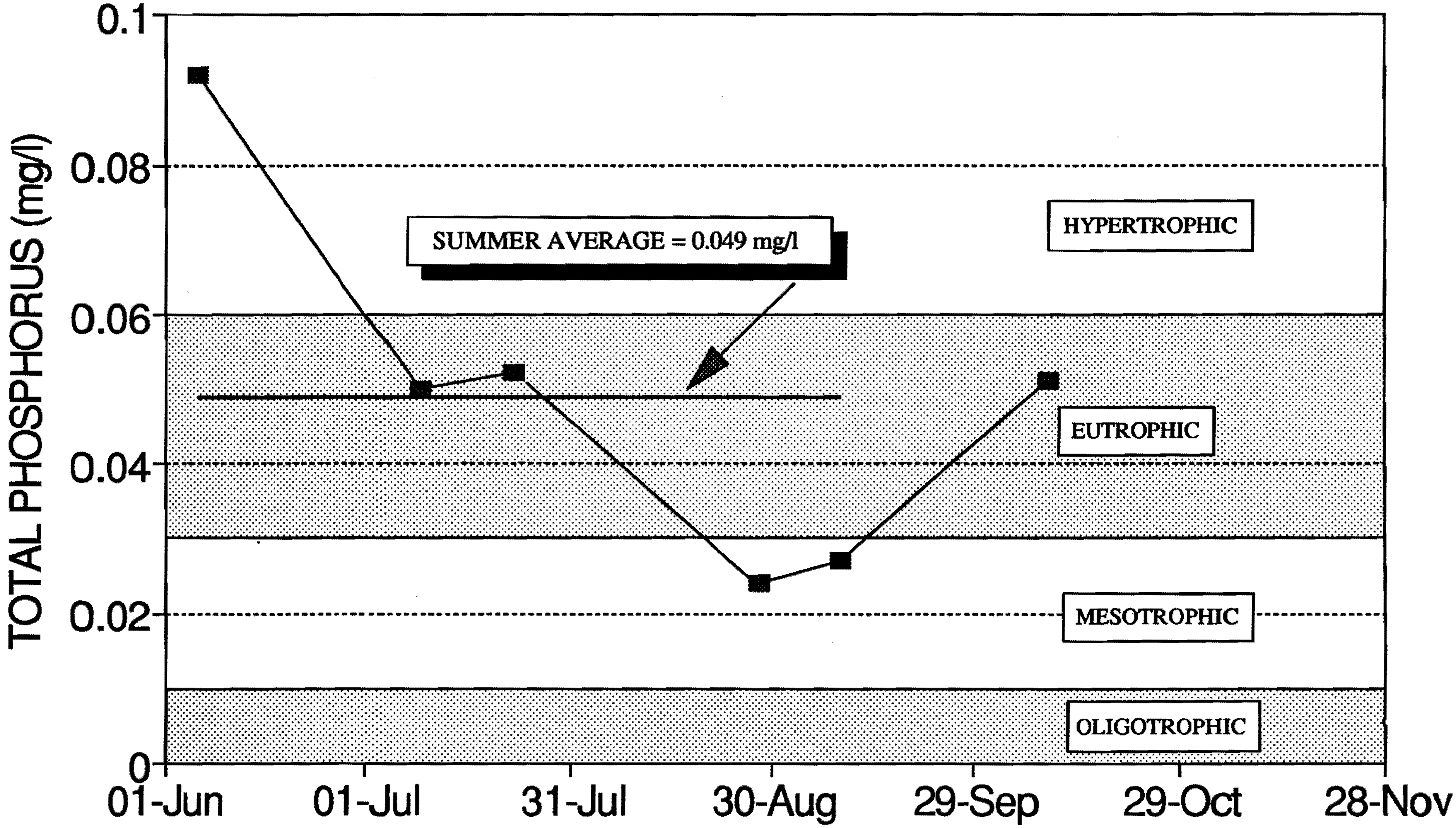

Figure 12

NUGGET LAKE--STATION 4
1991 EPILIMNETIC CHLOROPHYLL a

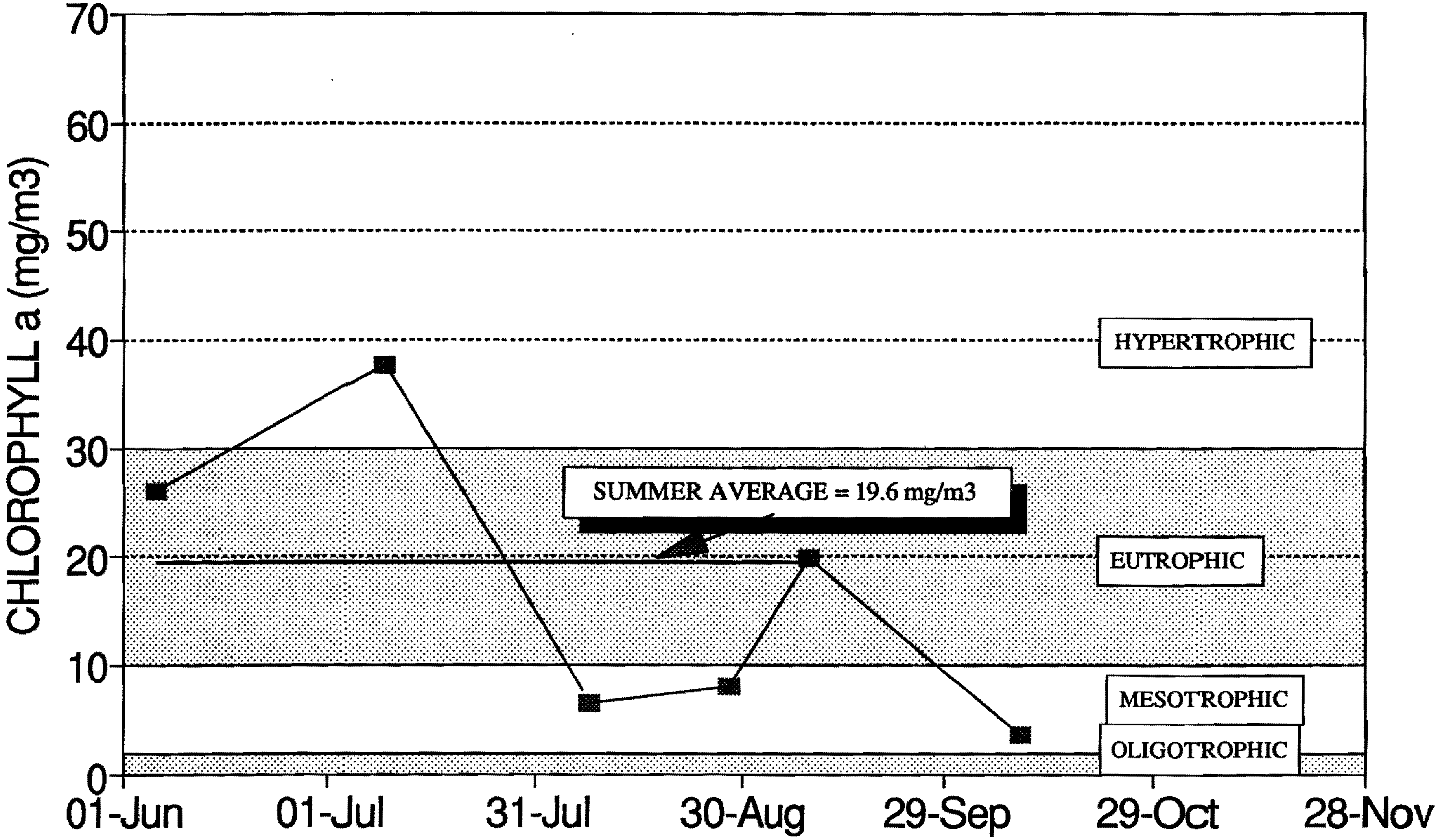

Figure 13

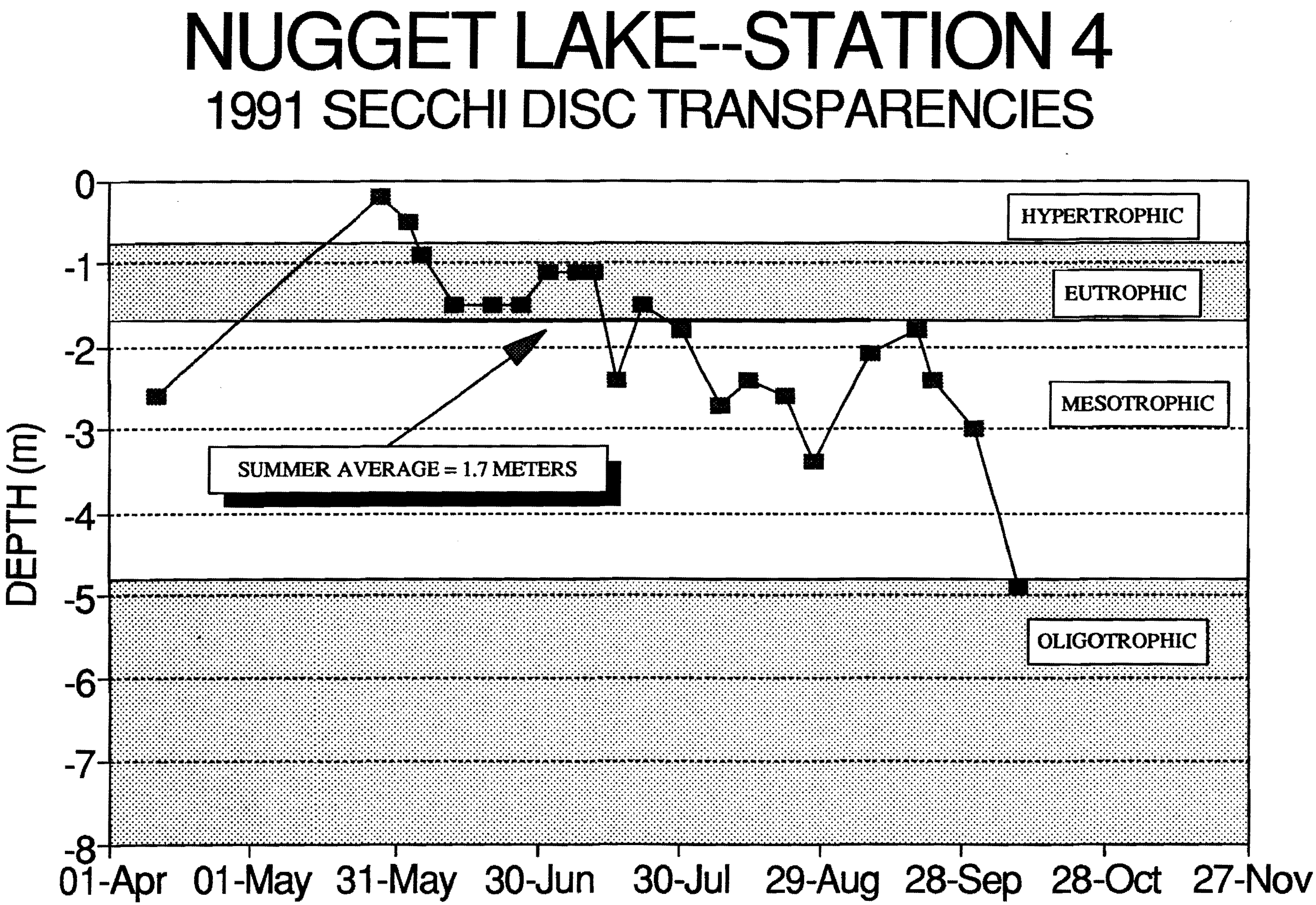
NUGGET LAKE--STATION 4
1991 SECCHI DISC TRANSPARENCIES
HYPERTROPHIC
EUTROPHIC
MESOTROPHIC
OLIGOTROPHIC
SUMMER AVERAGE = 1.7 METERS
DEPTH (m)
0
-1
-2
-3
-4
-5
-6
-7
-8
01-Apr
01-May
31-May
30-Jun
30-Jul
29-Aug
28-Sep
28-Oct
27-Nov

Figure 14

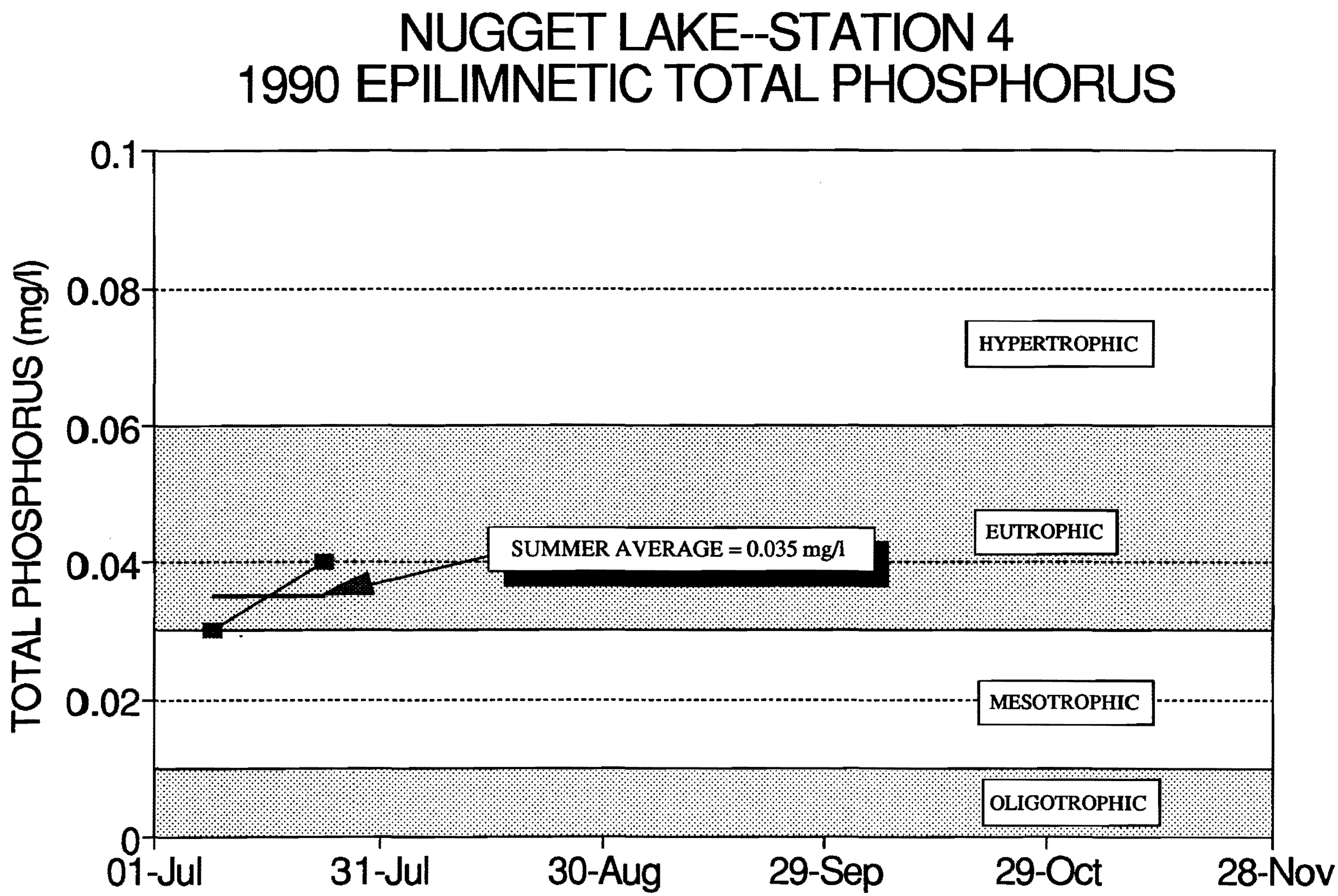
NUGGET LAKE--STATION 4
1990 EPILIMNETIC TOTAL PHOSPHORUS
TOTAL PHOSPHORUS (mg/l)
0.1
0.08
0.06
0.04
0.02
0
HYPERTROPHIC
EUTROPHIC
SUMMER AVERAGE = 0.035 mg/l
MESOTROPHIC
OLIGOTROPHIC
01-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov

Figure 15

NUGGET LAKE--STATION 4
1990 SECCHI DISC TRANSPARENCIES

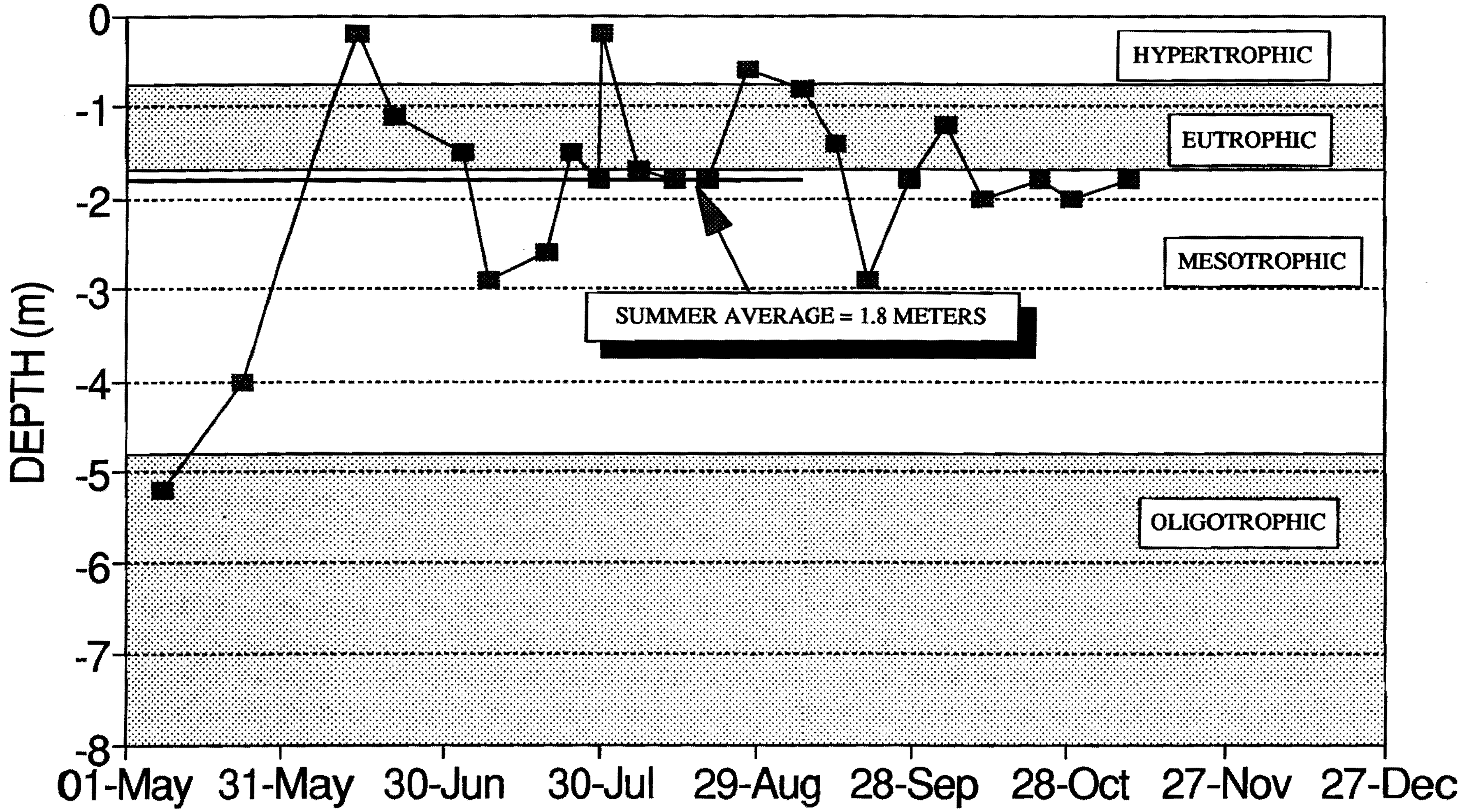

Figure 16

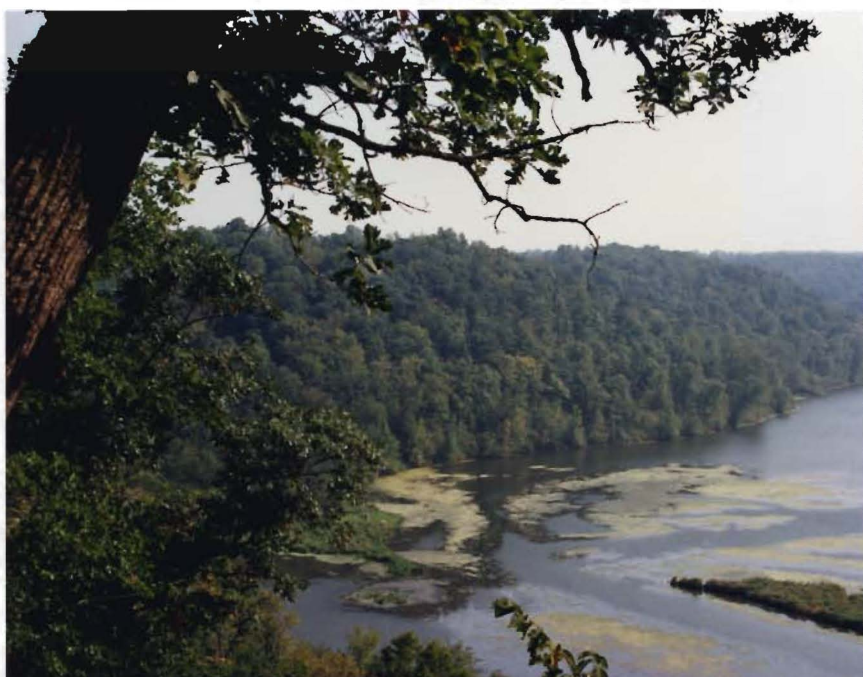

Figure 17

NORTHERN PORTION OF NUGGET LAKE -- ALGAL BLOOMS
ON AUGUST 27, 1991

Although phosphorus is the primary factor governing algal abundance in Nugget Lake, its algal growth may also be determined by other environmental factors. These include:

- hydraulic residence time
- light
- sediments and suspended material
- other non-nutrient factors

One, or a combination, of these factors may limit the growth of algae in a lake. Data collected during 1990 and 1991, however, indicate algal growth in Nugget Lake was determined by phosphorus on all sampling occasions (Figures 8 to 16). Increased phosphorus concentrations on these occasions were associated with increased chlorophyll a concentrations, and a reduction in water transparency (i.e., lower Secchi disc measurements). These data suggest reductions in phosphorus are necessary to reduce algal growth, and improve the overall water quality of the lake. Although phosphorus reductions will improve the water quality of the lake, it is likely that the lake will probably remain eutrophic. The large agricultural watershed will likely contribute sufficient phosphorus to maintain the lake in a eutrophic condition even after land treatment measures have been implemented. However, improvements in water quality will make the lake more desirable for recreational activities by park visitors.

Observations by Nugget Lake park staff, however, indicate that algal abundance does not always determine the lake's water transparency. Sediments washed into the lake following rainstorms create turbid conditions which determine its water transparency. Poor water transparency is observed for a period of time after each rainstorm until sediments settle to the lake bottom or are flushed from the lake. During this period, limited algal growth occurs in the lake due to unfavorable light conditions. These observations indicate a reduction of sediment loading from the tributary watershed will be necessary to improve the lake's water transparency after rainstorms.

Evaluation of the Tributary Watershed

A tributary watershed evaluation was completed to identify the relative sources of the lake's sediment and water quality problems. The components of the evaluation included:

- streambank erosion survey
- watershed assessment

- bacteria assessment

Their role in the lake's problems are discussed in the following sections of this report.

Streambank Erosion Survey

Detailed results of the streambank erosion survey are presented in Appendix B. Eroded portions of Plum Creek and Rock Elm Creek are shown on aerial photographs. Tables B-1 and B-2 present the following information for each eroded site:

- Its location on the stream--left bank, right bank, or both
- Whether the site was eroding, trampled, or slumping
- The length of the site
- The average height of the bank
- Its lateral recession rate
- Its annual erosion rate

Tables B-3 and B-4 present the following information for each site:

- The land use within 1 to 2 rods of the stream
- Whether cattle have access to the stream
- Identification of two practices to reduce erosion at the site (i.e., streambank fencing, shaping and seeding, riprapping, and cattle or machine stream crossing)

Survey results indicate major portions of Plum Creek and Rock Elm Creek are experiencing streambank erosion. Figure 18 presents the aggregate eroded stream length (sum of the lengths of all eroded stream sites) of Plum Creek and Rock Elm Creek. Severely eroded streambank represented approximately 17 percent of the total stream length in Plum Creek and about 9 percent of the total stream length in Rock Elm Creek.

Survey results also indicate significant loads of sediment are added to Nugget Lake each year as a result of streambank erosion. Figure 18 presents the aggregate annual sediment yield (sum of the yields of all eroded stream sites) of Plum Creek and Rock Elm Creek. The data indicate sediment loads to Nugget Lake from eroded portions of the streams total 24,064 cubic feet per year. As discussed earlier, the average annual rate of sediment deposition in Nugget Lake is approximately 76,677 cubic feet. Streambank erosion, therefore, represents approximately one-third of the lake's annual sedimentation problem. Consequently, a significant reduction in streambank erosion would result in a significant reduction in sediment yield to Nugget Lake each year.

The data (Figure 18) indicate streambank erosion along Plum Creek contributes greater quantities of sediment to Nugget Lake than streambank erosion along Rock Elm Creek.

- Plum Creek--1991 sediment loads from streambank erosion totaled 18,113 cubic feet per year. This represents approximately 24 percent of the lake's annual sedimentation problem.

- Rock Elm Creek--1991 sediment loads from streambank erosion totaled 5,950 cubic feet per year. This represents approximately 8 percent of the lake's annual sedimentation problem.

Although streambank stabilization measures are needed in both streams, implementation of streambank stabilization measures along Plum Creek would result in greater reductions in the sediment load to Nugget Lake than implementation of measures along Rock Elm Creek.

During 1978, the Pierce County Soil Conservation Service completed a streambank erosion survey along the portions of Plum Creek and Rock Elm Creek that are located between the junction of the two streams and Highway 72. The survey results are presented in Appendix C.

Streambank erosion along Plum Creek and Rock Elm Creek has increased significantly during the 1978 to 1991 period. A comparison of the 1978 and 1991 survey results is presented in Figure 19. In 1978, streambank erosion was noted in approximately 1 percent of the surveyed portion of Plum Creek, and 4 percent of the surveyed portion of Rock Elm Creek. By 1991, erosion in these portions of Plum Creek and Rock Elm Creek had increased to 26 percent and 14 percent, respectively. The data suggest streambank erosion will continue to increase unless stabilization measures are implemented.

Watershed Assessment

The Nugget Lake watershed is primarily an agricultural watershed. Land use within the 11,390 acre watershed includes:

- Cropland Acres--5,581 acres (49% of the watershed)
- Forested Acres--3,348 acres (29% of the watershed)
- Pasture and wildlife areas--1,367 acres (12% of the watershed)
- Nugget Lake Park--752 acres (7% of the watershed)
- Building sites, Rock Elm Landfill--342 acres (3% of the watershed)

Past efforts to control erosion within the watershed have resulted in the implementation of land conservation measures in 82 percent of the cropland acres within the watershed. Current conservation measures include:

- Contour Farming--3,642 acres (65% of cropland)
- Conservation Reserve Program (CRP)--940 acres (17% of cropland)
- Other Cropped Areas (No contour strips, CRP, or contouring)--999 acres (18% of cropland

Given good landowner cooperation, it appears that a significant amount of the sedimentation from the watershed could be reduced. However, additional efforts to control watershed erosion through the implementation of land conservation measures have been unsuccessful. The Pierce County Land Conservation Department and the federal ASCS office have offered cost-sharing for land conservation programs for many years. They offer payment of up to 75 percent of the installation costs of grassed waterways and streambank riprapping. Several CRP signup opportunities have been offered to watershed landowners in recent years. The soil conservation office has offered to install contour farming practices at no charge to the landowner. Funding for the utilization of conservation tillage practices has been offered to landowners. The lack of success in these efforts to implement additional land conservation measures indicates additional cost-sharing, other incentives, or an aggressive education program may be necessary to implement additional conservation measures within the watershed.

Few erosion control structural measures have been constructed within the watershed. A total of nine grade stabilization structures are currently within watershed boundaries. These control a drainage area of 623 acres or 5.5 percent of the watershed drainage area.

The watershed assessment results indicate structural measures offer a greater potential for the control of watershed erosion and streambank erosion than land conservation measures. Because few structural measures currently exist in the watershed, the potential for additional structures is great. In contrast, approximately 82 percent of the cropland acres currently employ land conservation measures. Structural measures such as, grade stabilization structures and sedimentation basins, could:

- reduce watershed erosion during runoff events
- remove sediments from runoff prior to reaching Plum Creek
- slow the rate of runoff into Plum Creek.

The Pierce County Land Conservation Department and the federal ASCS office currently offer programs to pay up to 75 percent of the cost of installing grade stabilization structures. Additional funding for structural measures may be available from other sources (i.e., the SCS PL-566 program or the Wisconsin DNR Non-Point Source Program).

Bacterial Assessment

A bacteria assessment of Plum Creek and Rock Elm Creek was completed during 1991 to evaluate feedlot contributions from the tributary watershed. A comparison of fecal coliform bacteria concentrations during base flow conditions and following rainstorms was used for the assessment. Fecal coliform bacteria are normally found in the intestines of warm-blooded animals. Feedlot additions of animal wastes to streams increase their bacteria levels. Bacteria assessment results are presented in Tables D-1 through D-4, of Appendix D.

Assessment results indicate feedlots are adding animal wastes to Plum Creek and Rock Elm Creek via stormwater runoff. The results, presented in Figures 20 (Plum Creek) and 21 (Rock Elm Creek), show the occurrence of significant increases in bacteria levels in both streams following rainstorms. The data, however, indicate larger quantities of animal waste are added to Rock Elm Creek than Plum Creek.

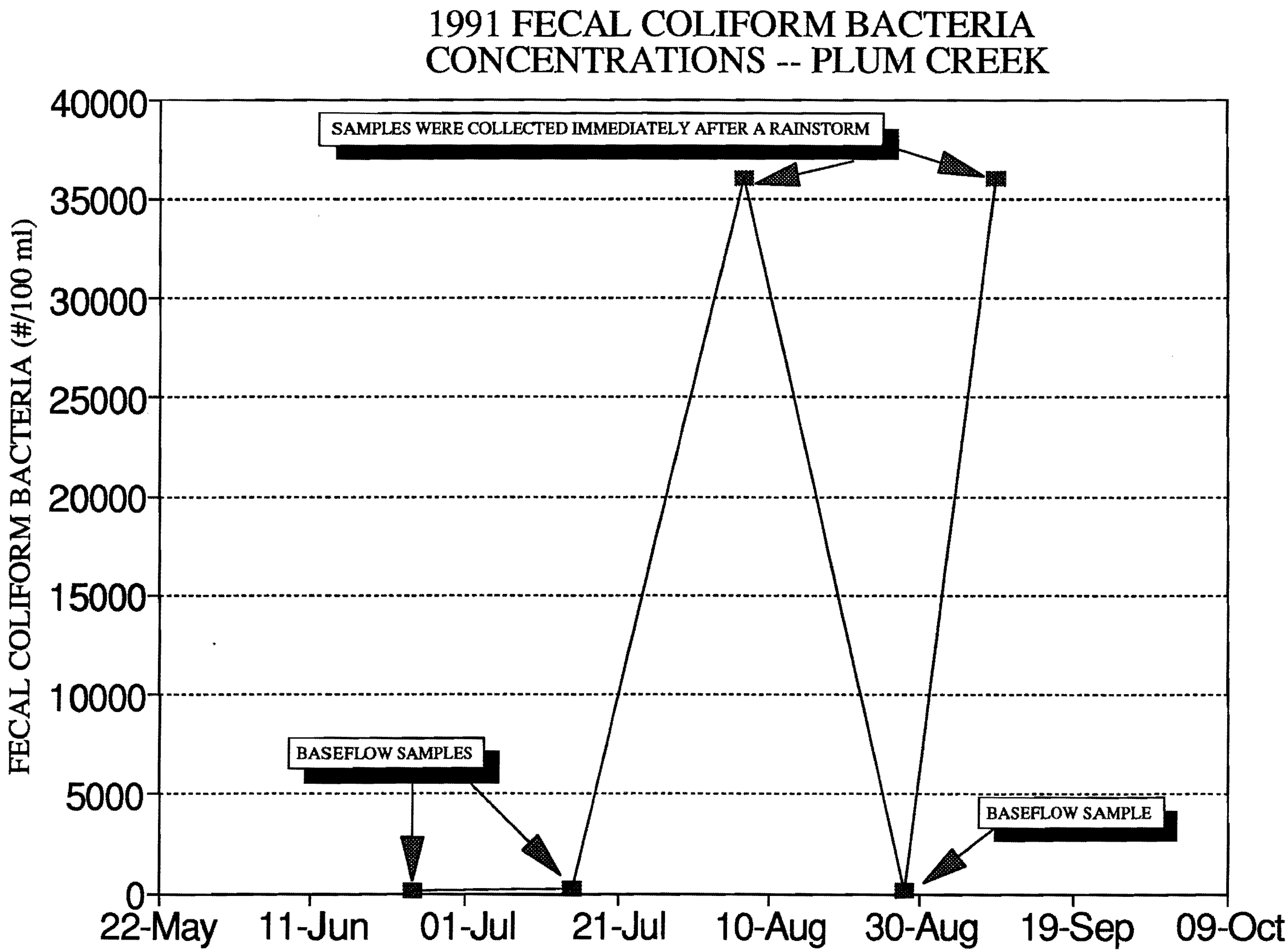
1991 FECAL COLIFORM BACTERIA
CONCENTRATIONS -- PLUM CREEK
SAMPLES WERE COLLECTED IMMEDIATELY AFTER A RAINSTORM
BASEFLOW SAMPLES
BASEFLOW SAMPLE
FECAL COLIFORM BACTERIA (#/100 ml)
40000
35000
30000
25000
20000
15000
10000
5000
0
22-May
11-Jun
01-Jul
21-Jul
10-Aug
30-Aug
19-Sep
09-Oct

Figure 20

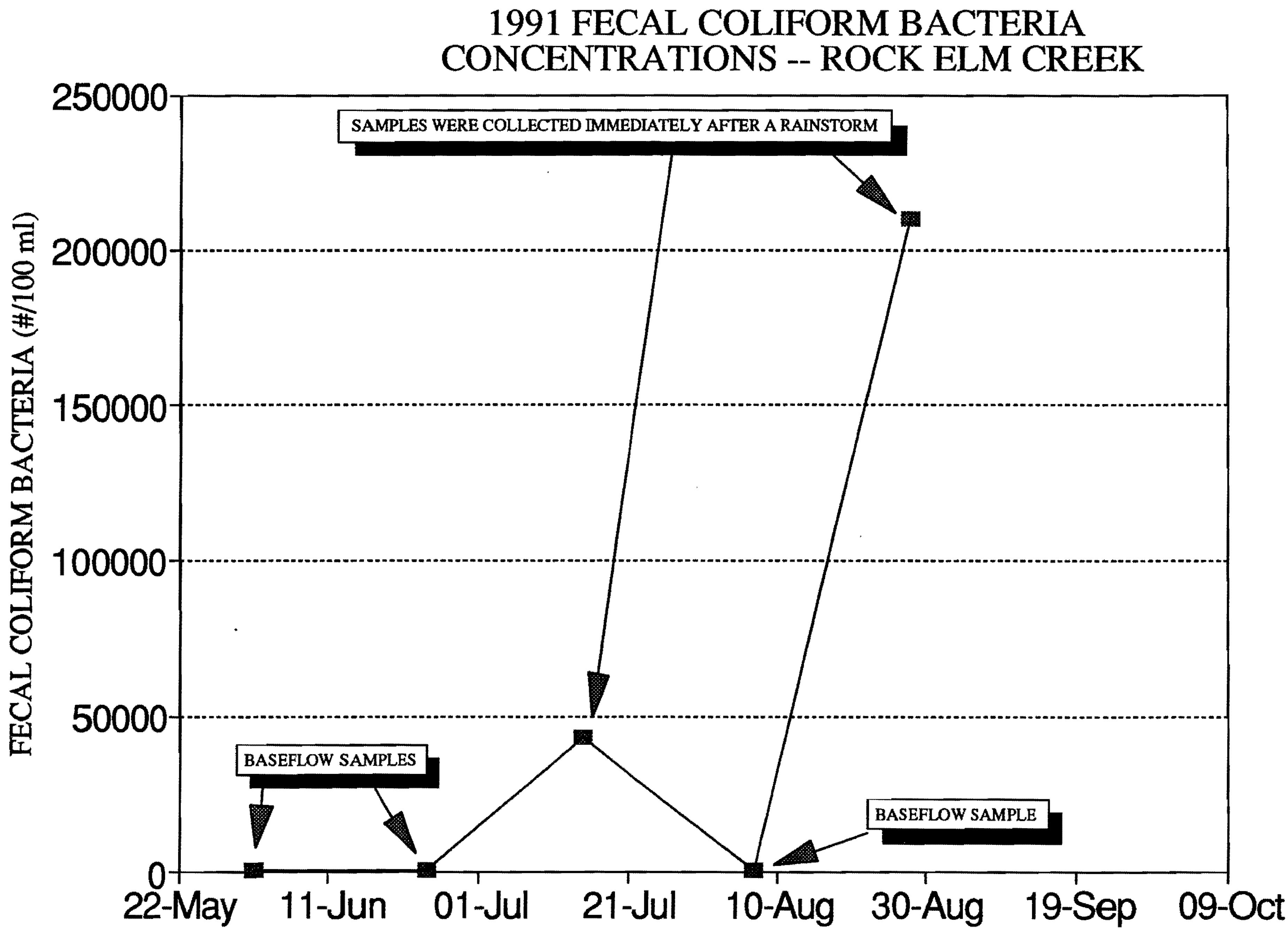
1991 FECAL COLIFORM BACTERIA
CONCENTRATIONS -- ROCK ELM CREEK
FECAL COLIFORM BACTERIA (#/100 ml)
250000
200000
150000
100000
50000
0
22-May
11-Jun
01-Jul
21-Jul
10-Aug
30-Aug
19-Sep
09-Oct
SAMPLES WERE COLLECTED IMMEDIATELY AFTER A RAINSTORM
BASEFLOW SAMPLES
BASEFLOW SAMPLE

Figure 21

Data were also collected from Nugget Lake, near the swimming beach, to evaluate the effect of stream bacteria additions to the lake. Although fecal coliform bacteria themselves typically do not present a health hazard, they have been used to indicate the potential presence of disease-carrying bacteria. Therefore, the presence of large quantities of fecal coliform bacteria in the lake is an indication of a possible health threat to swimmers. The data are presented in Table D-5, Appendix D, and in Figure 22. High concentrations of fecal coliform bacteria were found in Nugget Lake following a rainstorm on September 9, 1991. The data indicate animal wastes entering Plum Creek and Rock Elm Creek via runoff increase the bacteria levels of Nugget Lake.

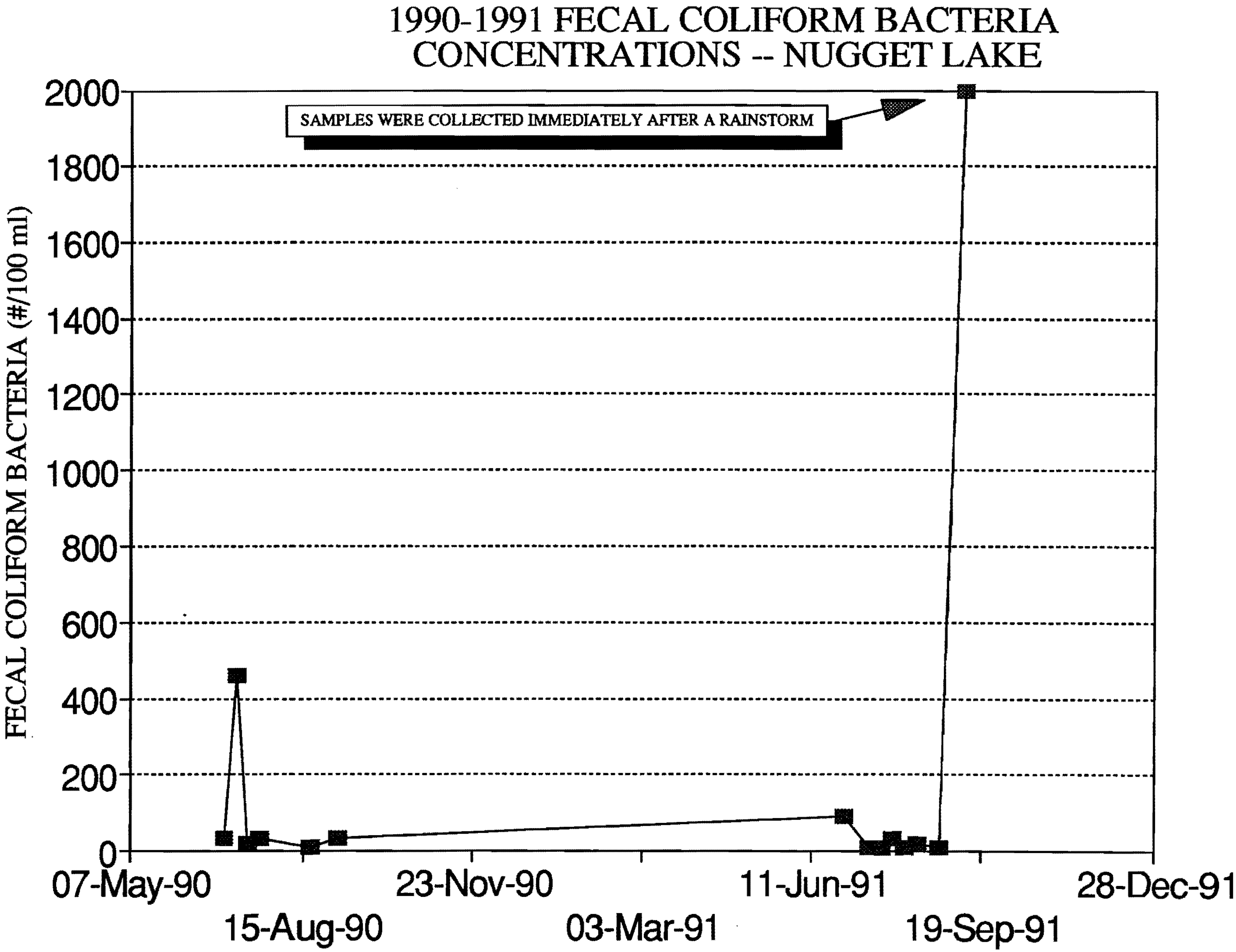
1990-1991 FECAL COLIFORM BACTERIA
CONCENTRATIONS -- NUGGET LAKE
SAMPLES WERE COLLECTED IMMEDIATELY AFTER A RAINSTORM
FECAL COLIFORM BACTERIA (#/100 ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
07-May-90
15-Aug-90
23-Nov-90
03-Mar-91
11-Jun-91
19-Sep-91
28-Dec-91

Figure 22

RECOMMENDATIONS

The 1991 study of Nugget Lake and its watershed provided sufficient information to evaluate the lake's problems and the relative sources of its problems. The lake's current problems include:

- High rate of sedimentation--The northern portion of Nugget Lake is rapidly filling in, with approximately 1.76 acre-feet of sediment deposited in the lake each year.

- Water quality problems--The lake's eutrophic classification indicates accelerated water quality degradation has occurred. The classification is consistent with observations of visible algal blooms and dense weed growths in the northern portion of the lake. It is also consistent with observations in the southern portion of the lake, including abundant algal growth in the surface waters and a lack of oxygen in the lake's deeper waters.

The sources of the lake's problems include

- Watershed erosion--Approximately two thirds of the lake's sedimentation problem appears to be due to watershed erosion. The lake's water quality problems appear to be primarily due to runoff from the tributary watershed.

- Streambank erosion--Approximately one-third of the lake's sedimentation problem appears to be due to streambank erosion.

- Feedlot Runoff--Runoff from feedlots within the tributary watershed carries high levels of bacteria into Plum Creek and Rock Elm Creek. The runoff results in elevated bacteria level in the Nugget Lake swimming beach area following rainstorms.

Recommendations to solve the lake's sedimentation and water quality problems focus on changes in the tributary watershed. They include:

- Structural Measures
- Land Conservation Measures
- Streambank Stabilization Measures
- Waste Management Systems

Current sediment deposits in the northern portion of Nugget Lake prevent boating, except within the main channel. Continued sedimentation will likely prevent navigation in this portion of Nugget Lake. Therefore, dredging the northern portion of Nugget Lake for navigational purposes is also recommended. Recommendations are detailed in the following paragraphs.

Structural Measures

Structural Measures appear to offer the greatest potential for reducing sediment and nutrient yield to Nugget Lake. Few measures are currently found in the watershed, and the potential for these measures is, therefore, great. Such measures include:

- Water and sediment control basins (W&SCBs), which are short earth embankments or a combination ridge and channel generally constructed across the slope and minor watercourses to reduce ephemeral gully erosion, trap and collect sediment, and improve the potential of areas for farming. They are similar to terraces, except for length. Up to 75 percent funding may be obtained through the SCS PL-566 program. Additional funding may be available through the Wisconsin DNR Non-Point Source Program.

- Grade stabilization structures, which are used to control the grade and head cutting in natural and artificial channels to prevent the formation or advancement of gullies. Grassed waterways may be used as a companion practice. The Pierce County Land Conservation Department and the federal ASCS currently offer a program to cover up to 75 percent of the cost of installing grade stabilization structures.

- Sedimentation basins, both regional and on-site detention basins. Stormwater detention can help control the rate and quality of runoff entering Nugget Lake via Plum Creek and Rock Elm Creek. It is presumed that public ownership of regional basins will result in significantly better operation and maintenance of detention facilities as opposed to a system of many smaller privately-owned, on-site detention basins. These smaller basins are often not properly maintained and consequently become nonfunctional in the absence of inspection and enforcement of operational standards.

Regional stormwater detention ponds used to control stormwater runoff quality were studied intensively by the U.S. EPA as part of their Nationwide Urban Runoff Program (NURP) projects. They concluded that detention ponds with sufficiently large permanent volumes of water ("dead storage") were superior to basins which drained dry between storm events in their ability to remove sediment, phosphorus, and other contaminants from runoff. Their superior performance was attributed to the long detention times these basins afforded stormwater runoff. This gave extremely small particulate materials a chance to settle out of suspension during the time interval between storm events, and allowed the biological system of the pond an opportunity to remove soluble phosphorus from solution during the same time period. The EPA subsequently developed a set of design criteria for stormwater detention ponds, based on the results of NURP studies, which will improve runoff water quality. It is recommended that these criteria be used to design sedimentation basins in the Nugget Lake watershed (Walker, 1987). The feasibility of alum treatment of stormwater entering detention basins should also be determined. Alum treatment of stormwater has been shown to be effective in the removal of phosphorus (Diversion and Treatment of Stormwater Runoff and Cooling Water Inflows to Loon Lake: A Feasibility Study, 1988; and Harper, et. al.). These detention ponds must be maintained to ensure proper operation and must periodically be dredged to restore sediment and stormwater storage capacities. Up to 75 percent funding of sedimentation basins may be obtained through the SCS PL-566 program. Additional funding may be available through the Wisconsin non-point source program.

Land Conservation Measures

Although most cropland areas within the watershed currently use at least one type of land conservation measure, additional measures may be implemented. Past experience suggests successful implementation may not occur unless additional cost-sharing, other incentives, or an aggressive education program are included in the implementation plan. Additional land conservation measures include:

- Conservation tillage system--Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion. Funding to implement this measure may be available through the Pierce County Land Conservation Department, the federal ASCS office, the SCS PL-566 program, and the Wisconsin DNR Non-Point Source Program.

- Contour farming--A method of tillage, land preparation, planting, and cultivation on the contour to reduce sheet and rill erosion. Currently, approximately 65 percent of existing cropland uses contour farming practices. The Soil Conservation office has offered to install contour farming practices at no charge to the landowner. An aggressive education and/or promotion program may be necessary to implement this measure within the watershed.

- Terraces with subsurface outlet drains--An earth embankment, a channel or combination of a ridge and channel constructed across the slope. Its purpose is to reduce sheet and rill erosion by reducing the slope length thereby reducing the sediment content of water, and improving water quality. Other functions are to intercept and conduct surface runoff to a nonerosive outlet, conserve moisture, and prevent development of ephemeral gullies. The results of the watershed assessment suggest terracing is not currently used in the Nugget Lake watershed. Funding to implement this measure may be available from the Soil Conservation Service PL-566 program and the Wisconsin DNR Non-Point Source program.

- Grassed waterway or outlet--A constructed flow area for concentrated flows, established in a suitable vegetation for the safe disposal of runoff. This practice is effective in reducing ephemeral gully erosion. Features in designs of grassed waterways or outlets include earth shaping, stabilizing outlets, draining wet cropland, grass seeding, and mulching of the seeded area. Funding may be available from the Soil Conservation Service PL-566 program and the Wisconsin DNR Non-Point Source program.

- Nutrient management--Managing the amount, form, placement, and timing of application of nutrients for crop protection, including both animal wastes and commercial fertilizers. The use of soil tests, manure analysis, legume credits, an fertilizer recommendations are essential in this measure. In some cases, machinery adjustments and/or modifications are needed. The extent of the use of this measure in the watershed is not currently known. Additional management, however, will reduce nutrient loading to Nugget Lake. Funding may be available from the Soil Conservation Service PL-566 program.

Streambank Stabilization Measures

Streambank stabilization measures are recommended to reduce the annual sediment load to Nugget Lake. The measures focus on structures to slow the rate of flow following runoff events and measures to prevent erosion of the streambank.

- Rate Control Structures--Following storm events, runoff from the Nugget Lake watershed reaches Plum Creek and Rock Elm Creek quickly. The large volume of water and its fast flow rate result in streambank and stream channel erosion. Stormwater detention structures within the watershed to slow the rate of runoff to the streams would reduce streambank erosion. In addition, stormwater detention structures within the stream channel would slow rate of flow, thereby, reducing streambank erosion. Funding may be available through the SCS PL-566 program and the Wisconsin DNR Non-Point Source program.

- Riprapping--Severe erosion is currently present in approximately 17 percent of the total length of Plum Creek and approximately nine percent of the total length of Rock Elm Creek. Riprapping of these areas is recommended to reduce streambank erosion. The Pierce County Land Conservation Department and the federal ASCS office currently offer a program to fund up to 75 percent of the cost of streambank riprapping. Additional funding may be available through the Wisconsin DNR Non-Point Source program.

- Alternative streambank erosion control measures--The feasibility of the following measures should be evaluated when finalizing plans for streambank erosion control.

  --Buried sheet pile walls stabilize eroded slopes, prevent further undercutting, and allow restoration of the damage.

--Stream bed weirs are rock buried in the stream bed perpendicular to the flow to limit erosion and degradation of the bed.

Waste Management Systems

Waste management systems should be installed to prevent the addition of animal wastes to Plum Creek and Rock Elm Creek via stormwater runoff. Each system includes all necessary components for managing liquid and solid waste in a manner that does not degrade tributary water resources. Funding for the construction of waste management systems may be obtained from the Wisconsin DNR Non-Point Source program. Up to $20,000 is currently available for construction of manure pits to manage feedlot wastes.

Dredging

It is recommended that the northern portion of Nugget Lake be dredged for navigational purposes. Sediment deposits currently prevent boating in this portion of the lake except within the main channel. Additional sedimentation will prohibit navigation in this portion of the lake. A dredging plan should be prepared to detail the:

- dredging methodology
- area of the lake to be dredged
- volume of sediment to be removed
- disposal site and disposal methodology
- dredging costs
- funding sources

Currently, a 50 percent cost-share is available for navigational dredging. Funding may be obtained from the Wisconsin State Waterways Commission.

REFERENCES

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Appendix A

Nugget Lake Water Quality Data

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- July 9, 1990

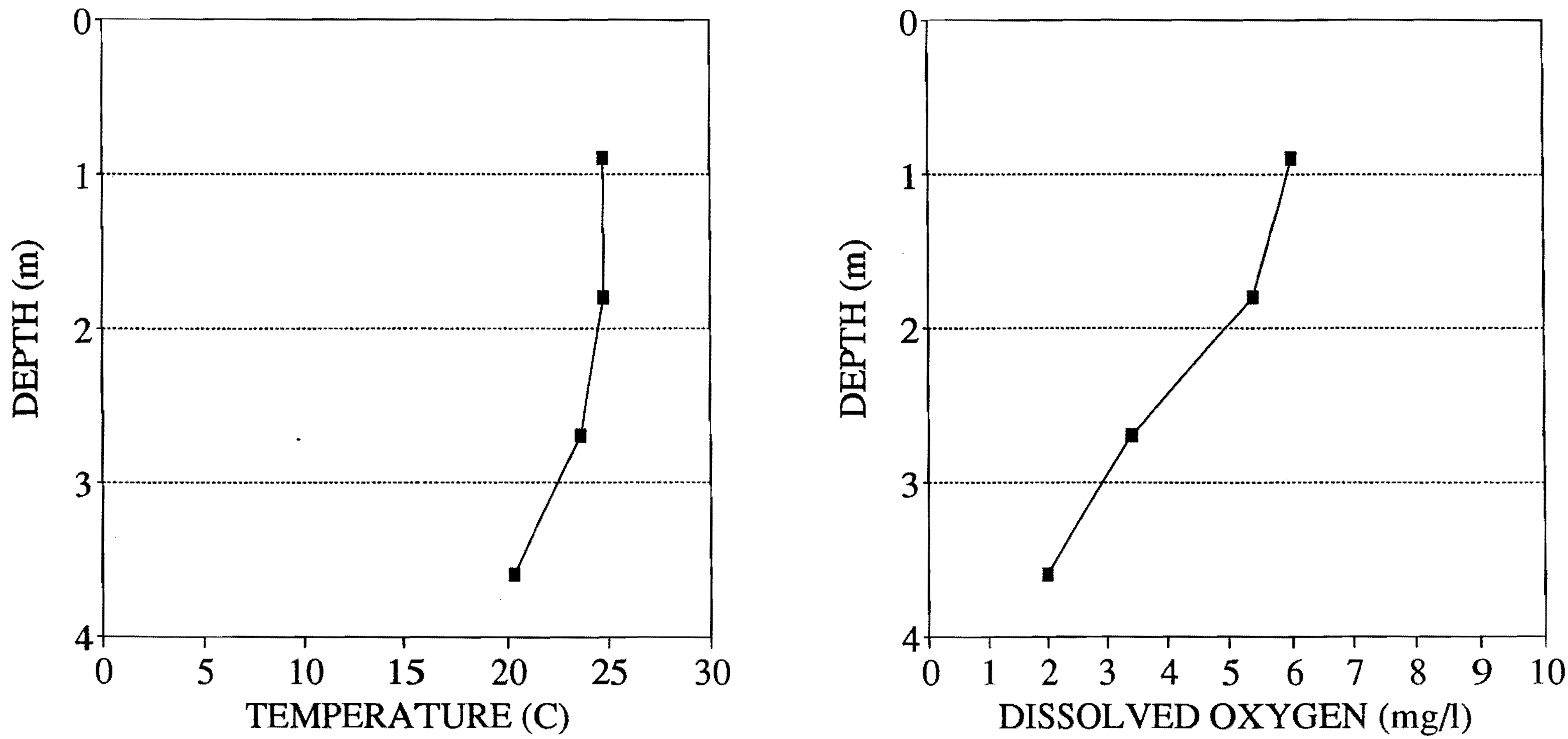


Figure A-1

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- August 28, 1990

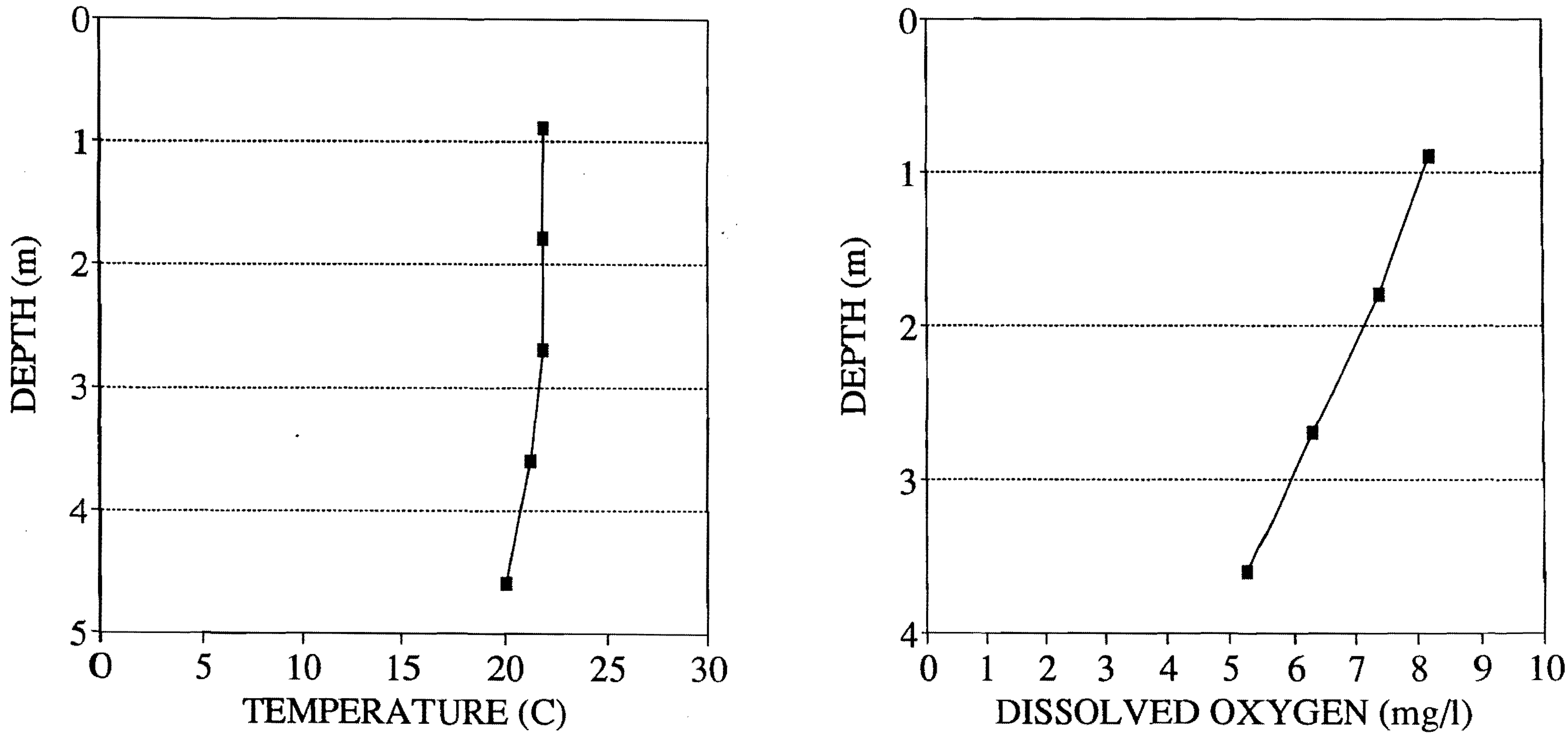
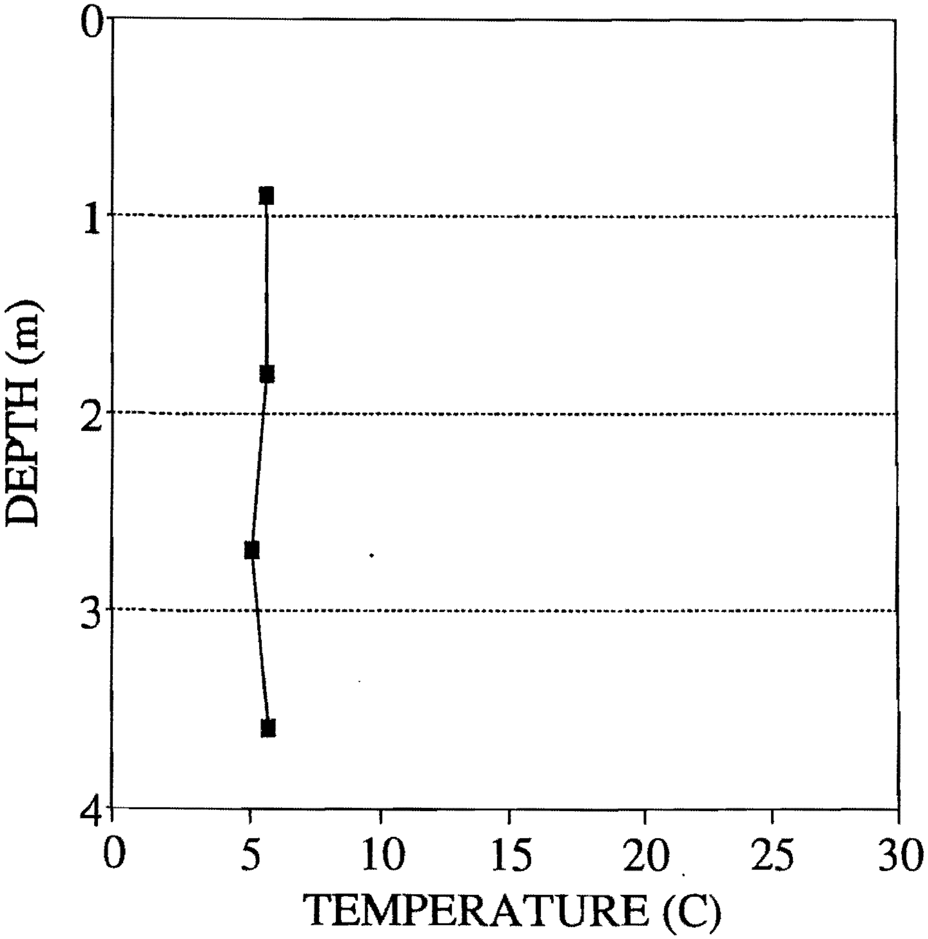


Figure A-2

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- October 29, 1990



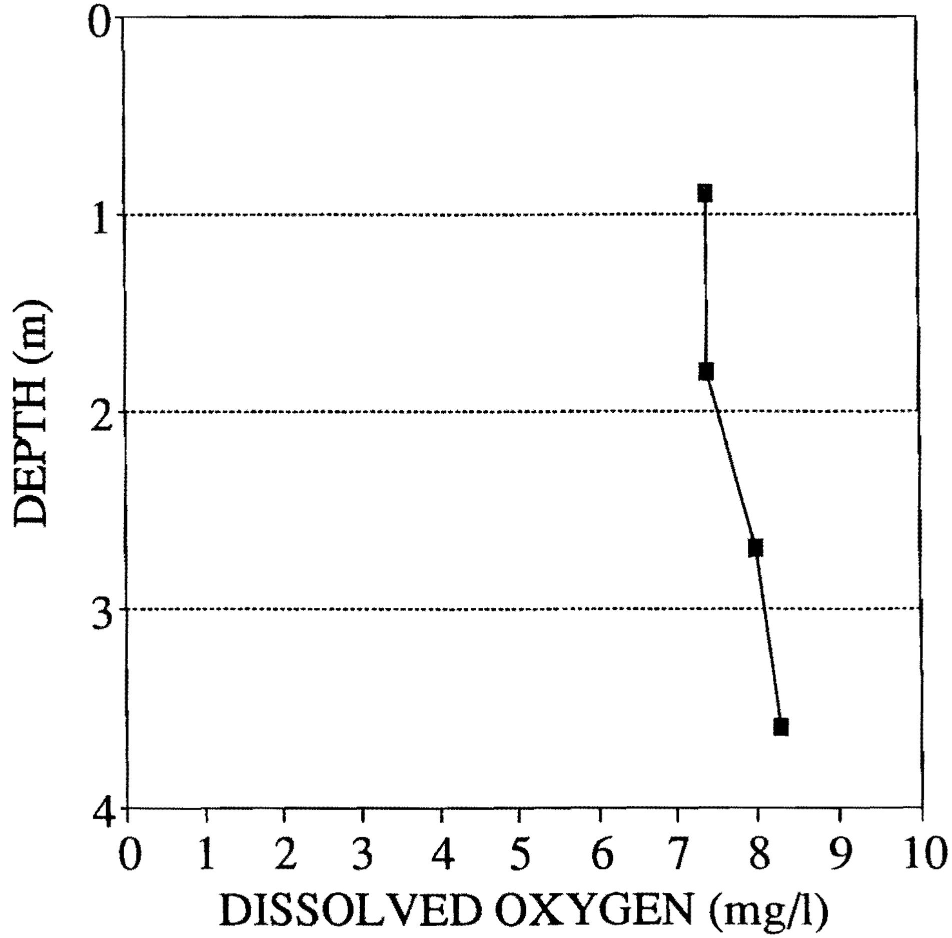


Figure A-3

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- July 9, 1991

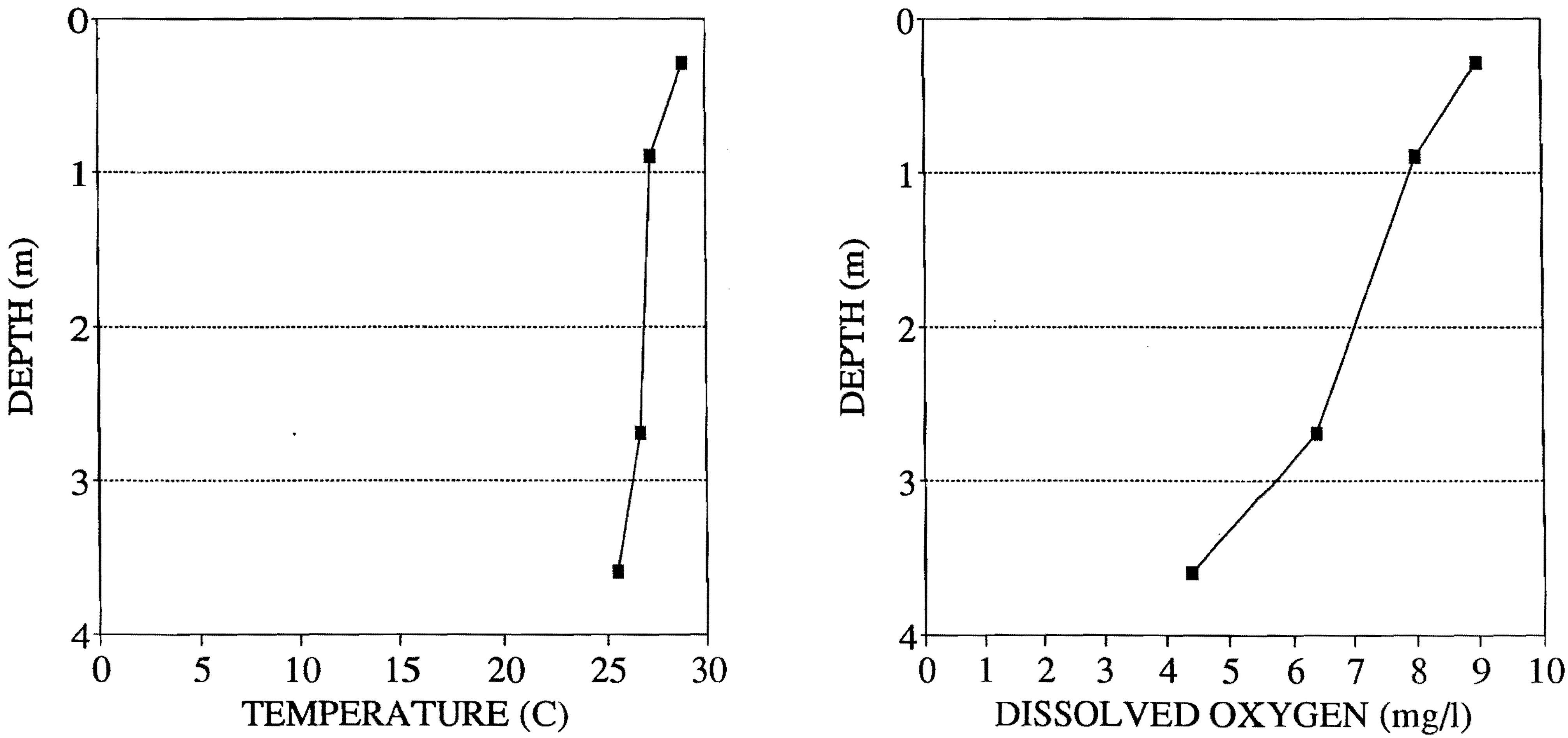
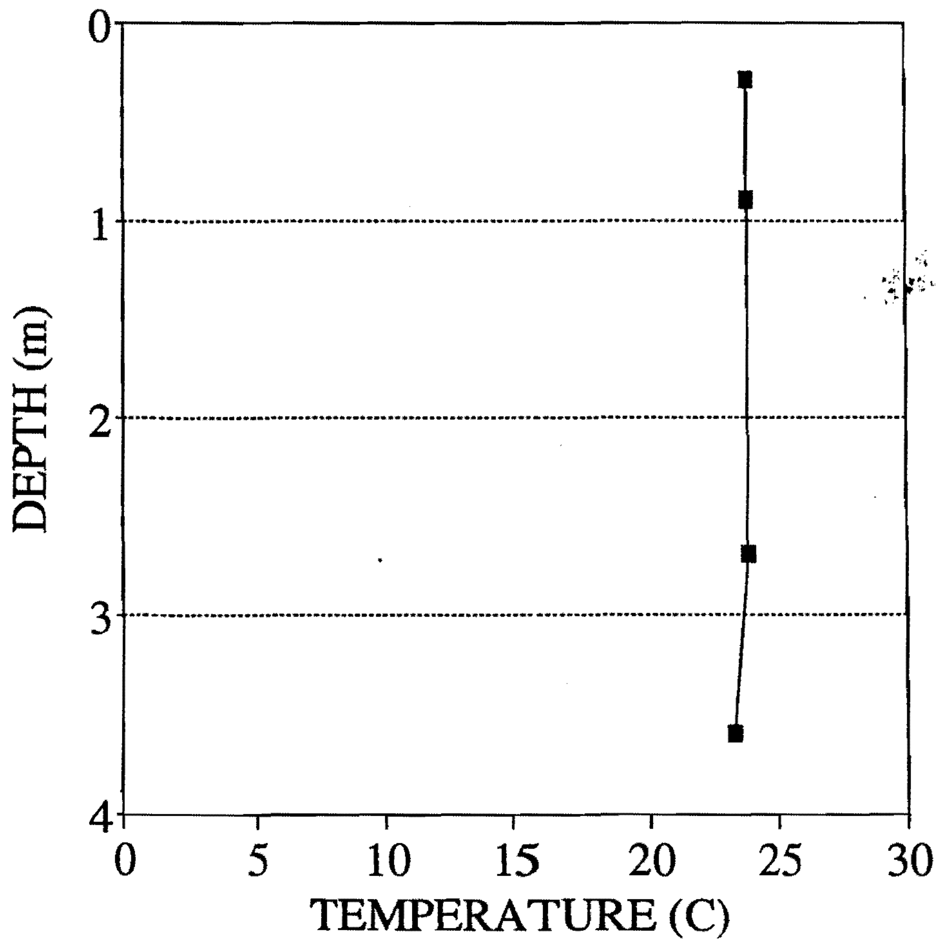


Figure A-4

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- August 8, 1991



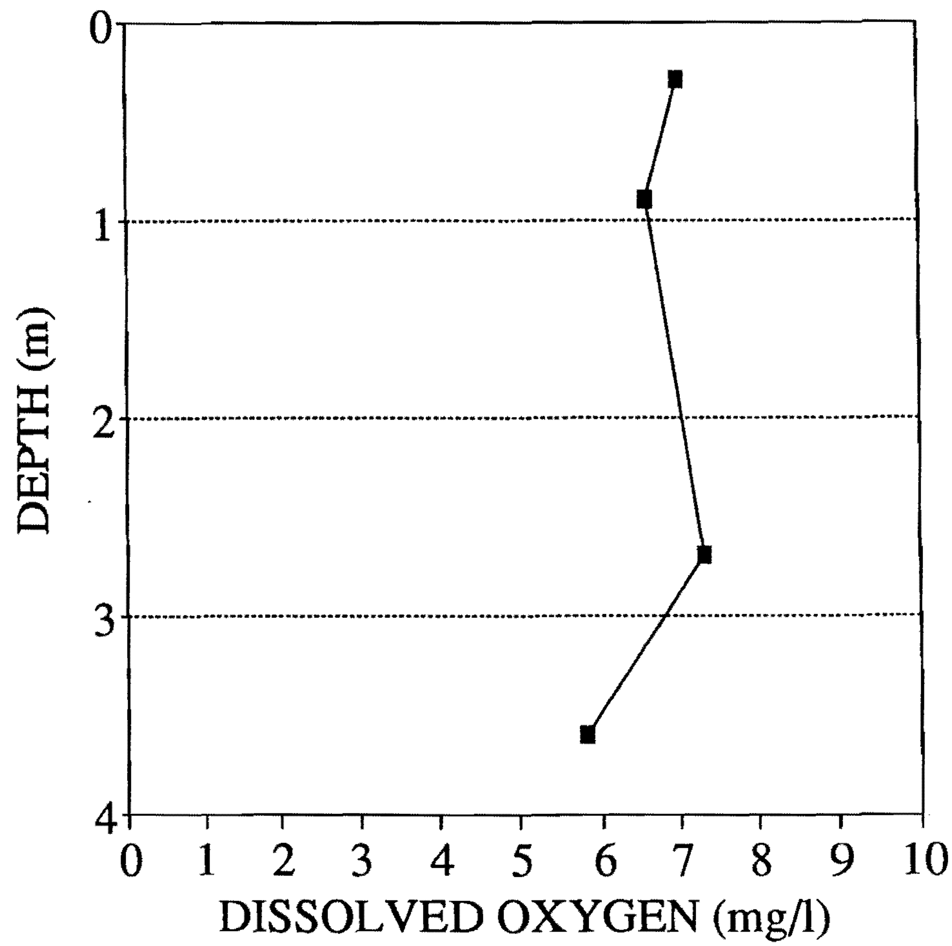
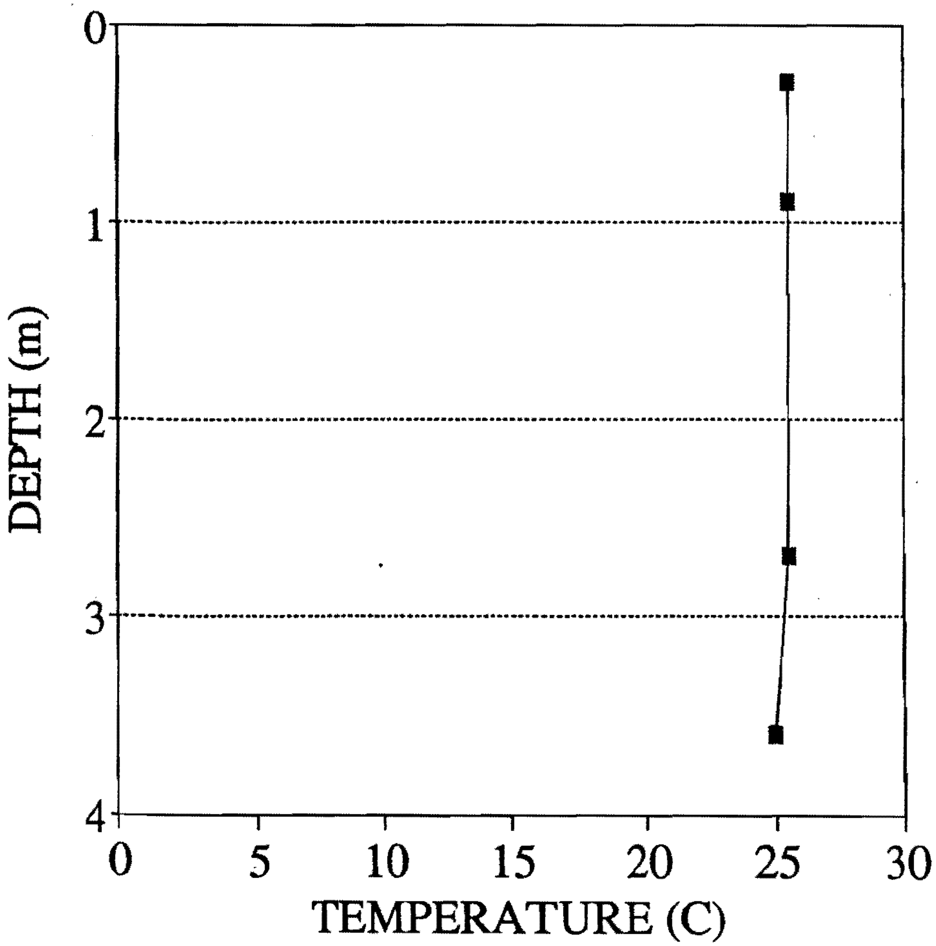


Figure A-5

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- September 9, 1991



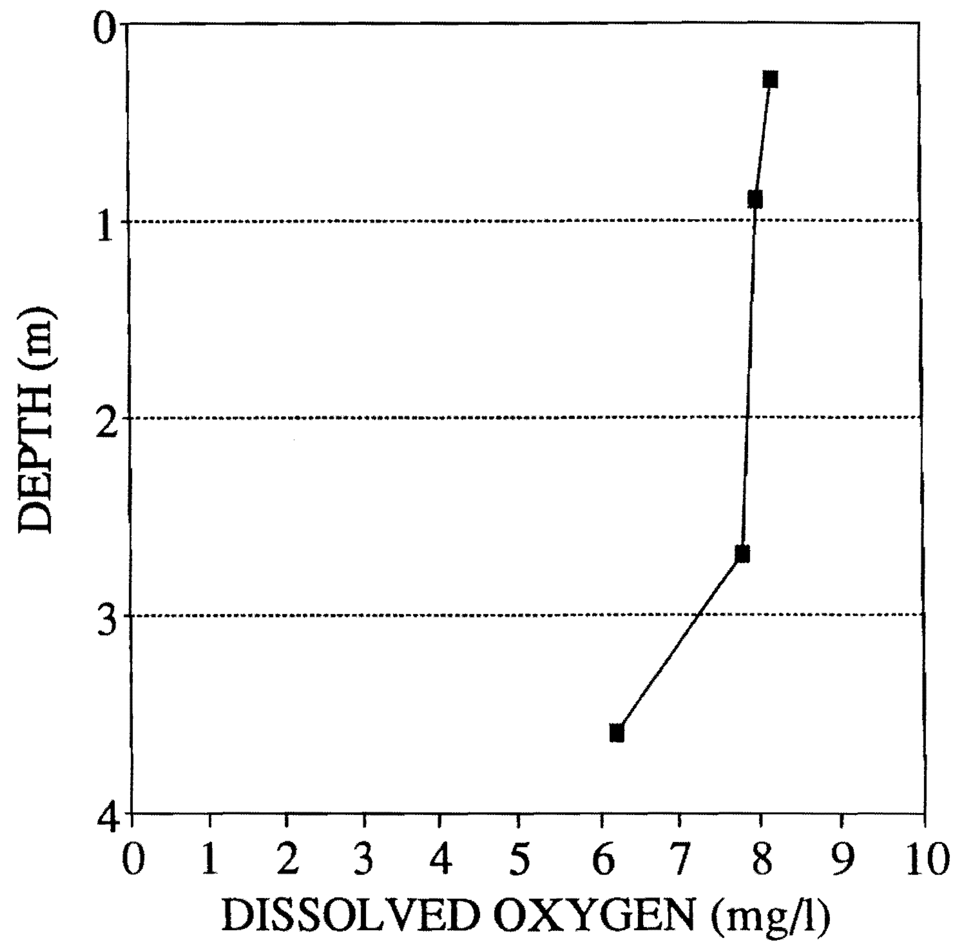


Figure A-6

NUGGET LAKE--STATION 3

Temperature/Dissolved Oxygen Profiles -- October 10, 1991

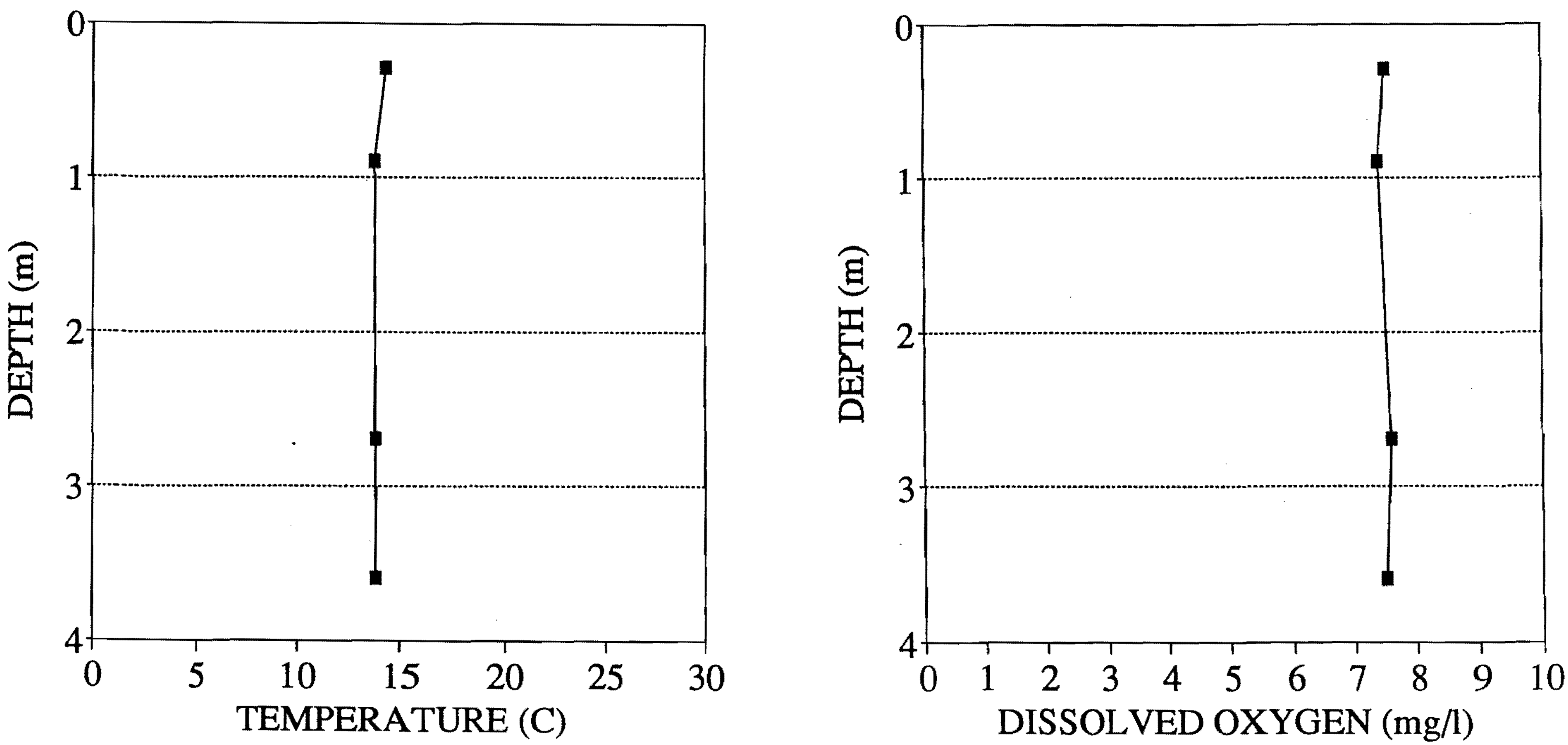


Figure A-7

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- July 9, 1990

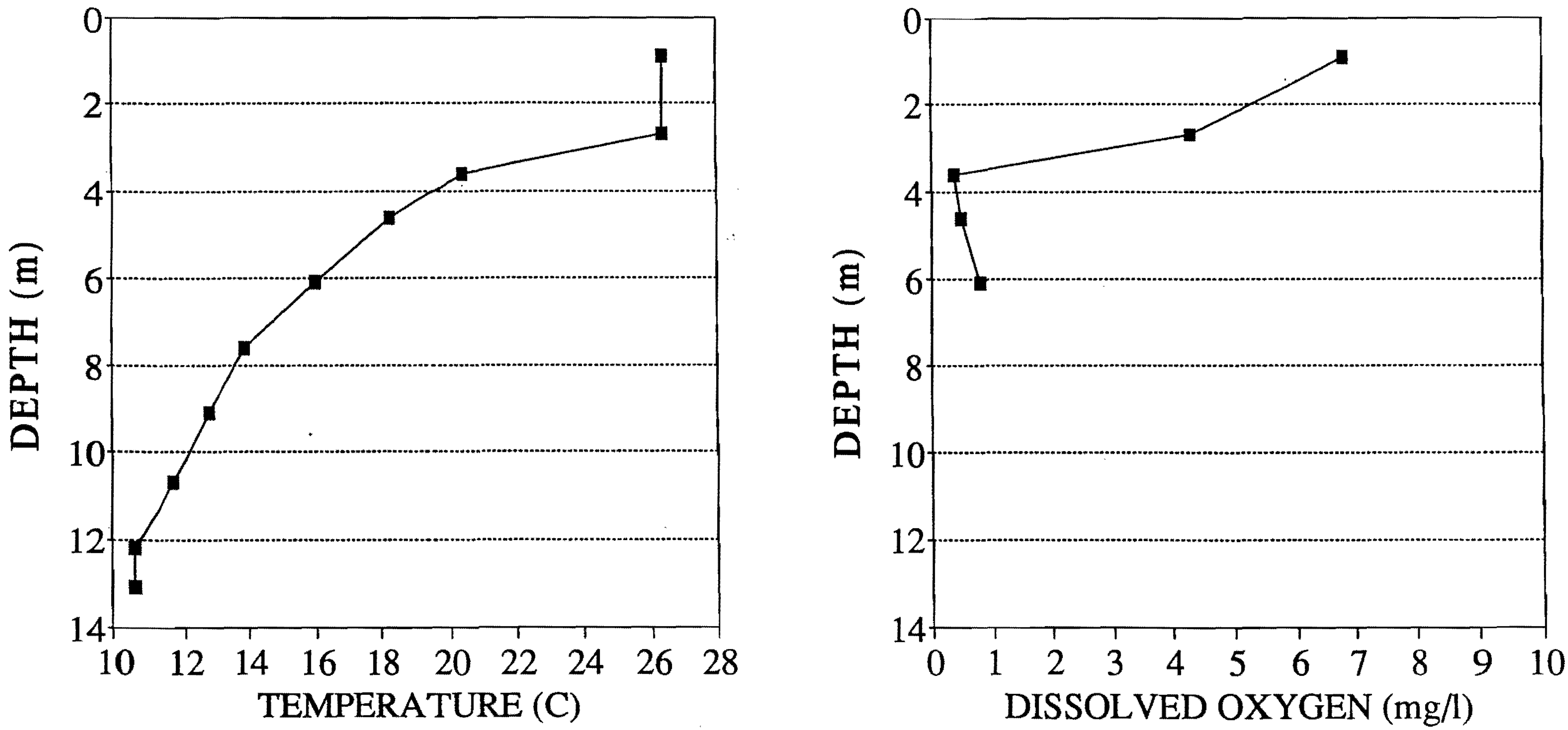


Figure A-8

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- July 24, 1990

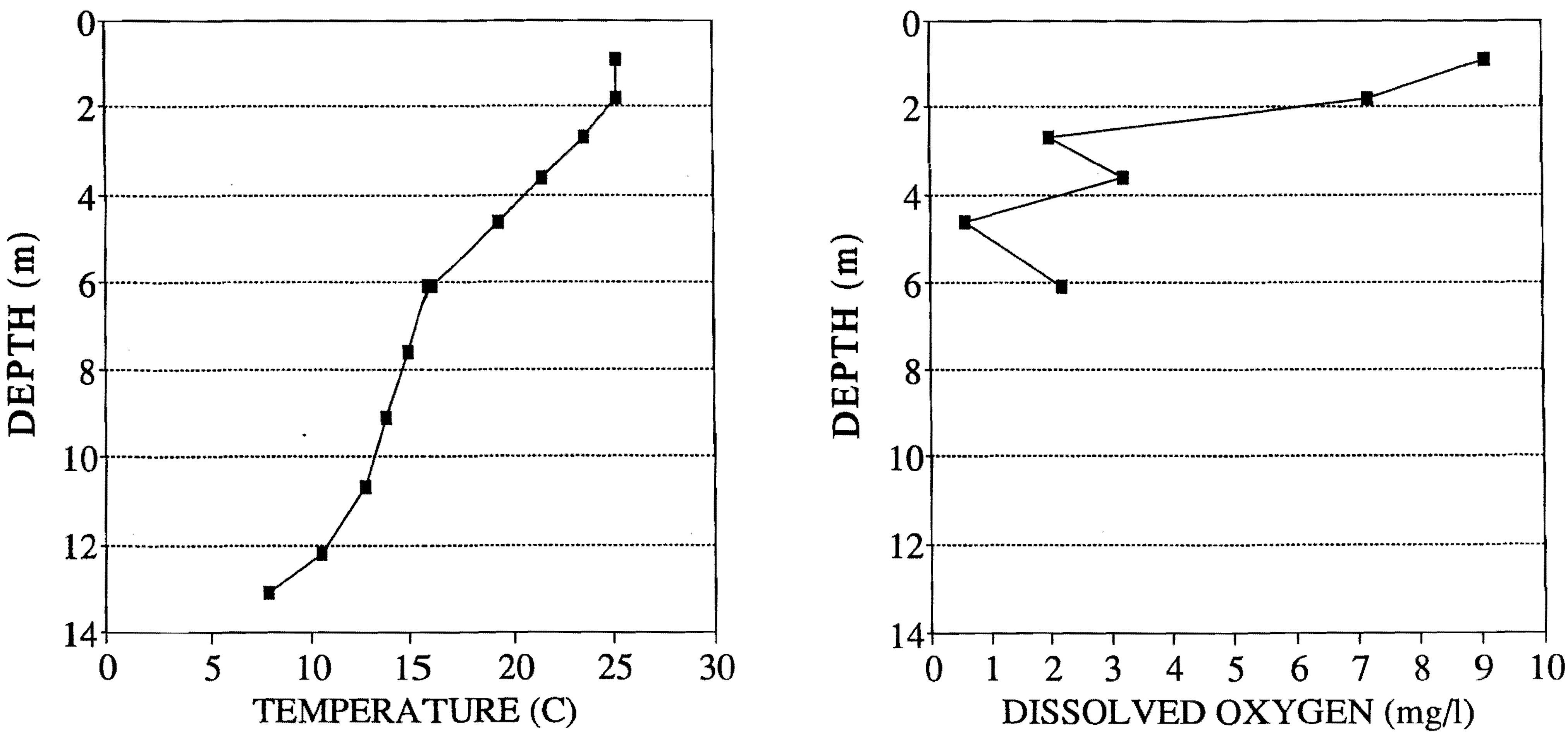


Figure A-9

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- August 28, 1990

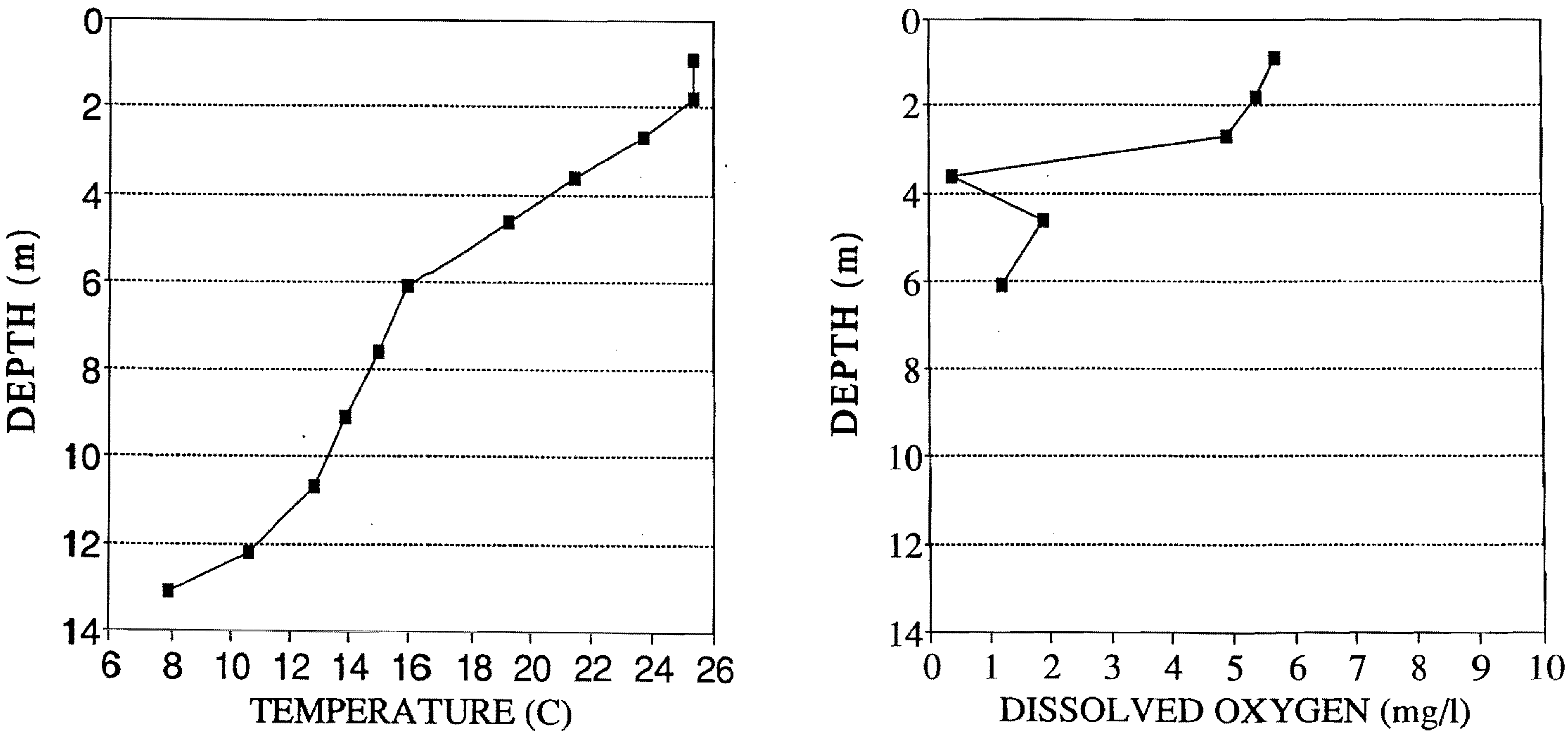
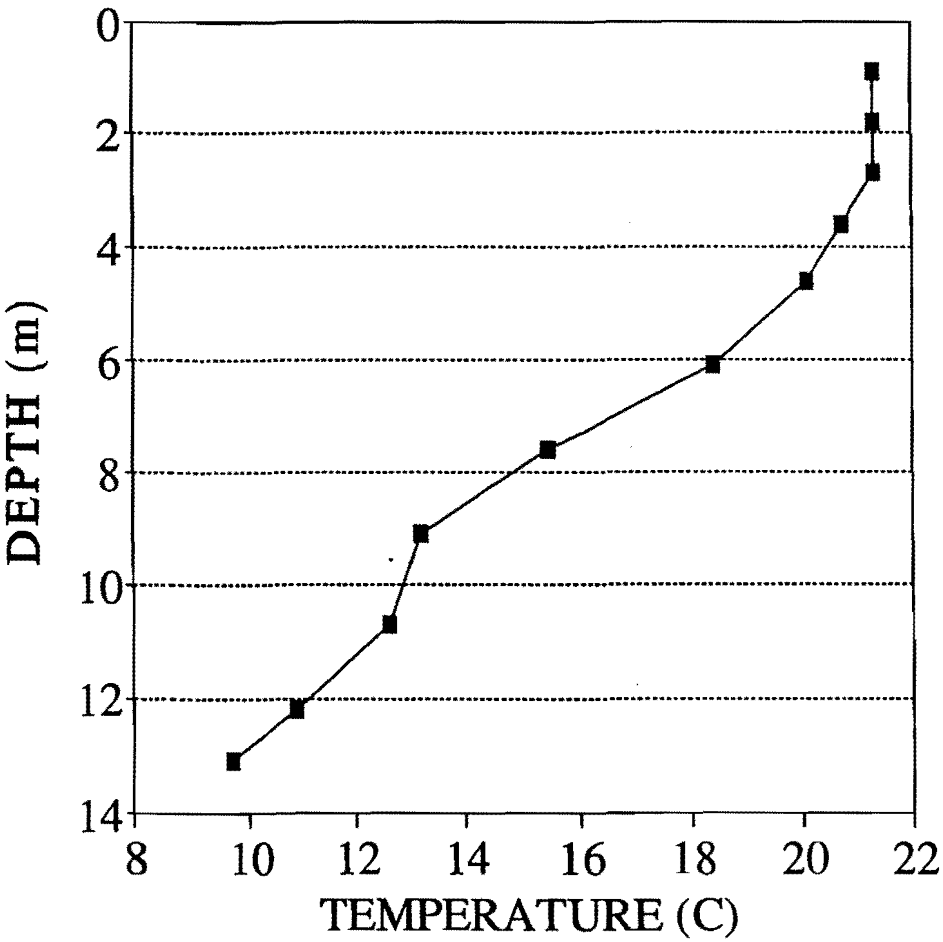


Figure A-10

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- September 28, 1990



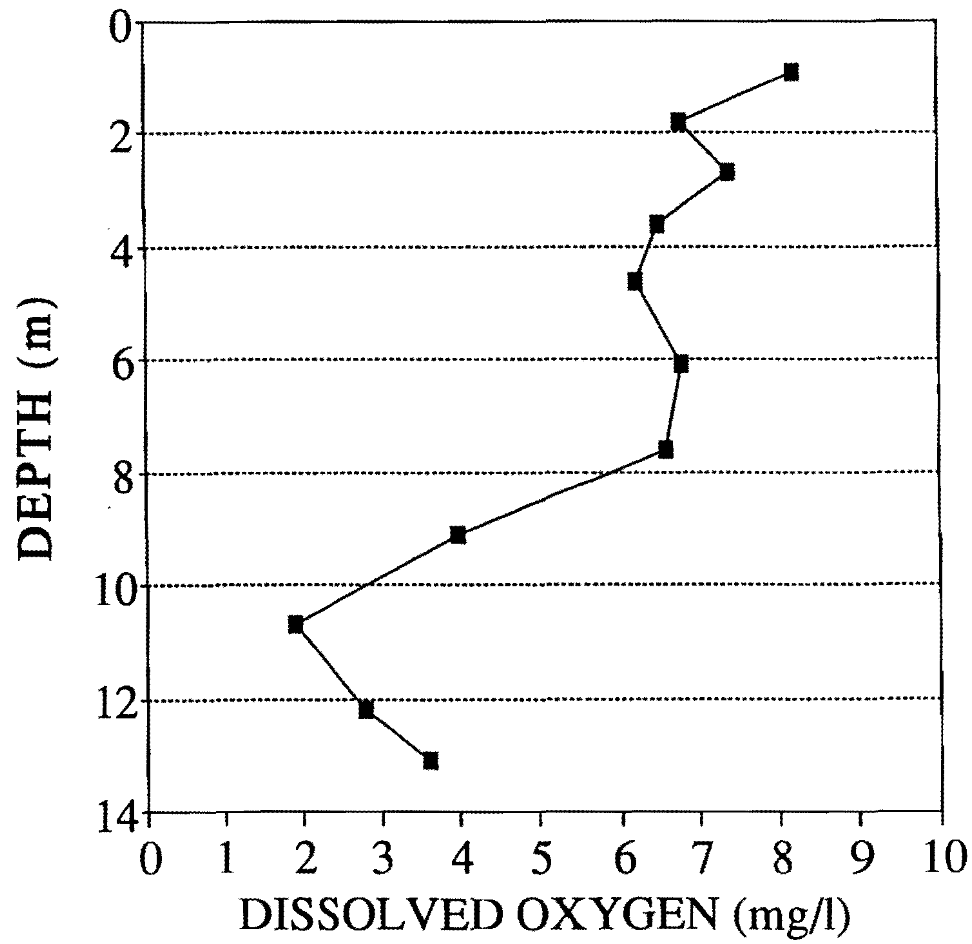


Figure A-11

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- June 6, 1991

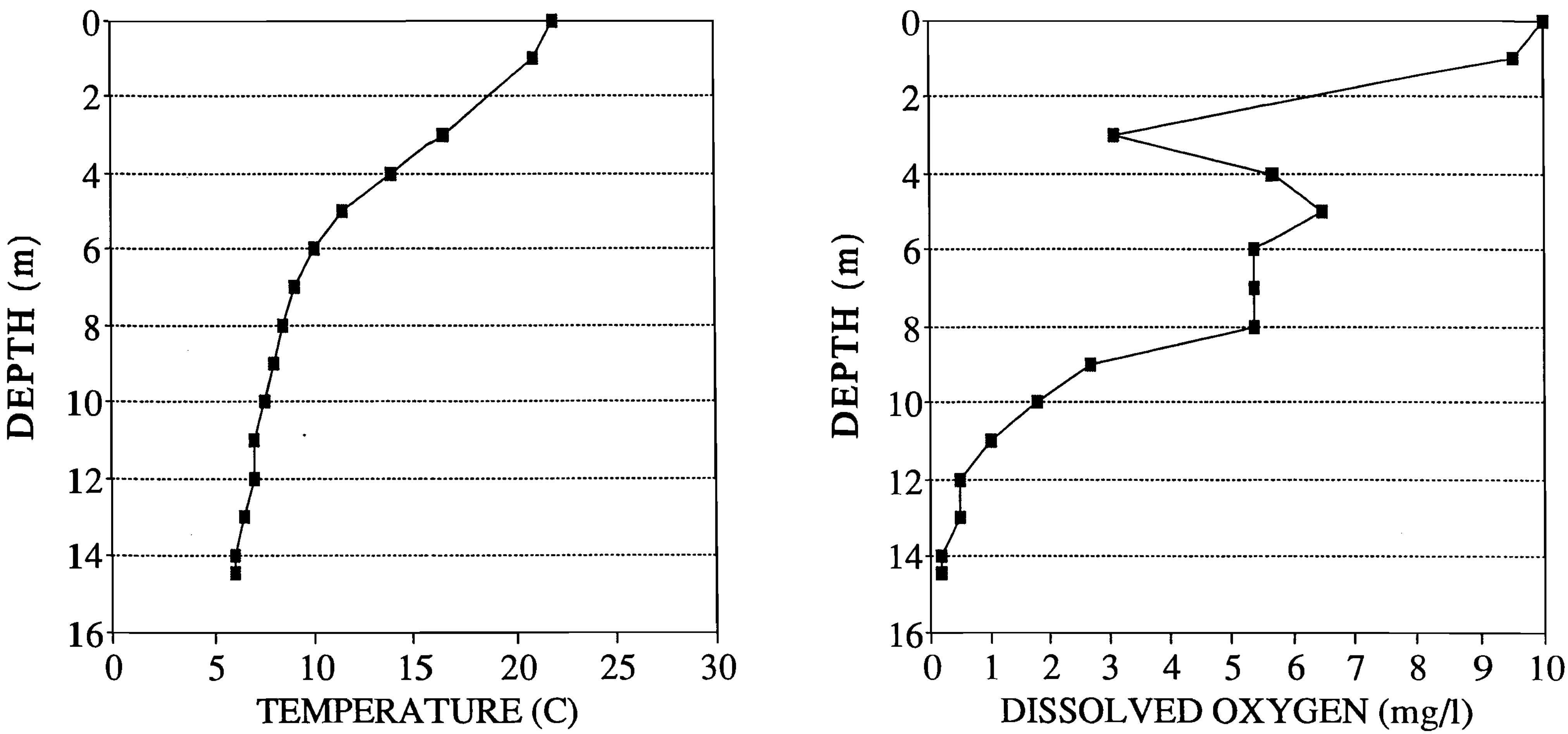


Figure A-12

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- July 7, 1991

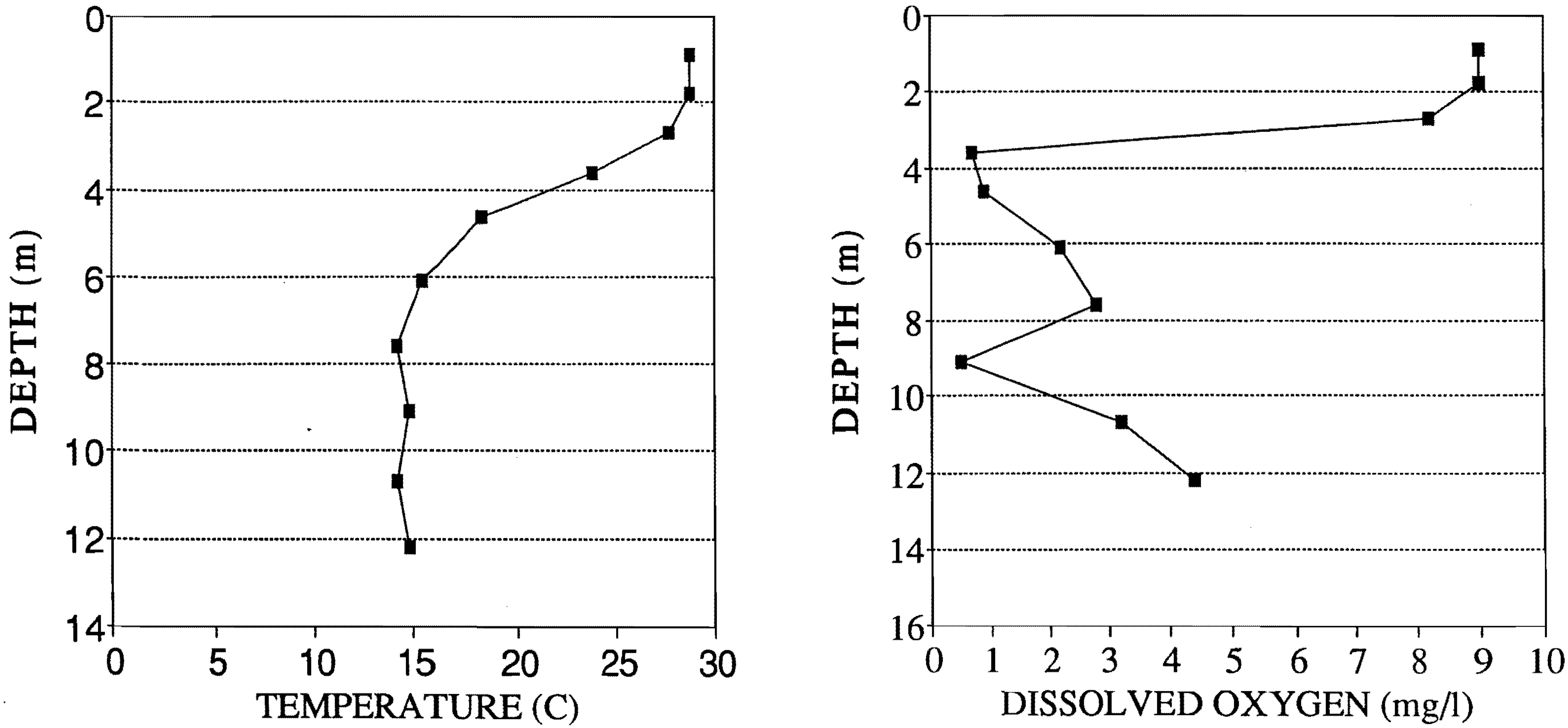
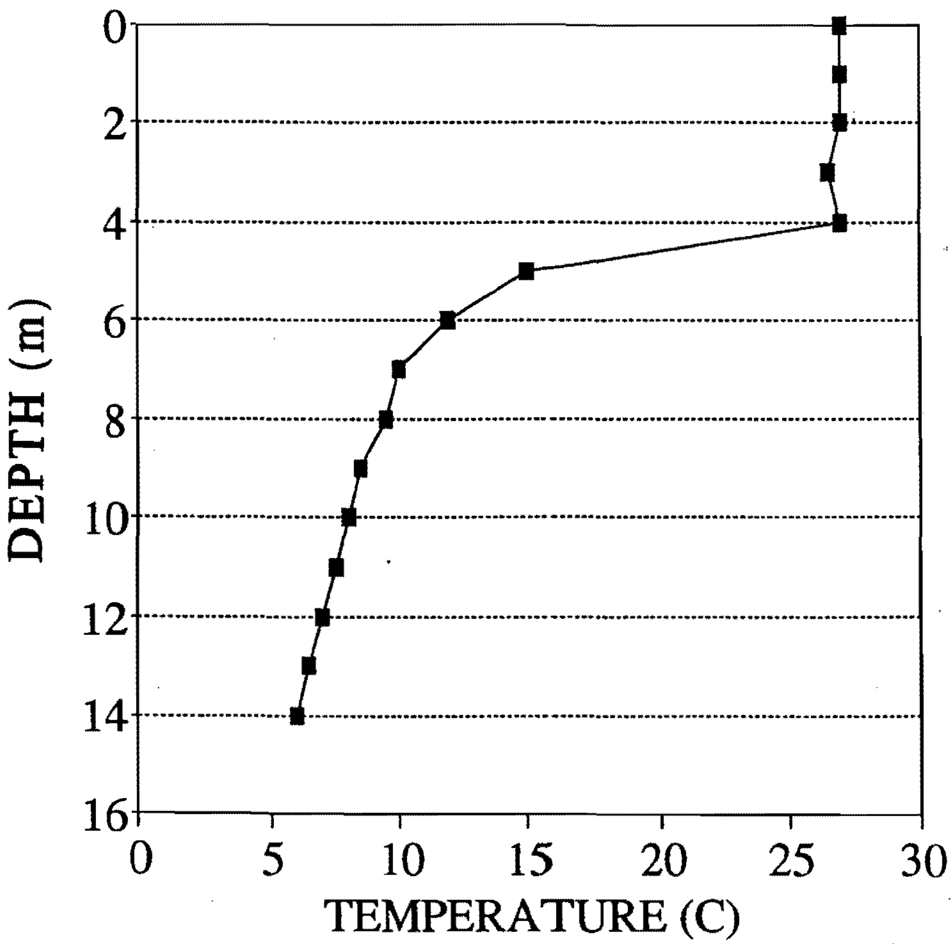


Figure A-13

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- July 23, 1991



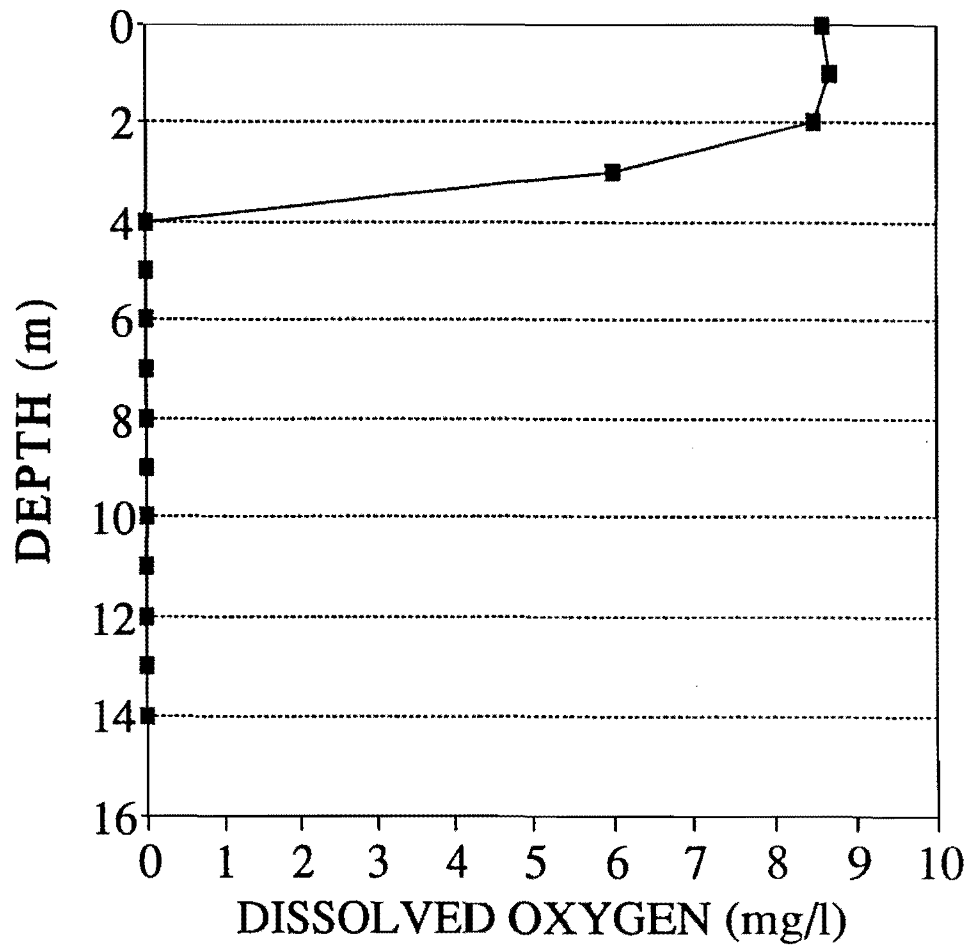


Figure A-14

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- August 8, 1991

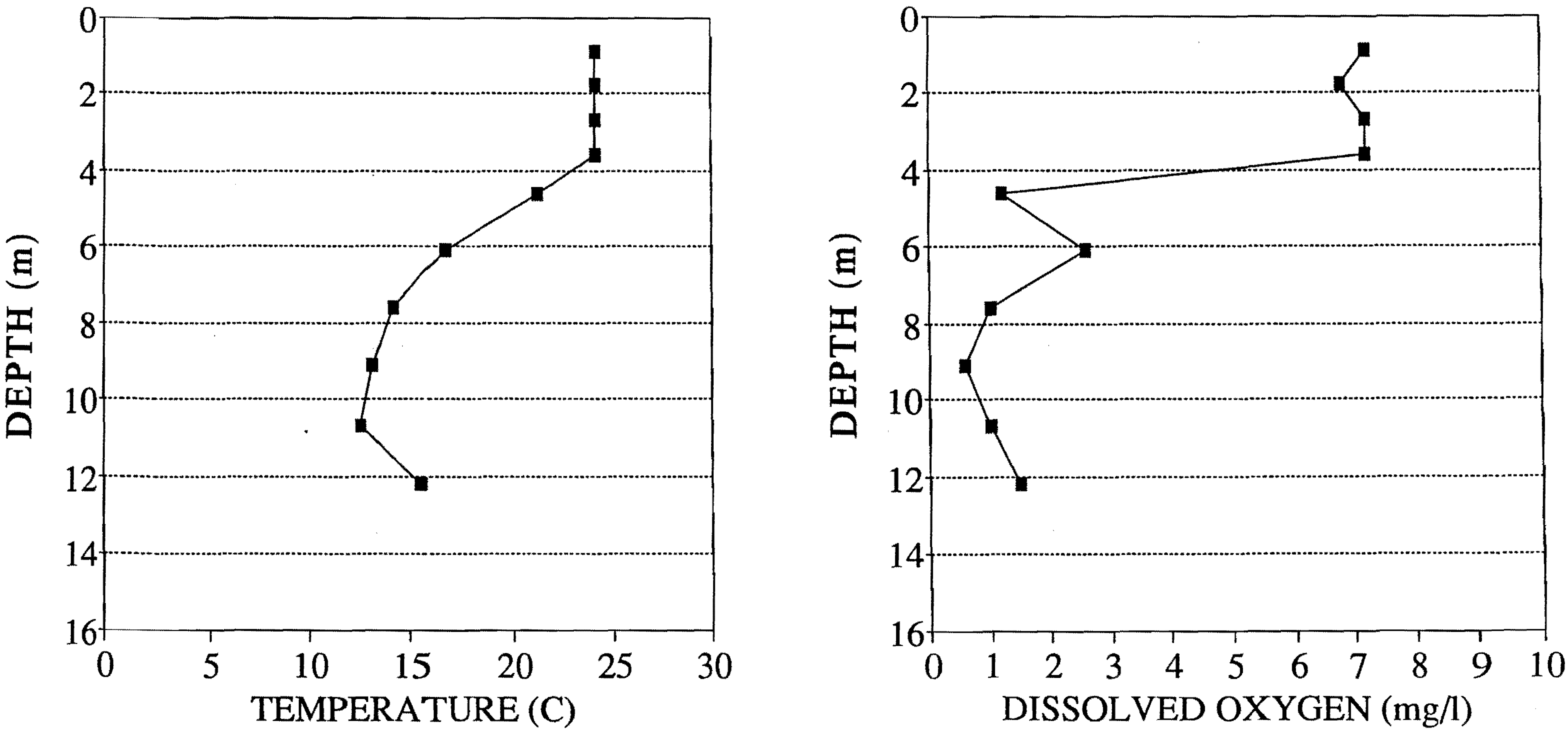
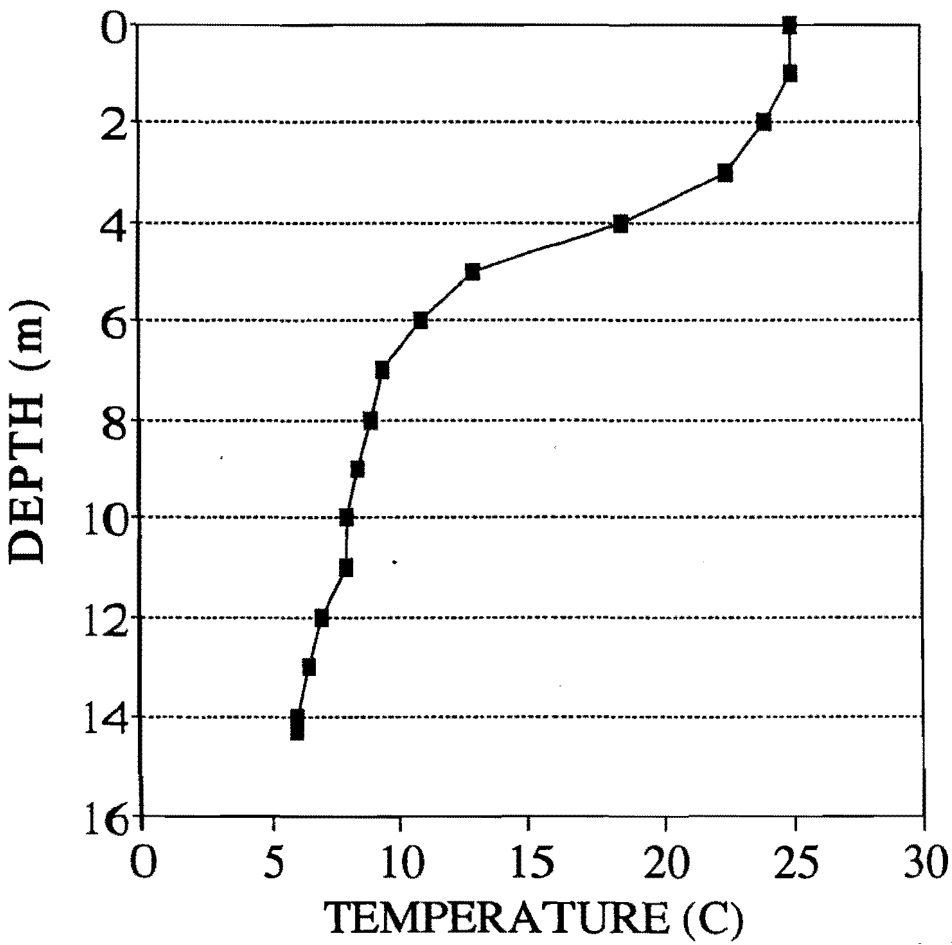


Figure A-15

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- August 28, 1991



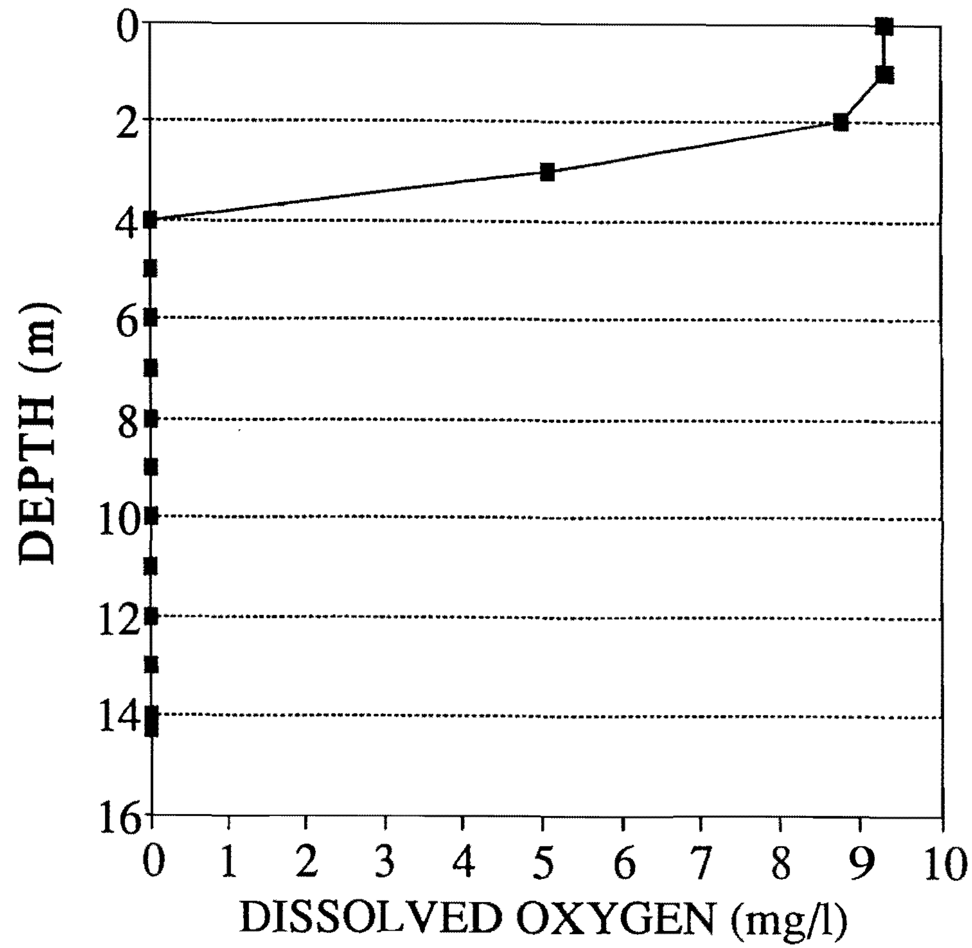


Figure A-16

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- September 9, 1991

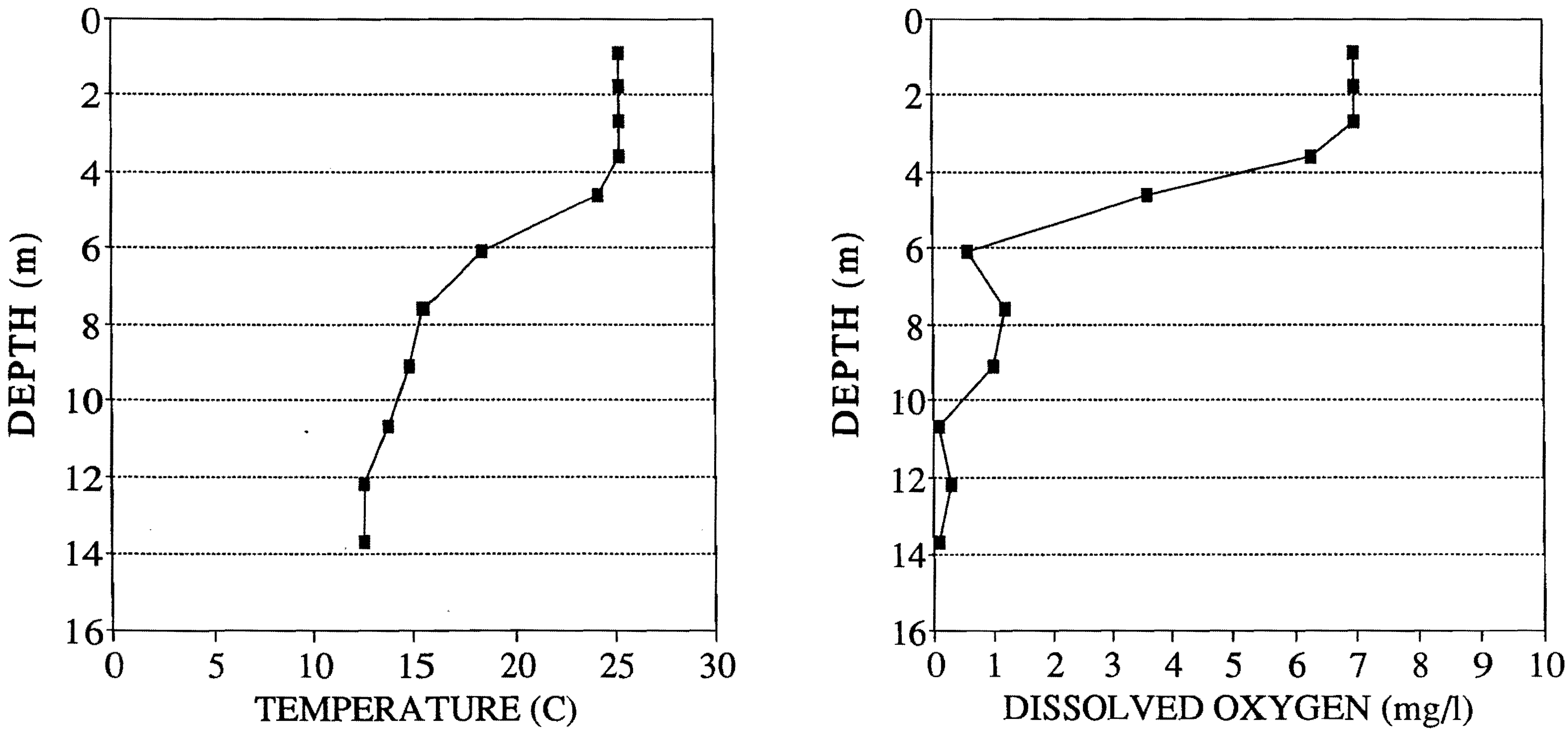
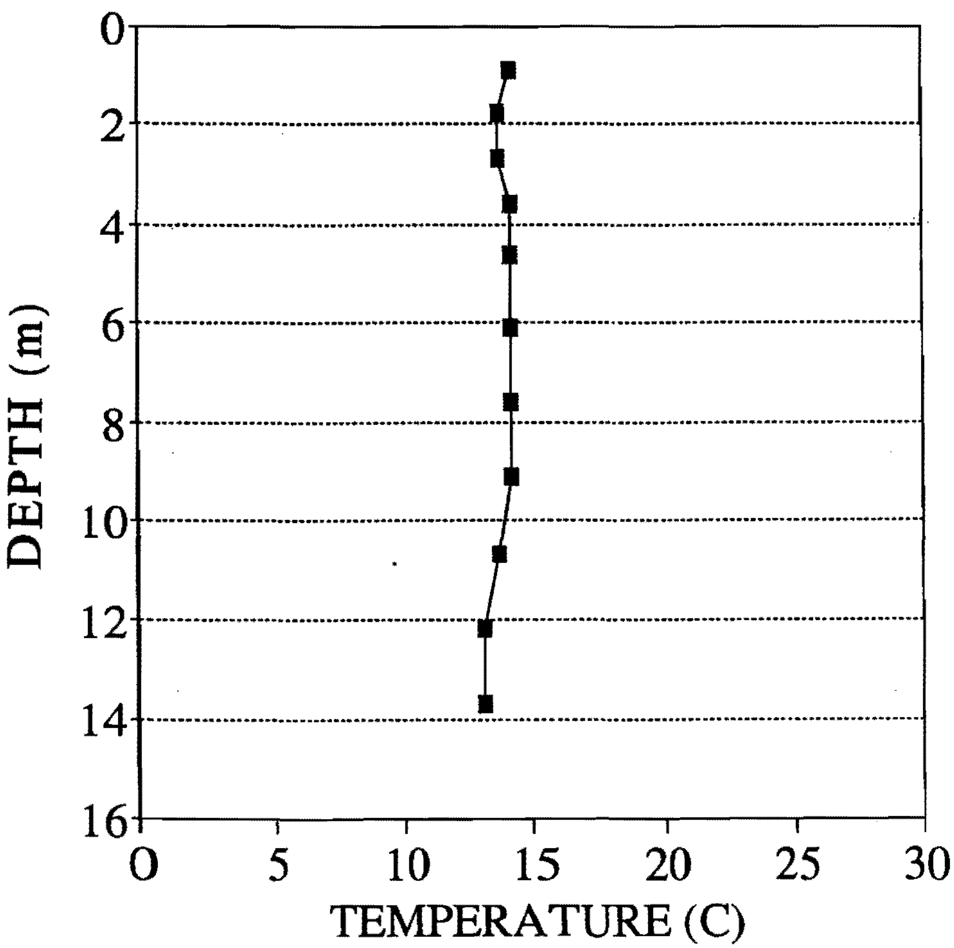


Figure A-17

NUGGET LAKE--STATION 4

Temperature/Dissolved Oxygen Profiles -- October 10, 1991



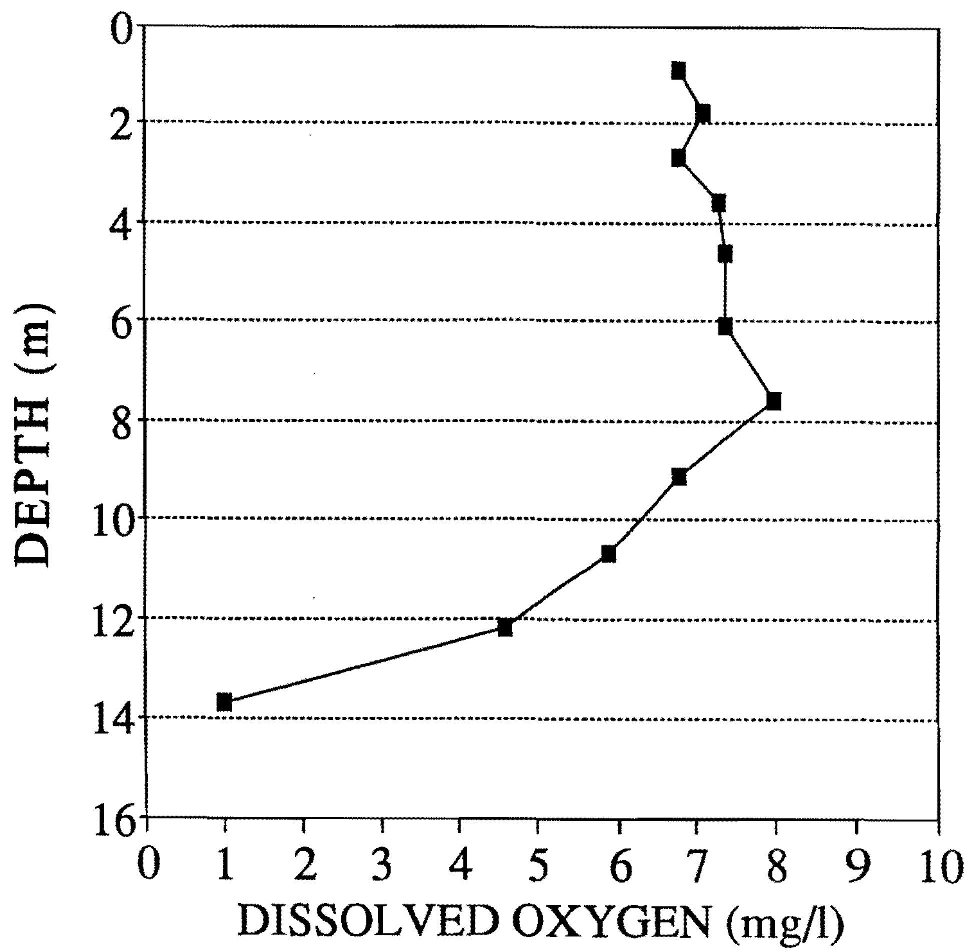


Figure A-18

TABLE A-1. 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 3

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	pH	Total P (mg/l)
07/09/91	3.6	0.9	0.9	61.6	28.9	9.0	9.4	0.064
			1.8	--	27.2	8.0	9.3	--
			2.7	--	26.7	6.4	7.7	--
			3.6	--	25.6	4.4	8.3	0.115
08/08/91	3.6	1.7	0.9	27.7	23.9	7.0	8.2	--
			1.8	--	23.9	6.6	8.2	--
			2.7	--	23.9	7.3	8.2	--
			3.6	--	23.3	5.8	7.6	--
09/09/91	3.6	1.4	0.9	25.1	25.6	8.2	8.4	0.039
			1.8	--	25.6	8.0	8.3	--
			2.7	--	25.6	7.8	8.3	--
			3.6	--	25.0	6.2	7.6	0.074
10/10/91	3.6	4.0	0.9	3.7	14.4	7.5	7.6	0.042
			1.8	--	13.9	7.4	7.7	--
			2.7	--	13.9	7.6	7.8	--
			3.6	--	13.9	7.5	7.7	0.041

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2. 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	Specific Cond. (umhos/cm @ 25 degrees C)	pH	Total P (mg/l)	Ortho P (mg/l)	Nitrate + Nitrite (mg/l)	Ammonia N (mg/l)	TKN (mg/l)	Alkalinity (mg/l)
06/06/91	15.1	0.9	0-2	26.0	--	--	--	8.2	0.092	0.027	0.49	0.055	0.9	52
			0.0	--	22.0	10.0	157	--	--	--	--	--	--	--
			1.0	--	21.0	9.5	157	--	--	--	--	--	--	--
			2.0	--	20.8	8.0	152	--	--	--	--	--	--	--
			3.0	--	16.5	3.1	166	--	--	--	--	--	--	--
			4.0	--	14.0	5.7	184	--		--	--	--	--	--
			4.5	--	--	--	--	--	0.060	--	--	--	--	--
			5.0	--	11.5	6.5	185	--	--	--	--	--	--	--
			6.0	--	10.1	5.4	188	--	--	--	--	--	--	--
			7.0	--	9.1	5.4	182	--	--	--	--	--	--	--
			8.0	--	8.5	5.4	176	--	--	--	--	--	--	--
			9.0	--	8.0	2.7	178	--	--	--	--	--	--	--
			10.0	--	7.5	1.8	184	--	--	--	--	--	--	--
			11.0	--	7.0	1.0	190	--	--	--	--	--	--	--
			12.0	--	7.0	0.5	191	--	--	--	--	--	--	--
			13.0	--	6.5	0.5	200	--	--	--	--	--	--	--
			14.0	--	6.0	0.2	210	--	--	--	--	--	--	--
			14.5	--	6.0	0.2	--	--	0.086	--	--	--	--	--

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2 (Continued). 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	pH	Total P (mg/l)
07/09/91	12.2	1.1	0.9	37.8	28.8	9.0	9.2	0.050
			1.8	--	28.8	9.0	9.2	--
			2.7	--	27.7	8.2	9.1	--
			3.6	--	23.9	0.7	7.5	--
			4.6	--	18.4	0.9	7.2	--
			6.1	--	15.5	2.2	7.2	--
			7.6	--	14.3	2.8	7.2	--
			9.1	--	14.9	0.5	7.3	--
			10.7	--	14.3	3.2	7.3	--
			12.2	--	14.9	4.4	7.4	0.119

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2 (Continued). 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	Specific Cond. (umhos/cm @ 25 degrees C)	pH	Total P (mg/l)	Ortho P (mg/l)	Nitrate + Nitrite (mg/l)	Ammonia N (mg/l)	TKN (mg/l)
07/23/91	14.5	1.5	0-2	--	--	--	--	9.2	0.052	0.004	0.9	0.011	0.9
			0.0	--	27.0	8.6	194	--	--	--	--	--	--
			1.0	--	27.0	8.7	194	--	--	--	--	--	--
			2.0	--	27.0	8.5	194	--	--	--	--	--	--
			3.0	--	26.5	6.0	195	--	--	--	--	--	--
			4.0	--	27.0	0.0	175	--	--	--	--	--	--
			5.0	--	15.1	0.0	182	--	0.046	--	--	--	--
			6.0	--	12.0	0.0	183	--	--	--	--	--	--
			7.0	--	10.0	0.0	185	--	--	--	--	--	--
			8.0	--	9.5	0.0	179	--	--	--	--	--	--
			9.0	--	8.5	0.0	181	--	--	--	--	--	--
			10.0	--	8.0	0.0	183	--	--	--	--	--	--
			11.0	--	7.5	0.0	194	--	--	--	--	--	--
			12.0	--	7.0	0.0	203	--	--	--	--	--	--
			13.0	--	6.5	0.0	200	--	--	--	--	--	--
			14.0	--	6.0	0.0	225	--	--	--	--	--	--

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2 (Continued). 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	pH	Total P (mg/l)
08/08/91	12.2	2.7	0.9	6.62	24.2	7.2	8.1	--
			1.8	--	24.2	6.8	8.1	--
			2.7	--	24.2	7.2	8.1	--
			3.6	--	24.2	7.2	8.0	--
			4.6	--	21.3	1.2	7.2	--
			6.1	--	16.7	2.6	7.2	--
			7.6	--	14.3	1.0	7.2	--
			9.1	--	13.2	0.6	7.3	--
			10.7	--	12.6	1.0	7.4	--
			12.2	--	15.5	1.5	7.4	--

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2 (Continued). 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	Specific Cond. (umhos/cm @ 25 degrees C)	pH	Total P (mg/l)	Ortho P (mg/l)	Nitrate + Nitrite (mg/l)	Ammonia N (mg/l)	TKN (mg/l)
08/28/91	14.8	3.4	0-2	8.0				8.8	0.024	0.018	<0.007	0.025	0.8
			0.0	--	25.0	9.3	225	--	--	--	--	--	--
			1.0	--	25.0	9.3	221	--	--	--	--	--	--
			2.0	--	24.0	8.8	224	--	--	--	--	--	--
			3.0	--	22.5	5.1	231	--	--	--	--	--	--
			4.0	--	18.5	0.0	237	--	--	--	--	--	--
			5.0	--	13.0	0.0	254	--	0.030	--	--	--	--
			6.0	--	11.0	0.0	219	--	--	--	--	--	--
			7.0	--	9.5	0.0	213	--	--	--	--	--	--
			8.0	--	9.0	0.0	215	--	--	--	--	--	--
			9.0	--	8.5	0.0	208	--	--	--	--	--	--
			10.0	--	8.0	0.0	206	--	--	--	--	--	--
			11.0	--	8.0	0.0	213	--	--	--	--	--	--
			12.0	--	7.0	0.0	231	--	--	--	--	--	--
			13.0	--	6.5	0.0	244	--	--	--	--	--	--
			14.0	--	6.0	0.0	252	--	--	--	--	--	--
			14.3	--	6.0	0.0	255	7.5	1.06	--	--	2.26	--

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-2 (Continued). 1991 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Chl. a (mg/cu.m)	Temp. (Celsius)	D.O. (mg/l)	pH	Total P (mg/l)
09/09/91	13.7	2.1	0.9	19.8	25.3	7.0	7.9	0.027
			1.8	--	25.3	7.0	8.1	--
			2.7	--	25.3	7.0	8.0	--
			3.6	--	25.3	6.3	8.0	--
			4.6	--	24.2	3.6	7.4	--
			6.1	--	18.4	0.6	7.2	--
			7.6	--	15.5	1.2	7.3	--
			9.1	--	14.9	1.0	7.2	--
			10.7	--	13.8	0.1	7.2	--
			12.2	--	12.6	0.3	7.3	--
			13.7	--	12.6	0.1	7.3	0.830
10/10/91	13.7	4.9	0.9	3.68	14.3	6.8	7.7	0.051
			1.8	--	13.8	7.1	7.8	--
			2.7	--	13.8	6.8	7.7	--
			3.6	--	14.3	7.3	7.7	--
			4.6	--	14.3	7.4	7.8	--
			6.1	--	14.3	7.4	7.8	--
			7.6	--	14.3	8.0	7.6	--
			9.1	--	14.3	6.8	7.7	--
			10.7	--	13.8	5.9	7.7	--
			12.2	--	13.2	4.6	7.6	--
			13.7	--	13.2	1.0	7.6	0.990

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-3. 1990 NUGGGET LAKE WATER QUALITY DATA--STATION 3

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Temp. (Celsius)	D.O. (mg/l)	pH
07/09/90	3.6	2.3	0.9	24.8	6.0	8.2
			1.8	24.8	5.4	8.2
			2.7	23.7	3.4	7.6
			3.6	20.4	2.0	7.2
08/28/90	4.6	--	0.9	21.9	8.2	8.2
			1.8	21.9	7.4	8.1
			2.7	21.9	6.3	8.0
			3.6	21.3	5.3	7.6
			4.6	20.1		7.3
10/29/90	3.6	1.7	0.9	5.7	7.4	7.3
			1.8	5.7	7.4	7.4
			2.7	5.1	8.0	7.5
			3.6	5.7	8.3	7.5

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-4. 1990 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Temp. (Celsius)	D.O. (mg/l)	pH	Total P (mg/l)
07/09/90	13.1	2.9	0.3	--	--	--	0.03
			0.9	26.4	6.8	8.4	--
			2.7	26.4	4.3	7.8	--
			3.6	20.4	0.4	7.2	--
			4.6	18.3	0.5	7.2	--
			6.1	16	0.8	7.4	--
			7.6	13.9	--	7.4	--
			9.1	12.8	--	7.5	--
			10.7	11.7	--	7.5	--
			12.2	10.6	--	7.7	--
			13.1	10.6	--	7.7	0.15
07/24/90	13.1	1.8	0.3	--	--	--	0.04
			0.9	25.3	9.1	7.4	--
			1.8	25.3	7.2	8.5	--
			2.7	23.7	2	7.3	--
			3.6	21.5	3.2	6.9	--
			4.6	19.3	0.6	7.0	--
			6.1	16	2.2	6.9	--
			7.6	15	--	7.2	--
			9.1	13.9	--	7.3	--
			10.7	12.8	--	7.4	--
			12.2	10.6	--	7.3	--
			13.1	7.9	--	7.3	0.08

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-4. 1990 NUGGGET LAKE WATER QUALITY DATA--STATION 4

Date	Max. Depth (M)	Secchi Disc (M)	Sample Depth (M)	Temp. (Celsius)	D.O. (mg/l)	pH
08/28/90	13.1	--	0.3	--	--	--
			0.9	21.3	5.7	7.6
			1.8	21.3	5.4	7.5
			2.7	21.3	4.9	7.4
			3.6	20.7	0.4	7
			4.6	20.1	1.9	7
			6.1	18.4	1.2	7
			7.6	15.5	--	7.1
			9.1	13.2	--	7.2
			10.7	12.6	--	7.2
			12.2	10.9	--	7.4
			13.1	9.7	--	7.4
09/28/90	13.1	1.7	0.3	--	--	--
			0.9	17.2	8.2	7.9
			1.8	16.7	6.8	7.6
			2.7	16.7	7.4	7.5
			3.6	16.7	6.5	7.6
			4.6	16.1	6.2	7.5
			6.1	16.1	6.8	7.5
			7.6	16.1	6.6	7.5
			9.1	15.5	4	7.4
			10.7	14.9	1.9	7.3
			12.2	13.8	2.8	7.3
			13.1	14.9	3.6	7.3

Denotes conditions unfavorable for the survival of gamefish.

TABLE A-5. NUGGET LAKE OUTFLOW DATA

PLUM CREEK BELOW DAM OFF. AT NUGGET LAKE
STATION PL-1

PARAMETER	07/02/90	07/31/90	09/06/90	10/03/90	12/05/90
pH, Field	8.26	8.06	8.1	8.12	8.16
pH, Lab	7.6	7.7	7.4	7.4	8
Total Alkalinity (mg/l as CaCo3)	73	65	102	109	95
Total Calcium (mg/l)	17	15	23	24	23
Chloride (mg/l)	6.5	6	6	7	6
Specific Conductance (umho/cm @ 25 C)	179	146	459	240	226
Total Hardness (mg/l as CaCo3)	77	67	100	110	99
Total Magnesium (mg/l)	8	7	10	11	10
Ammonia Nitrogen (mg/l)	0.23	0.17	0.95	1.3	0.59
Nitrate + Nitrite Nitrogen (mg/l)	0.48	0.25	0.17	0.4	0.34
Total Kjeldahl Nitrogen (mg/l)	1.1	1.1	--	--	1.2
Total Phosphorus (mg/l)	0.09	0.12	--	--	0.09
Ortho Phosphorus (mg/l)	0.037	0.046	0.162	0.22	0.029
Total Suspended Solids (mg/l)	14	13	8	8	2
Water Temperature (Degrees C)	18.5	22	11	11.5	2.5
Dissolved Oxygen (mg/l)	8.0	7.7	7.8	8.3	18.2
Fecal Coliform Bacteria (#/100 mls)	--	280	--	--	--
Fecal Streptococcus Bacteria (#/100 mls)	--	190	--	--	--

PLUM CREEK AT FAIRVIEW DR BELOW DAM AT NUGGET LAKE
STATION PL-2

PARAMETER	07/02/90	07/31/90	09/06/90	11/08/90	12/05/90
pH, Field	8.18	7.95	7.96	8.21	7.99
Ammonia Nitrogen (mg/l)	<0.02	0.1	0.04	0.02	0.03
Water Temperature (Degrees C)	19	19.5	13	4.5	3
Dissolved Oxygen (mg/l)	11.4	7.5	7.5	10.4	11.6

TABLE A-5 (Continued). NUGGET LAKE OUTFLOW DATA

PLUM CREEK AT PLUM CITY CTH S IN PLUM CITY
STATION PL-3

PARAMETER	07/02/90	07/31/90	09/06/90	12/05/90	01/09/91
pH, Field	8.23	7.96	8.05	8.27	8.51
pH, Lab	8.1	7.9	8	8.2	8.1
Total Alkalinity (mg/l as CaCo3)	193	141	250	255	261
Total Calcium (mg/l)	41	36	59	23	62
Chloride (mg/l)	7	6	7	7	7
Specific Conductance (umho/cm @ 25 C)	382	294	458	516	523
Total Hardness (mg/l as CaCo3)	190	160	270	99	280
Total Magnesium (mg/l)	22	17	29	10	31
Ammonia Nitrogen (mg/l)	<0.02	0.1	0.04	<0.02	<0.02
Nitrate + Nitrite Nitrogen (mg/l)	1.44	1.12	2.02	2.1	2.1
Total Kjeldahl Nitrogen (mg/l)	0.5	0.8	--	0.3	<0.2
Total Phosphorus (mg/l)	0.06	0.13	--	0.04	0.04
Ortho Phosphorus (mg/l)	0.024	0.052	0.033	0.023	0.022
Total Suspended Solids (mg/l)	16	51	8	9	10
Water Temperature (Degrees C)	19.5	19	13	3	2
Dissolved Oxygen (mg/l)	10.8	7.6	8.9	13.5	12.2