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Spatial, diel and seasonal variations in dissolved oxygen and temperature were measured in Triangle Lake, Oregon. Spatial dissolved oxygen and temperature variations measured in the stratified lake are presented to illustrate the horizontal uniformity of the lake and to demonstrate the applicability of the one dimensional assumption for sampling and theoretical modeling of temperature and dissolved oxygen.

A nocturnal density overturning within the epilimnion was investigated and its significance as a mode of vertical mixing evaluated. Seasonal variations in temperature and dissolved oxygen indicated that a complete winter overturn did not occur. The effect of seasonal variations in temperature and dissolved oxygen upon the habitat of game fish within the lake is presented.

Spatial, Diel and Seasonal Variations in Dissolved Oxygen and Temperature within a Stratified Lake

by

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INTRODUCTION

The usefulness of lakes and impoundments can be substantially reduced by the depletion of dissolved oxygen, DO, from the deeper portions of these water bodies. In addition, waters containing low DO concentrations which are released from impoundments may harm receiving streams. Species which normally require a relatively high concentration of DO are subject to stresses at reduced DO concentrations which make them less able to compete for needed resources with other species. Exposure to low DO for prolonged periods may result in reduction of the species and eventual elimination from the system.

The DO variations in temperate lakes depend to a large extent on the seasonal variations in temperature. During the spring, lake surface waters usually increase in temperature resulting in the formation of three general mixing regions. The warmer upper region (epilimnion) consists of relatively freely circulating water with small and variable temperature gradients. Below the epilimnion is a region of rapidly decreasing temperature with depth (metalimnion) in which vertical mixing is low due to the thermal stability. Within the metalimnion, the plane at which the vertical temperature gradient is greatest is defined as the thermocline. Vertical mixing is often a minimum at or near the thermocline. The region below the metalimnion (hypolimnion) contains smaller vertical temperature gradients and has low mixing, though possibly greater than the mixing across the thermocline.

During the late summer and fall, cooling of the surface waters occurs. The cooler surface water, being more dense, sinks to depths of equal density. Isothermal conditions from the surface to the depth to which the surface water sunk occurs as a result of this overturning. Overturning continues either until isothermal conditions exist throughout the depth of the lake or until surface waters begin to warm. Dimictic lakes overturn during autumn and spring. In warmer monomictic lakes in which temperatures remain above $4^{o}C$, overturning occurs only during the late summer-fall period.

During the periods of thermal stratification, the DO concentrations within the epilimnion remain high due to air-water oxygen transfer and photosynthetic oxygenation. When DO concentrations in the surface waters fall below saturation, oxygen is transferred from the air into the water while the reverse is true when oxygen concentrations exceed the saturation value. As a result, surface DO concentrations often remain quite close to saturation.

Low vertical mixing across the metalimnion results in only a small transfer of DO from the upper waters to the hypolimnion below.

Plankton which sink from the epilimnion and other organics exert an oxygen demand on the deeper waters. Sinking plankton also contribute to the buildup of benthal deposits which exert oxygen demands on the overlying waters. The combination of low DO input into the hypolimnion and oxygen demands within the hypolimnion result in the decline of hypolimnetic DO concentrations throughout the summer, generally until overturning leads to the mixing of upper and lower waters.

A principal assumption that simplifies both the theoretical and experimental investigation of DO changes in stratified lakes is that the horizontal variations in both temperature and DO are very small compared to the vertical variations. If this assumption is reasonably well approximated, sampling may be conducted at one horizontal station. In addition, if the one dimensional assumption is justified, the mathematical modeling of both temperature variations (11) and DO variations (1) is greatly simplified.

The one dimensional assumption implies that the horizontal mixing is sufficient to result in near horizontal uniformity and/or that the reactions occurring at different depths which change the DO and temperature are nearly identical across horizontal areas. The time over which DO and temperature changes occur are of particular importance. As an example, significant horizontal variations in photosynthesis which occur over time intervals shorter than the time needed for substantial horizontal mixing can result in a real world departure from the one-dimensional assumption (1). Sampling procedures and theoretical models which make use of the one-dimensional assumption would poorly measure or describe such variations. In stratified lakes, however, DO and temperature variations which occur over periods of weeks and months are often considered to be of greater significance than shorter term variations.

It was the purpose of this study to investigate through field measurements the factors affecting seasonal DO variations, to further investigate the significance of short term temperature and DO variations, and to investigate the validity and limitations of the one-dimensional assumption for temperature and DO.

EXPERIMENTAL SITE LOCATION AND CHARACTERISTICS

All field measurements were taken on Triangle Lake located approximately 35 miles west of Eugene, Oregon. The lake has a surface area of 293 acres, a maximum depth of 91 feet and a mean depth of approximately 31 feet (13). The shoreline areas are generally steep sloped (see Figure 1). The lake drainage area is 52.5 square miles. Most of the lake's average annual discharge of 152,000 acre feet occurs from November through March. The maximum recorded discharge is 4180 cfs which occurred on February 18, 1949. The average discharge from the lake during the months of July, August and September is 26.9, 15.7, and 16.1 cfs, respectively (20, 21).

The lake is used extensively for fishing, boating, and swimming. There are approximately 60 residences, many of them only summer residences, and several small businesses located on or near the shoreline. All homes and businesses utilize septic tanks with drain fields for waste water disposal.

Game fish including rainbow trout, cutthroat and kokanee salmon are present in Triangle Lake along with warm water fish such as largemouth bass, bluegill, yellow perch and catfish (13). The predominant aquatic vegetation is *Elodea densa* which grows along the entire shoreline of the lake out to a depth of 10 to 15 feet.

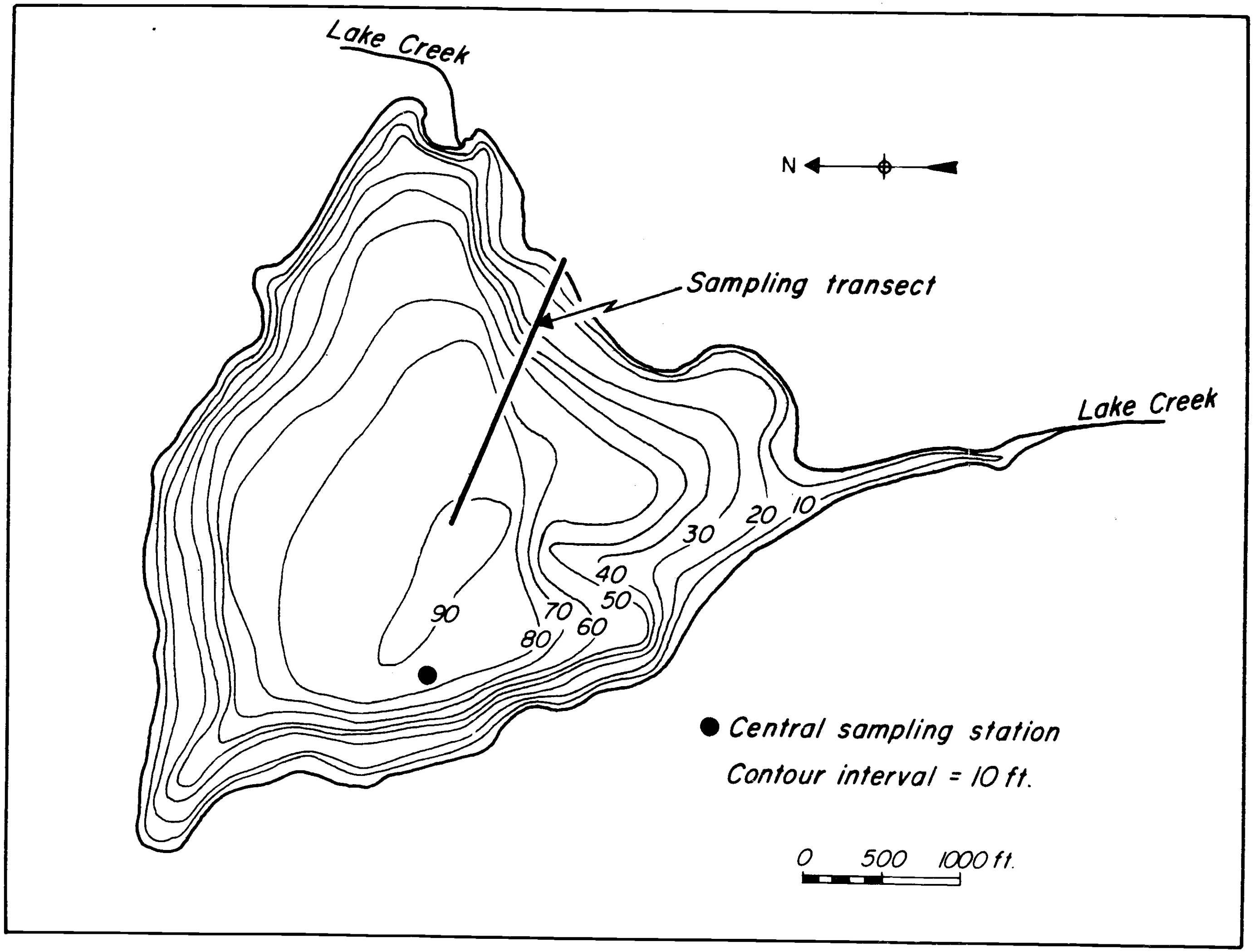

Figure 1. Hydrographic map of Triangle Lake, Oregon, showing central sampling station and sampling transect.

EXPERIMENTAL PROCEDURES

In situ temperature measurements were taken in Triangle Lake with a thermistor attached to a 100 foot graduated cord. The thermistor had an accuracy of 0.1°C with a reproducibility of 0.02°C. Temperatures were read directly to the nearest tenth of a degree and estimated to the nearest one-hundredth of a degree. The thermistor was suspended over the side of a boat and was allowed to reach equilibrium before temperatures were recorded. The thermistor had a time-constant of three seconds so it quickly came into equilibrium with the surrounding water. Prior to each sampling period the thermistor was checked against three laboratory thermometers to insure that the instrument had not suffered damage during storage.

During the period of August 1969 to April 1970, DO in Triangle Lake was measured by the Azide Modification of the Winkler Method (14). Samples were collected at appropriate depths using a Fractschy bottle suspended from a graduated cord. The Fractschy bottle was lowered so that the center of its one-foot length was at the depth to be sampled. The sample was transferred from the Fractschy bottle to a 300-ml BOD bottle which was allowed to overflow, displacing approximately one and two-thirds volumes. Negligible reaeration of the sample resulted from this procedure as DO's less than 0.10 mg/l were measured in samples collected from the bottom of the lake.

The samples were "fixed" immediately after being transferred to the BOD bottle and when the weather permitted, the samples were titrated in the field within two hours after collection. Periodically, duplicate samples were collected from the same depth as a check of the sampling procedure. The 0.025 N sodium thiosulfate titrant was standardized prior to each sampling period. Clear sharp titration endpoints aided in accurately determining the DO concentrations.

From May 1970 through August 1970 a YSI Model 54 RC DO Meter with probe was utilized for DO measurements. Mixing across the probe tip was provided by a Delta Model 1010-10 battery powered remote stirrer. The probe was calibrated at a depth of two feet from the surface and periodically checked by the Winkler method at greater depths. Use of the DO probe greatly reduced the required sampling time and the measurements agreed very closely to those recorded by the Winkler method.

During most sampling periods temperature and DO measurements were taken at two foot intervals to a depth of 30 feet and at five foot intervals for the remainder of the lake depth. Inclement weather during the winter months often resulted in a deviation from this standard procedure. Vertical temperature and DO profiles were measured at the central sampling station (see Figure 1) a minimum of once every ten days during the summer months and monthly during the fall, winter and spring. An abandoned, permanently anchored water ski jump marked the location of the central sampling station. This fixed marker was located near the deepest part of the lake and it made it easy to return to the same location for monitoring temperature and DO throughout the year.

Photosynthetic oxygen production was measured by the light and dark bottle method. Oxygen production was measured at depths of 5, 14, 24 and 35 feet. Approximately three liters of lake water was pulled from the desired depth by use of the Fractschy bottle. The three liters sample was placed in a container and thoroughly mixed. Two 300 ml light bottles, two 300 ml dark bottles, and three 300 ml bottles for initial DO values were randomly filled. The light and dark bottles were then suspended from a rod which held them in a horizontal position. The rod and bottles were then lowered back down to the depth at which the samples were pulled. This procedure was repeated for the remaining three depths and all the bottles were left suspended from a float for a period of 24 hours. After 24 hours had elapsed, all the bottles were pulled to the surface and the DO of each was measured. All three light and dark bottle experiments performed were conducted near the central sampling station.

Light penetration was measured as percent surface illumination by the use of a light meter equipped with a deck cell and a submersible cell capable of measuring both incidental and reflected light. The submersible cell was suspended from the boat on a 100 foot graduated cord. Measurements were recorded at two foot intervals to a depth at which light was less than 0.1 percent of surface illumination.

Chlorophyll a was measured according to the procedure outlined by Strickland and Parson (15) using a Beckman Model DB Spectrophotometer with a one centimeter light path. Nitrogen and phosphorus were measured according to the FWPCA Methods for Chemical Analysis of Water and Wastes (19). An autoanalyzer was used in all nitrogen and phosphorus determinations except Kjeldhal nitrogen. All other analyses were performed in accordance with Standard Methods (14).

RESULTS AND DISCUSSION

Spatial Variations

During the summer months, Triangle Lake becomes both thermally and chemically stratified. Figures 2 through 6 illustrate the horizontal and vertical variations of temperature, DO and light within the lake. These figures were prepared from data collected in three hour sampling periods along the transect shown in Figure 1.

The results shown in Figures 2 through 6 indicate that the vertical variations within the lake are far more significant than the horizontal variations. These results suggest that for many purposes, both mathematical and experimental, the lake may be considered to be horizontally uniform. Such an assumption greatly simplifies mathematical and experimental analysis.

A departure from horizontal uniformity which is of interest is shown in Figure 5. DO concentrations were found to decrease within the water regions adjacent to the bottom. Such decreases suggest that benthal oxygen uptake may be significant. Figure 5 also shows higher metalimnic DO within the open waters than within the waters closer to the shore. This difference might be caused by the benthal oxygen demand. Diffusion of both DO and oxygen demanding substances is most significant in the horizontal direction due to the vertical stability. Benthal oxygen demands are thus exerted mainly

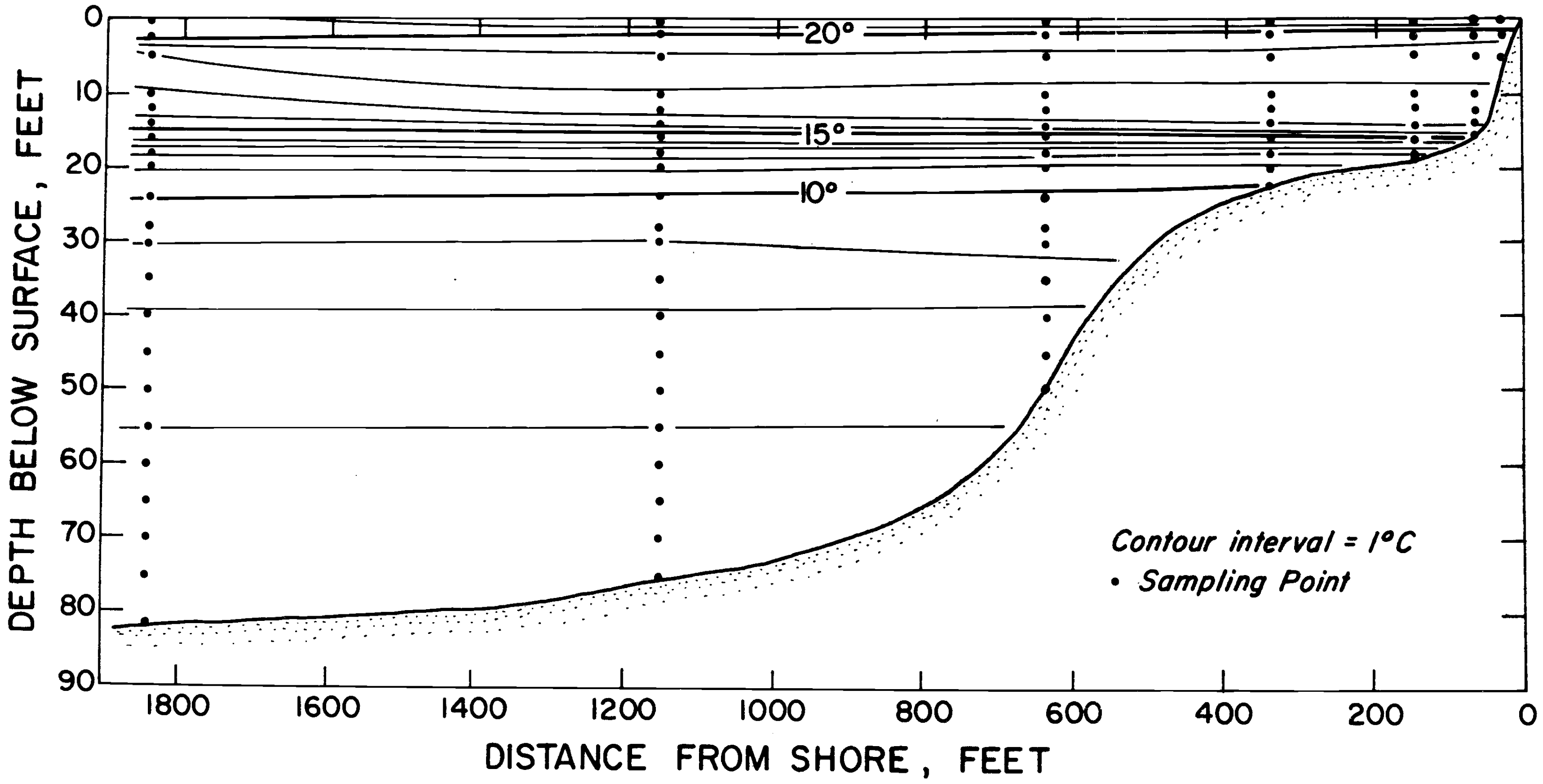

Figure 2. Cross-section of Triangle Lake, showing variations in temperature, June 17, 1970.

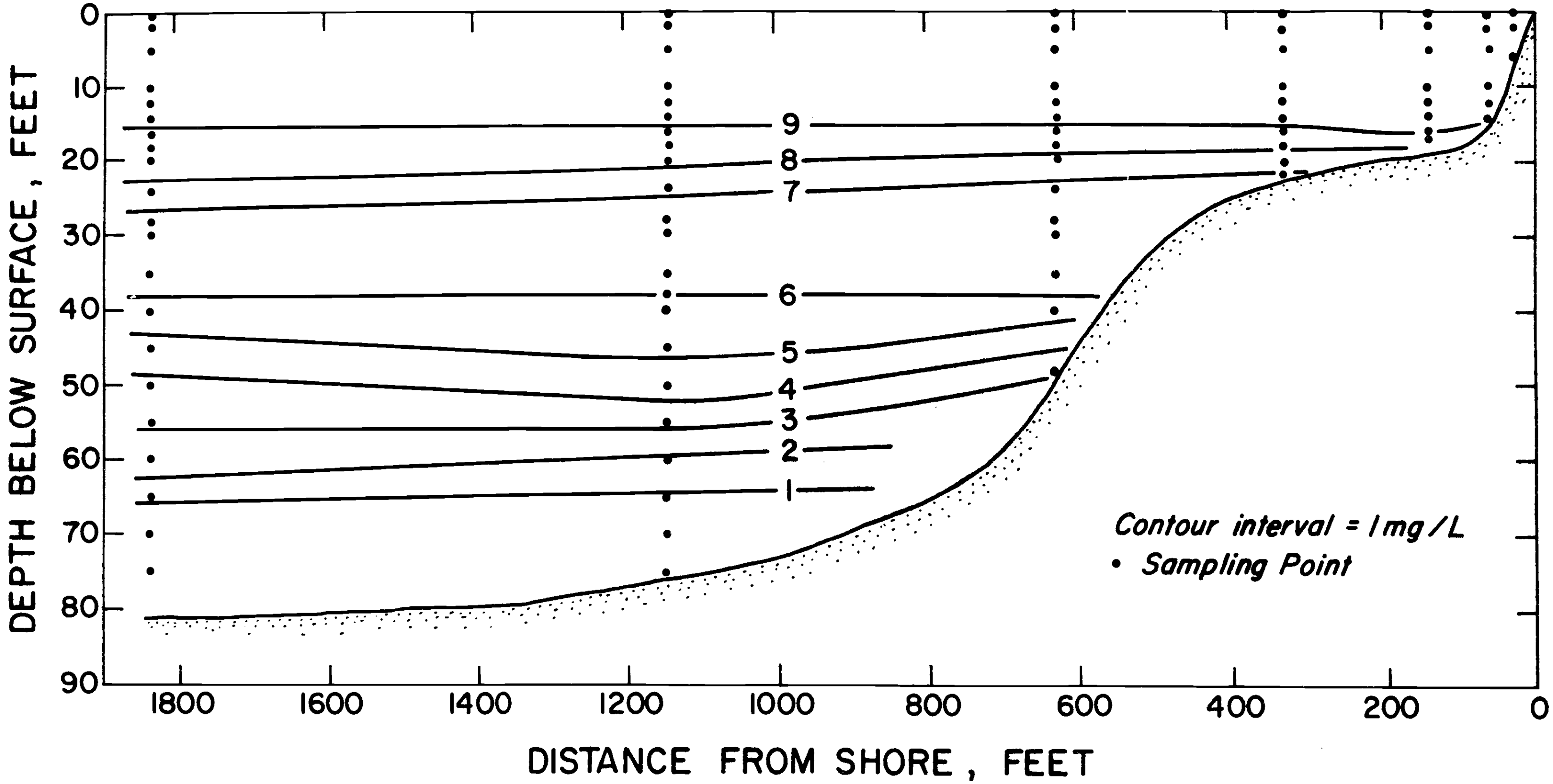

Figure 3. Cross-section of Triangle Lake, showing variation in dissolved oxygen, June 17, 1970.

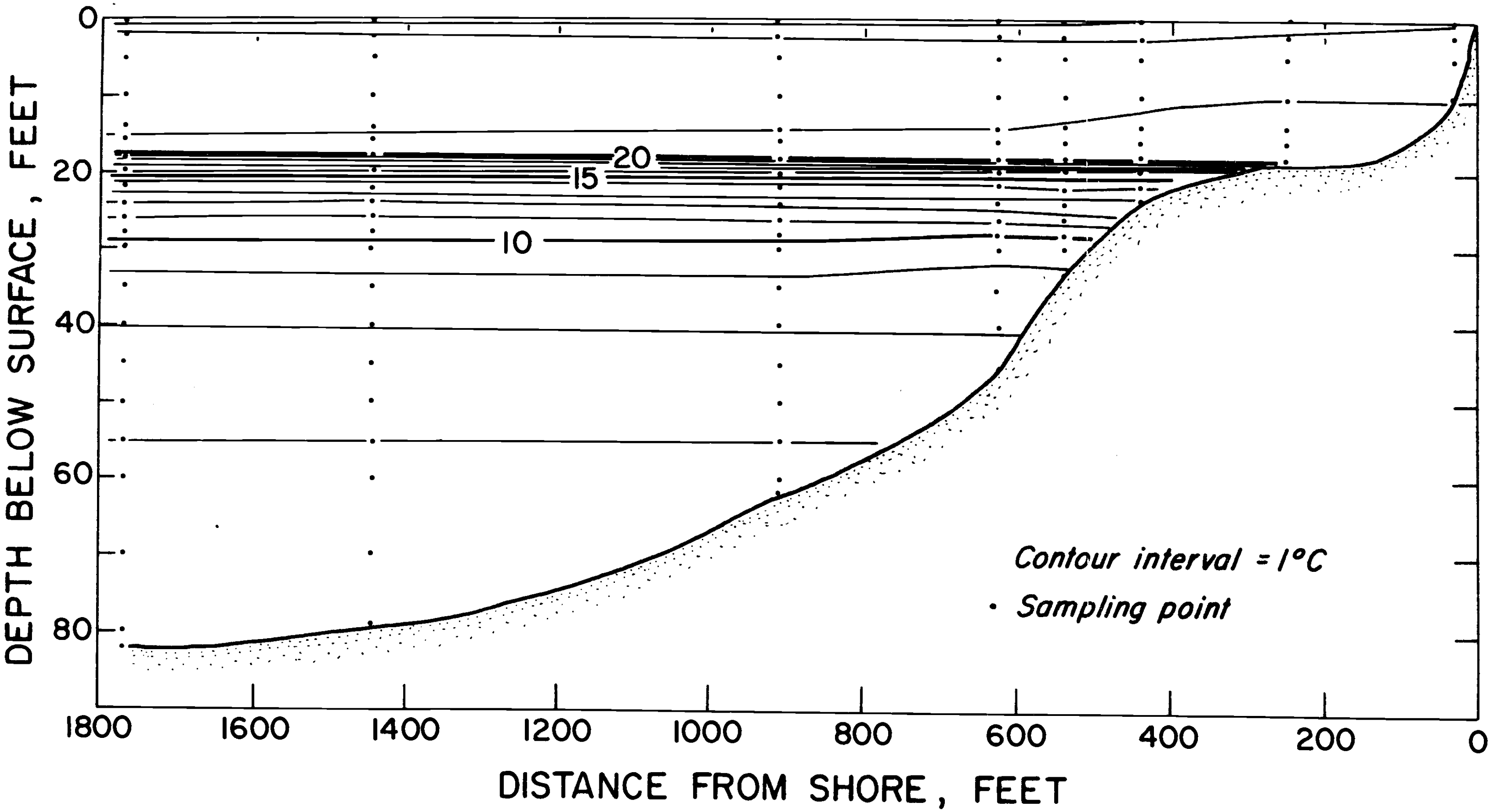

Figure 4. Cross-section of Triangle Lake, showing variations in temperature, August 26, 1970.

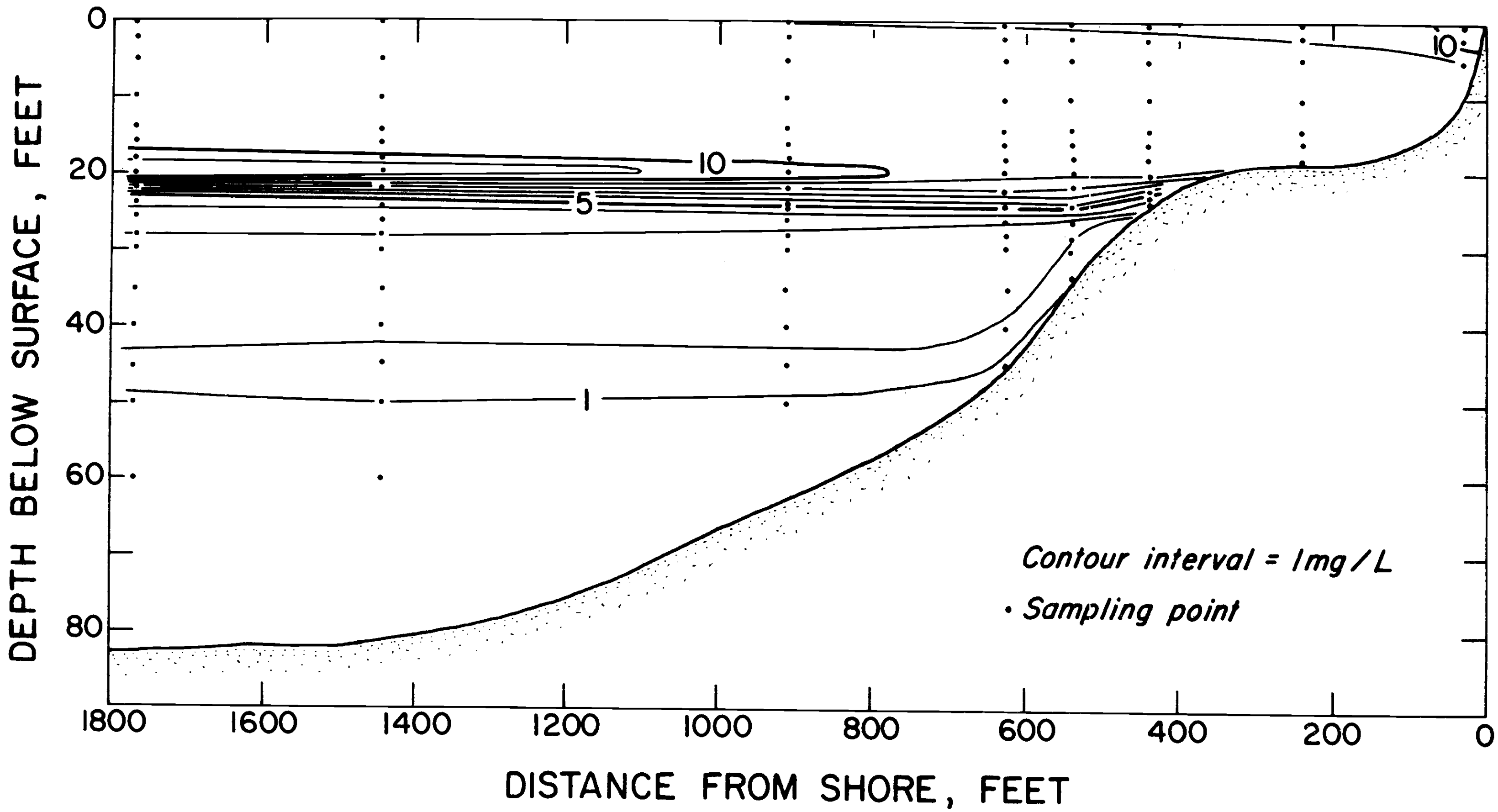

Figure 5. Cross-section of Triangle Lake, showing variations in dissolved oxygen, August 26, 1970.

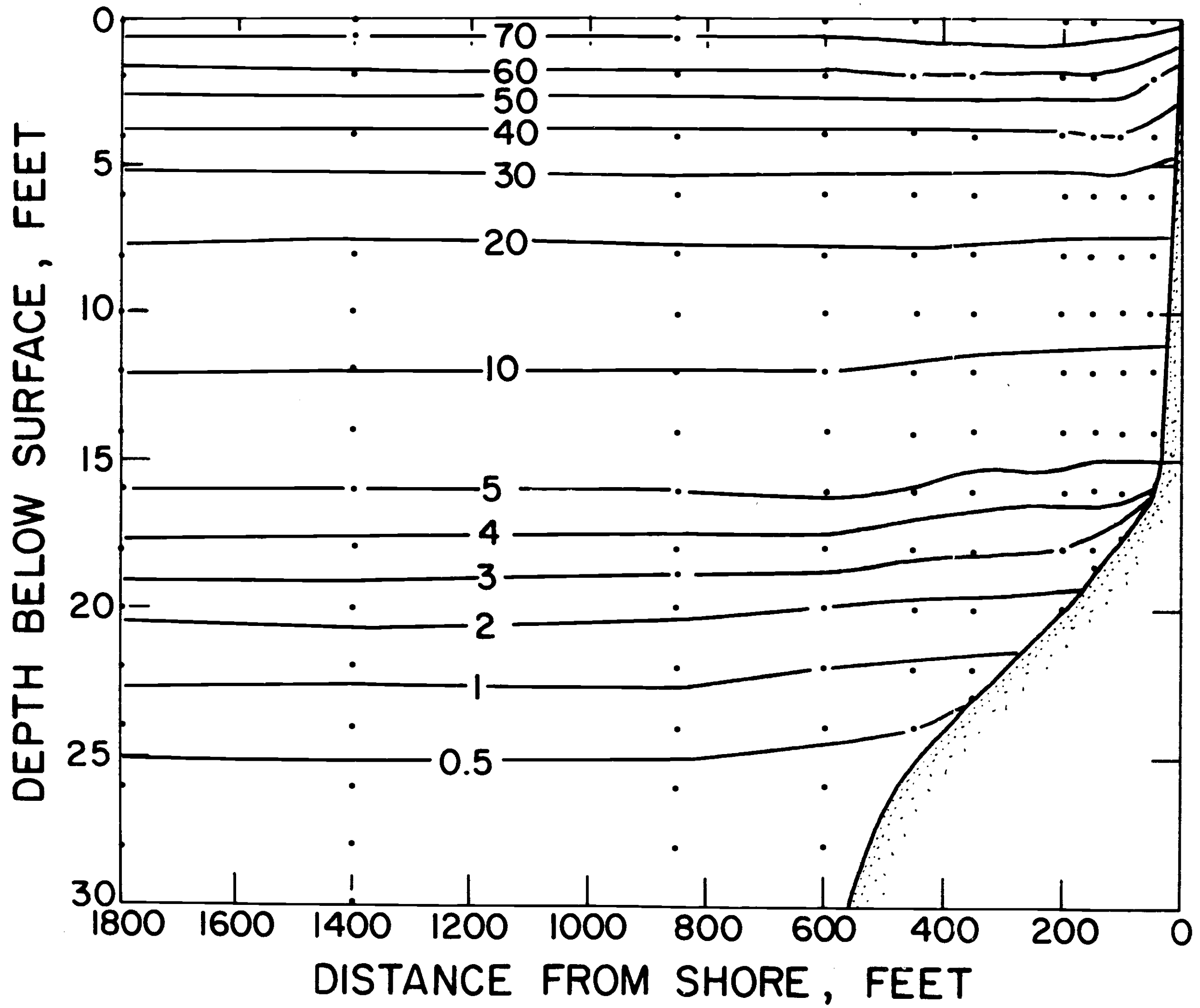

Figure 6. Cross-section of Triangle Lake, showing variations in light penetration as a percent of surface illumination, August 26, 1970.

on waters of the same depth. That is, benthal oxygen demands influence horizontally adjacent waters. Within a given horizontal slice, waters closest to the bottom will be most significantly affected, and thus, higher DO concentrations might be expected within the center of the lake.

The results shown in Figure 6 indicate that light penetration also appears to be slightly less nearer the shore. The one percent light penetration depth appears to be approximately one foot deeper in the lake center than nearer the shore. While this difference is small and does approach the limits of experimental reliability, this extra light penetration might be sufficient to result in enough additional metalimnetic photosynthesis to contribute to the horizontal DO variations shown in Figure 5.

During July of 1970, dense growths of Spirogyra were observed along the east shoreline of the lake. The algae were in the form of a mat and appeared to be supported by the water weed Elodea densa. (It was found that the algae mats sunk when not supported by this weed.) Diel DO variations were found to be greater in this shoreline region than in the lake center by approximately 2 to 3 mg/l. After the Spirogyra disappeared in early August of 1970, the DO in the littoral regions closely corresponded to that found in the lake center.

Diel Variations

Diel DO and temperature variations were measured on several occasions at the central sampling station throughout the water depth. Diel variations seldom exceeded 0.5 mg/l and were generally considerably less. Figures 7 and 8 show the temperature variations measured during two dates in July of 1970. Measurements were taken at intervals of one foot above the 20-foot depth and at wider intervals at greater depths. Measurements were usually taken at two hour intervals. Figures 7 and 8 extend only to a depth of 20 feet below the surface because diel temperature variations were insignificant below this depth. In the upper regions isothermal lines are plotted at intervals of 0.2^{o}C while at greater depths the intervals are increased to 1^{o}C.

The diel temperature variations within the surface waters resemble the seasonal variations that occur within the entire lake, although the diel temperature range is much smaller. During the period from morning (approximately 0800 hours) to mid-afternoon (approximately 1600-1800 hours) warming of the surface waters occurred. This surface warming results in temperature and density gradients within the surface regions, and may even result in an upper thermocline within the epilimnion (shown more clearly in Figure 8). Though these temperature gradients may be less than 1^{o}C per foot of depth, the density stratification may be sufficient to impede vertical mixing

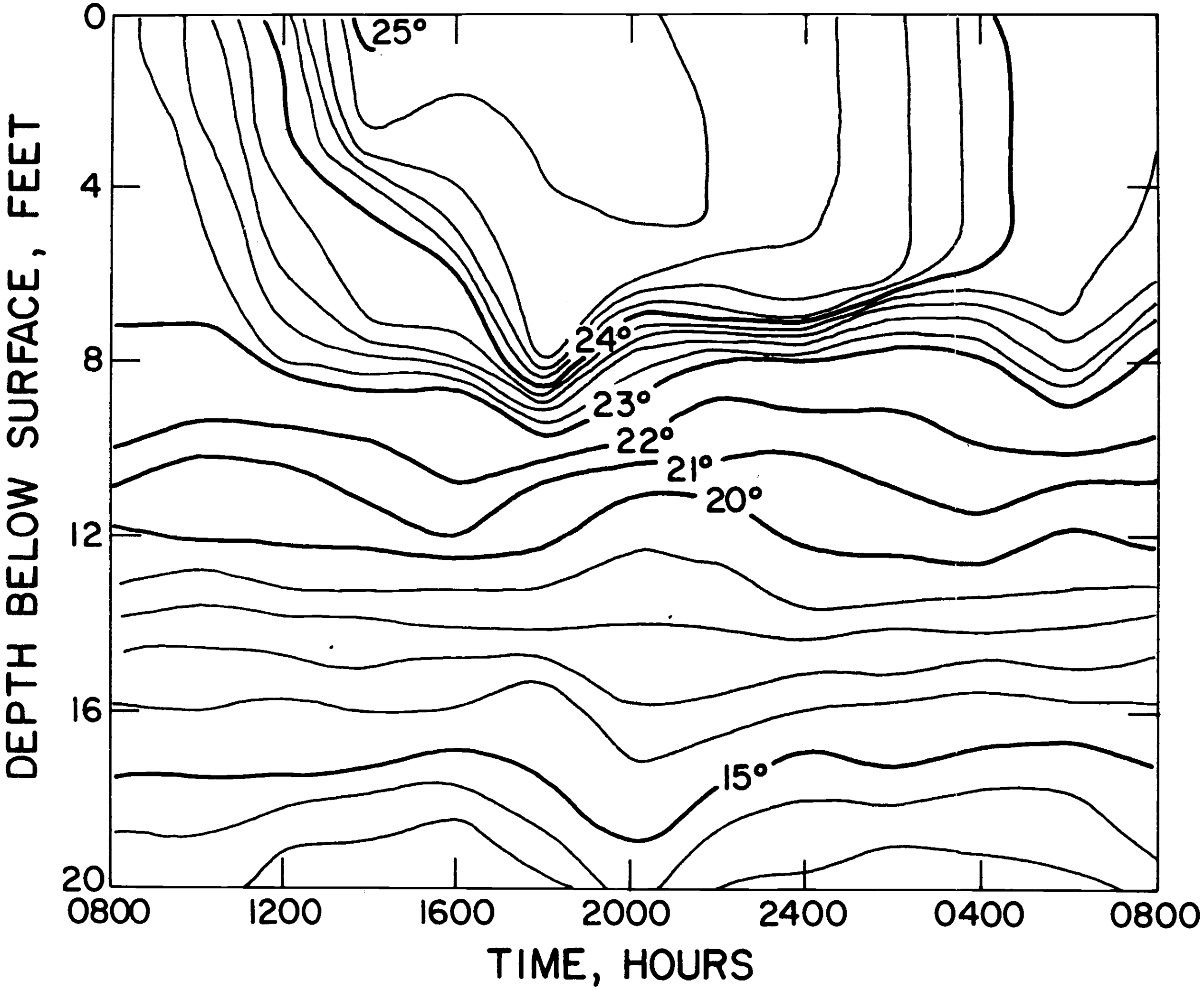

Figure 7. Diel variations in temperature, July 7-8, 1970. The contour interval is 0.2°C above 23°C to more clearly illustrate the temperature gradient.

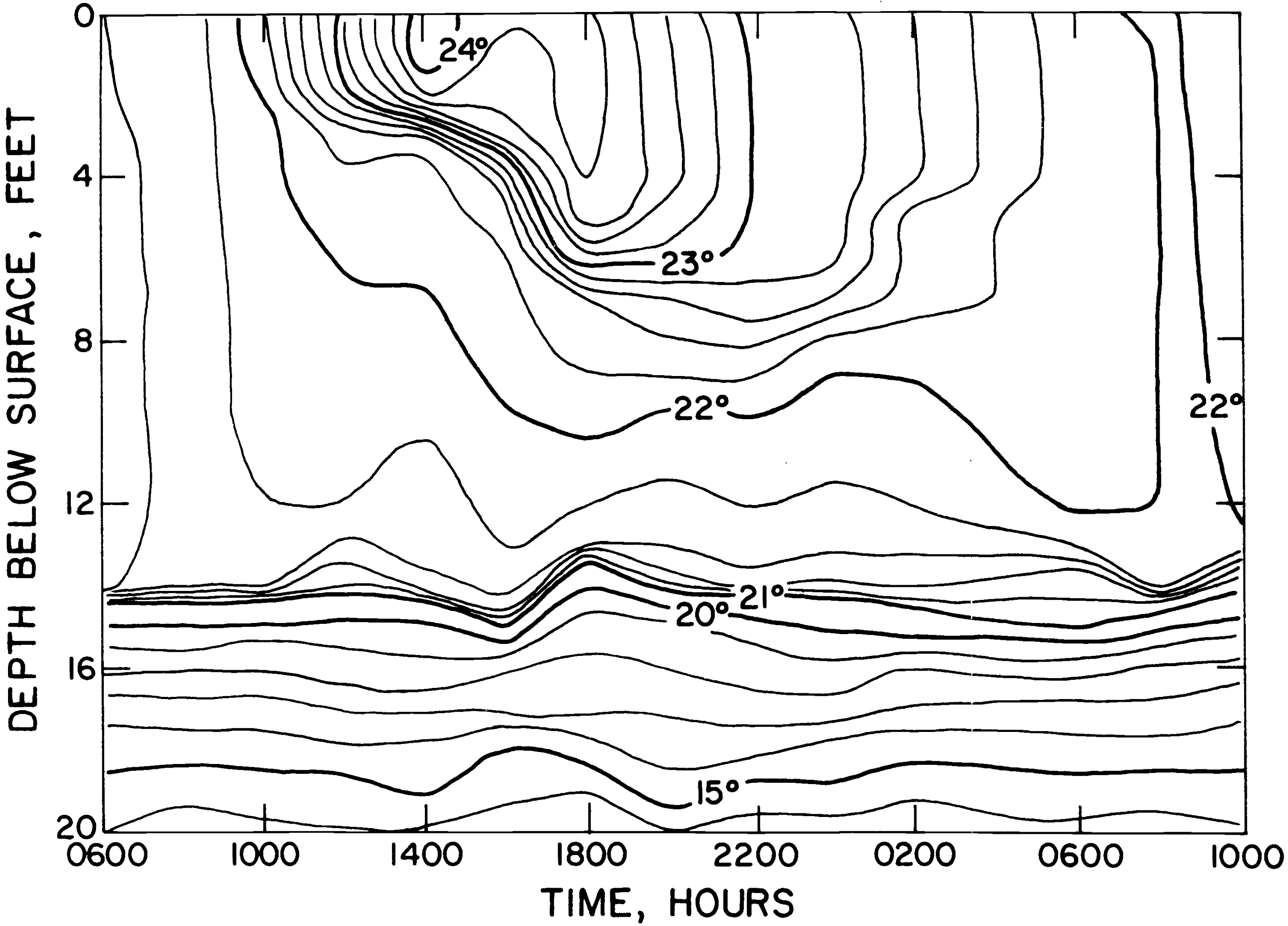

Figure 8. Diel variations in temperature, July 29-30, 1970. The contour interval is 0.2°C above 21°C to more clearly illustrate the temperature gradient.

(8). Such daytime epilimnetic stability persisted throughout the daylight hours even though the lake became quite "choppy" during the afternoon as a result of breezes from the Pacific coast.

During the evening and night period, the surface waters cooled and then sank to depths of equal density. This overturning continued until surface cooling ceased and surface warming began. The depth of the diel overturning is shown by the maximum depth of isothermal conditions within the upper waters just prior to sunrise. Below this depth, temperature gradients remain relatively stable throughout the day. Thus the depth of diel overturning can often be used to define the bottom of the epilimnion and the top of the metalimnion. That is, mixing within the epilimnion may largely be explained by diel density overturning which may often be more significant than wind induced turbulence alone.

The temperature and DO profiles measured on the same dates as the diel temperature variations are given in Figure 9. On both dates, DO maxima which exceed saturation were measured. The upper bounds of these high DO regions corresponded to the depth of the diel overturning while the lower bounds closely corresponded to the depth of one percent surface illumination. Oxygen production measurements by the *in situ* light-dark bottle method during June, July and August indicated that these DO maxima did not result from increased photosynthetic oxygenation at those depths. Rather, the

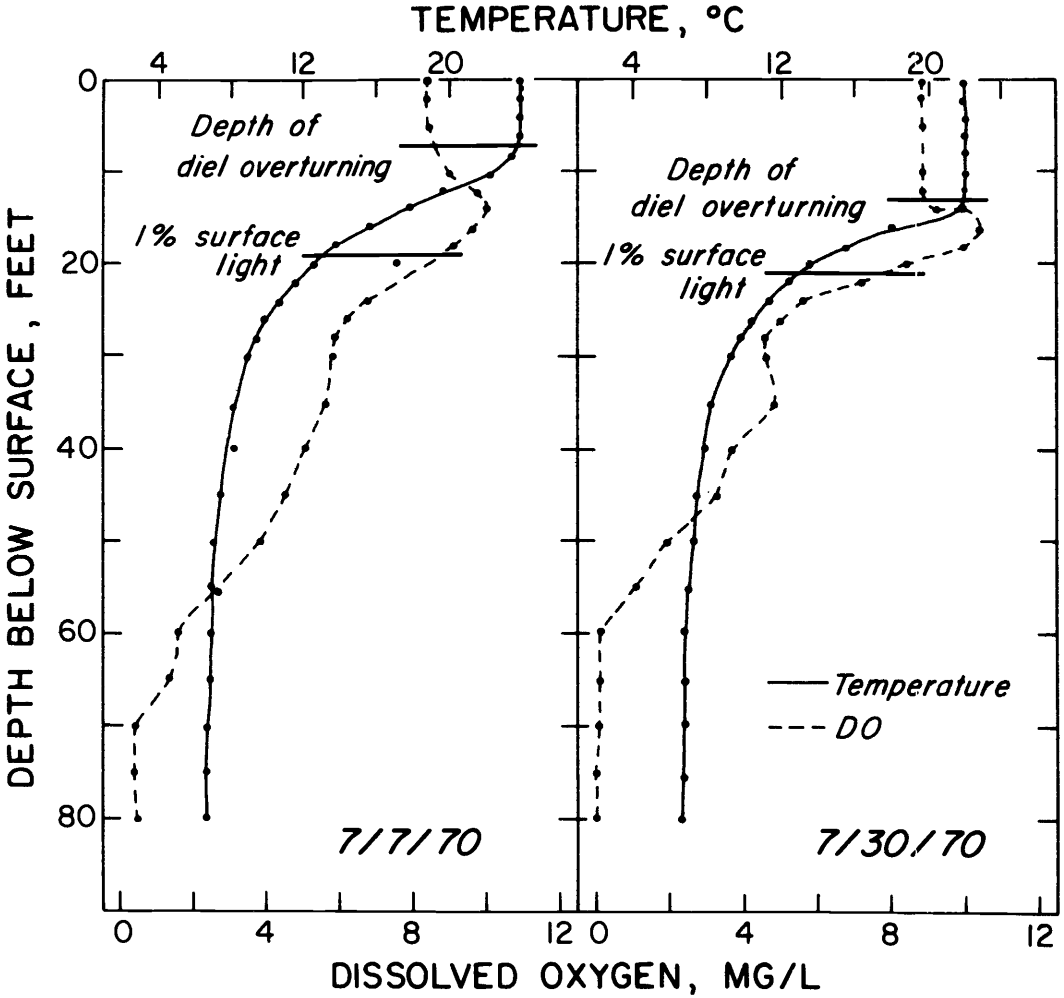

Figure 9. DO and temperature profiles at the central sampling station on July 7 and July 29, 1970.

magnitude of photosynthetic oxygenation occurring at those depths appeared to occur throughout the surface waters, decreasing substantially due to light limitations at depths below one percent surface illumination. Thus, the lower bounds of the DO maxima resulted from the decline of photosynthesis due to low light levels. In the region of diel overturning, waters were mixed daily to the surface and oxygen passed from the supersaturated waters to the atmosphere. Below the depth of diel overturning, vertical mixing was substantially reduced and DO values increased until gradients were sufficiently large that the vertical flux out of the region due to mixing balanced the photosynthetic oxygenation. Thus, the upper bounds of the DO maxima appeared to be controlled principally by diel overturning, while the lower bounds were controlled by light penetration.

Seasonal Variations

Monitoring of seasonal variations in temperature and DO in Triangle Lake began on August 26, 1969. Figure 10a illustrates the high degree of stratification existing at that date. The DO profile reveals a metalimnetic maxima succeeded by a minima. The maxima is located at the upper limit of the metalimnion in a region of low vertical mixing due to the existing density stratification. Oxygen produced at that depth, as a result of photosynthesis, accumulated to reach supersaturated levels.

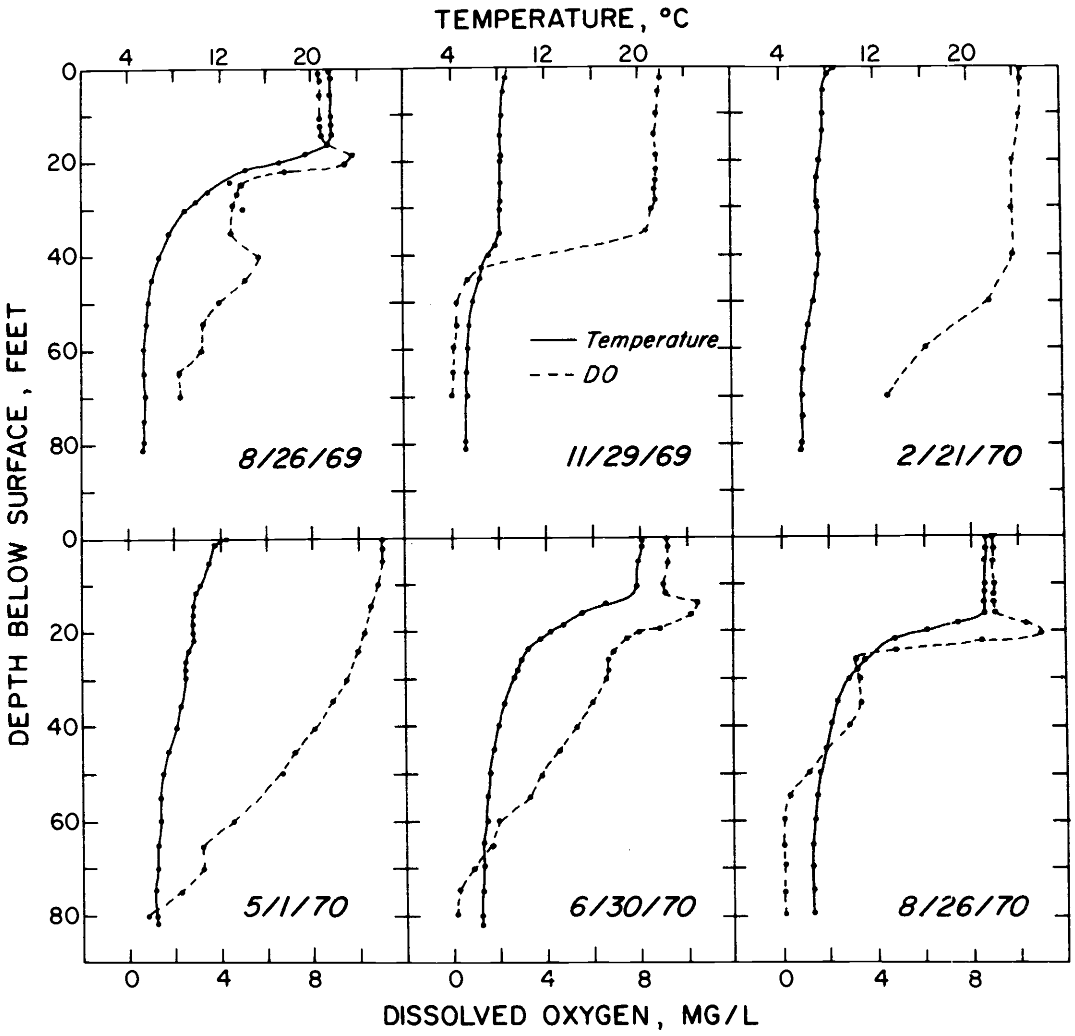

Figure 10. DO and temperature profiles as measured at the central sampling station on six different dates.

A metalimnetic minima is generally formed by a greater oxygen uptake in the metalimnion than in the upper region of the hypolimnion. The oxygen uptake results from dead and living plankton which sink into the metalimnion from above. The descent of the sinking plankton is sufficiently slowed as a result of the lower temperatures of the metalimnion to provide time for destruction of the easily oxidizable material, removing oxygen and leaving only the more resistant debris to sink into the hypolimnion (8).

In very clear lakes, photosynthetic oxygenation may occur in the upper portion of the hypolimnion. In the metalimnion, photosynthetic oxygenation might be less than at depths below due to a greater deficiency of available nutrients. Such conditions might also contribute toward a metalimnetic minima though it is unlikely that this occurred in Triangle Lake during the sampling period.

Seasonal overturning began with the onset of colder autumn temperatures and was most likely a result of greater diel overturning which progressively extended to deeper depths. DO remained near saturation in the epilimnion but continued to be depleted within the hypolimnion. By November 29, 1969 the epilimnion had cooled to 8.4°C with the thermocline lowered to 38 feet below the surface (see Figure 10b). The lowest hypolimnetic DO's observed during the study were measured on that date with 0.8 mg/l at 45 feet below the surface and less than 0.3 mg/l at deeper depths.

By December 30, 1969 the epilimnion had cooled to 7.3°C with the thermocline at 57 feet below the surface. The lake remained stratified with a minimum hypolimnetic temperature of 5.7°C. This was the nearest the lake was observed to approaching isothermal conditions as observed in Lake Sebasticook (10) and Lake Sammamish (9) during the Fall overturn. Sampling during this period, however, was conducted only on a monthly basis and thus shorter periods of complete overturning may have occurred. Colder waters from inflowing streams likely sank to the lower depths due to their greater density, contributing to the temperature gradient between the surface and bottom waters.

During January and February 1970 the temperature of the epilimnion fluctuated between 7° and 9°C; however, the lake remained slightly stratified with the temperature near the bottom remaining near 5.8°C. At a depth of 70 feet the DO increased from near zero on December 30, 1969 to 7.4 mg/l on January 24, 1970. However, a difference in DO of 2.6 mg/l between the surface and 70 feet was further evidence that a complete overturn had not taken place. By February 21, 1970 the DO at 70 feet had decreased to 4.50 mg/l. Beginning in March with increasing air temperatures, the lake began the transition from incomplete overturn to summer stratification. Figure 10d illustrates the degree of stratification on May 1, 1970.

The metalimnetic maxima which was measured in August 1969, was also measured during the summer of 1970. Figure 10e and 10f show both the formation of the metalimnetic maxima and the depletion of DO in the hypolimnion.

Hypolimnetic DO values were lower during the late summer of 1970 than during a similar period of 1969 (compare Figures 10a and 10f). The lower DO values may have occurred due to the incomplete overturning during the winter of 1969-1970. As a result of the incomplete overturn, DO values at the greater depths during the late winter-early spring period were likely lower than normal. (Recent measurements indicate that DO values near the bottom during January 1971 were approximately 9 mg/l compared to approximately 1-3 mg/l for the same period in 1970.)

Seasonal variations in temperature and DO are also represented in Figures 11 and 12, respectively. The lowering of a temperature contour line in Figure 11 depicts a warming of the lake waters while a rising contour is representative of a cooling trend. The depth of the thermocline for any date can be located on Figure 11 by selecting the depth at which the contours are the closest together, i.e., the sharpest temperature gradient. Due to the fluctuations in the elevation of the water surface caused by large inflows in January and February, the depths in Figures 11 and 12 are measured from the bottom, a constant datum. The depth of the lake remained relatively constant at 81 to 82 feet during the spring, summer and fall.

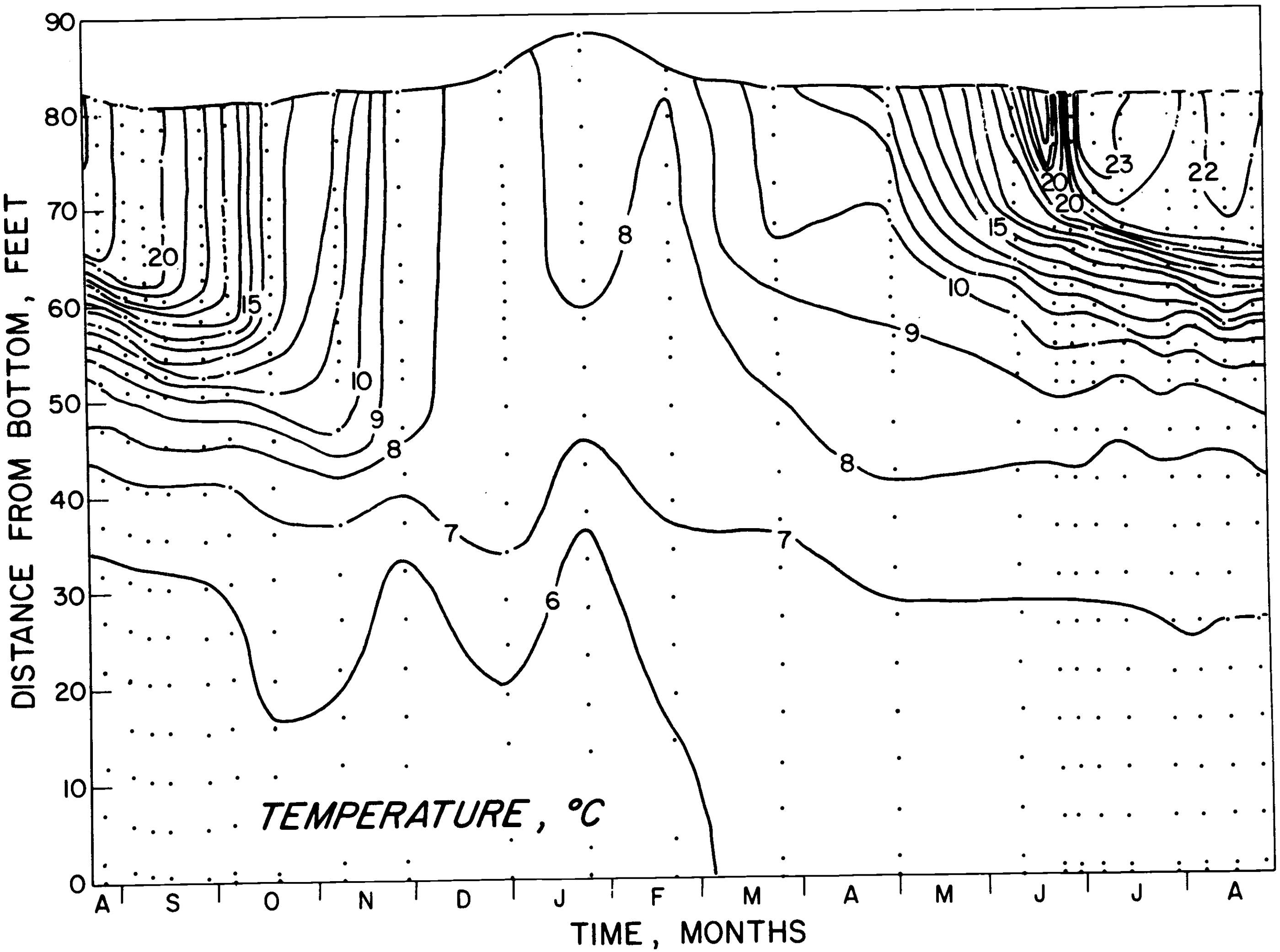

Figure 11. Seasonal variations in temperature at the central sampling station, August 1969 through August 1970.

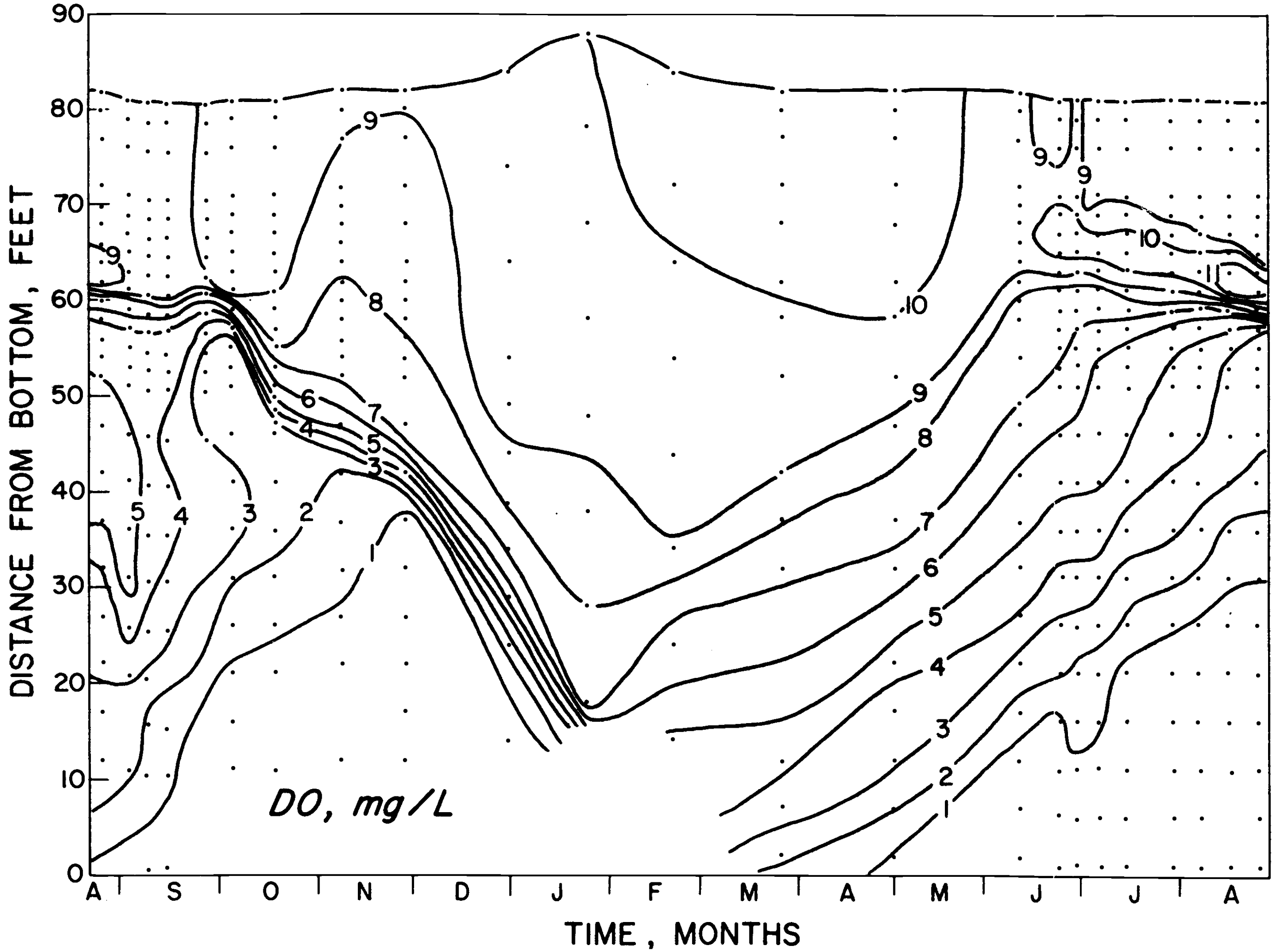

Figure 12. Seasonal variations in dissolved oxygen at the central sampling station, August 1969 through August 1970.

Figure 12 is incomplete for the months of January and February. The incompleteness stems from the lack of sufficient DO data to complete the contours at the depths near the bottom of the lake. However, the DO gradient between the surface and the bottom substantiates the fact that a complete overturn, which normally more completely restores DO over the full depth of the lake, did not occur. The relatively uniform slope of the DO contours in the hypolimnion between March and August 1969 indicates a relatively uniform oxygen demand.

The relatively minor summer temperature change within the hypolimnion along with the sharp temperature gradients across the thermocline suggests that the vertical transfer of DO into the hypolimnion from above was minimal. Under such conditions, a hypolimnetic oxygen uptake rate of approximately 0.3 $gm/m^2/day$ would be sufficient to result in the hypolimnetic DO decline observed from March through August 1970.

The temperature and DO data used to prepare Figures 11 and 12 are given in Appendices A and B.

Effect of Seasonal Variations of Temperature and DO on Fish Life

An attempt was made to illustrate the effects of seasonal temperature and DO variations upon game fish within Triangle Lake. It is acknowledged by the writer that while this analysis is not backed by exhaustive experimental data, it can be useful in illustrating the effect of temperature and DO upon the habitat of game fish.

Considerable research has been done by others in an attempt to determine the temperatures and concentrations of DO which are preferred by species of game fish and those which are lethal. Because the preferred and lethal concentrations of DO are dependent upon the experimental conditions under which the research is conducted, the values found in the literature vary over a wide range. It is also extremely difficult to extrapolate data gained in the laboratory to the conditions which exist in nature. Recognizing that these shortcomings exist, effects of seasonal variations of temperature and DO upon rainbow trout in Triangle Lake is presented herein. Rainbow trout were chosen because considerable data is available on this species and they have similar DO and temperature requirements as cutthroat trout and kokanee salmon which are also found in Triangle Lake.

It has been shown that with other parameters held constant, both the lethal and preferred concentrations of DO are functions of temperature (3, 6, 7). Lethal concentrations of DO vary from 1.1 mg/l at 6.4°C to 3.4 mg/l at 25°C (3). The minimum DO preferred for acceptable growth and development of rainbow trout is 6 mg/l (18). The upper limit of the preferred temperature range has been reported at 18.5°C (5). The lethal temperature for rainbow trout has been reported as low as 24°C (2) and 24.5°C (5); however, they have also been capable of withstanding temperatures as high as 28.3°C (16).

Livability zones in Figure 13 were constructed using DO and temperature requirements of rainbow trout as listed in the previous paragraph. Within Zone I lie the combinations of DO and temperature reported as preferred by rainbow trout or the minimum acceptable for normal growth and development. Within Zone IV are the combinations of DO and temperature which are inadequate and would prove fatal to rainbow trout if they were forced to live under such conditions for periods as short as three hours. The line separating Zones II and III was drawn in arbitrarily. Zone II represents combinations of temperature and DO under which rainbow trout could live for extended periods; however, their growth, reproduction and general well being would be less than in Zone I. Within Zone III the trout would lead a marginal existence. If forced to live in Zone III for a prolonged period the weaker fish would most likely die, growth and development would be severely curtailed and the species would likely eventually disappear.

Figure 14 was obtained by applying the livability zone criteria from Figure 13 to the seasonal temperature and DO variations in Triangle Lake as illustrated in Figures 11 and 12, respectively. From Figure 14 it is readily apparent that the environment afforded to rainbow trout within Triangle Lake ranges from preferred to completely undesirable. During the months of August and September of 1969, Zone I disappeared completely while nearly disappearing in August

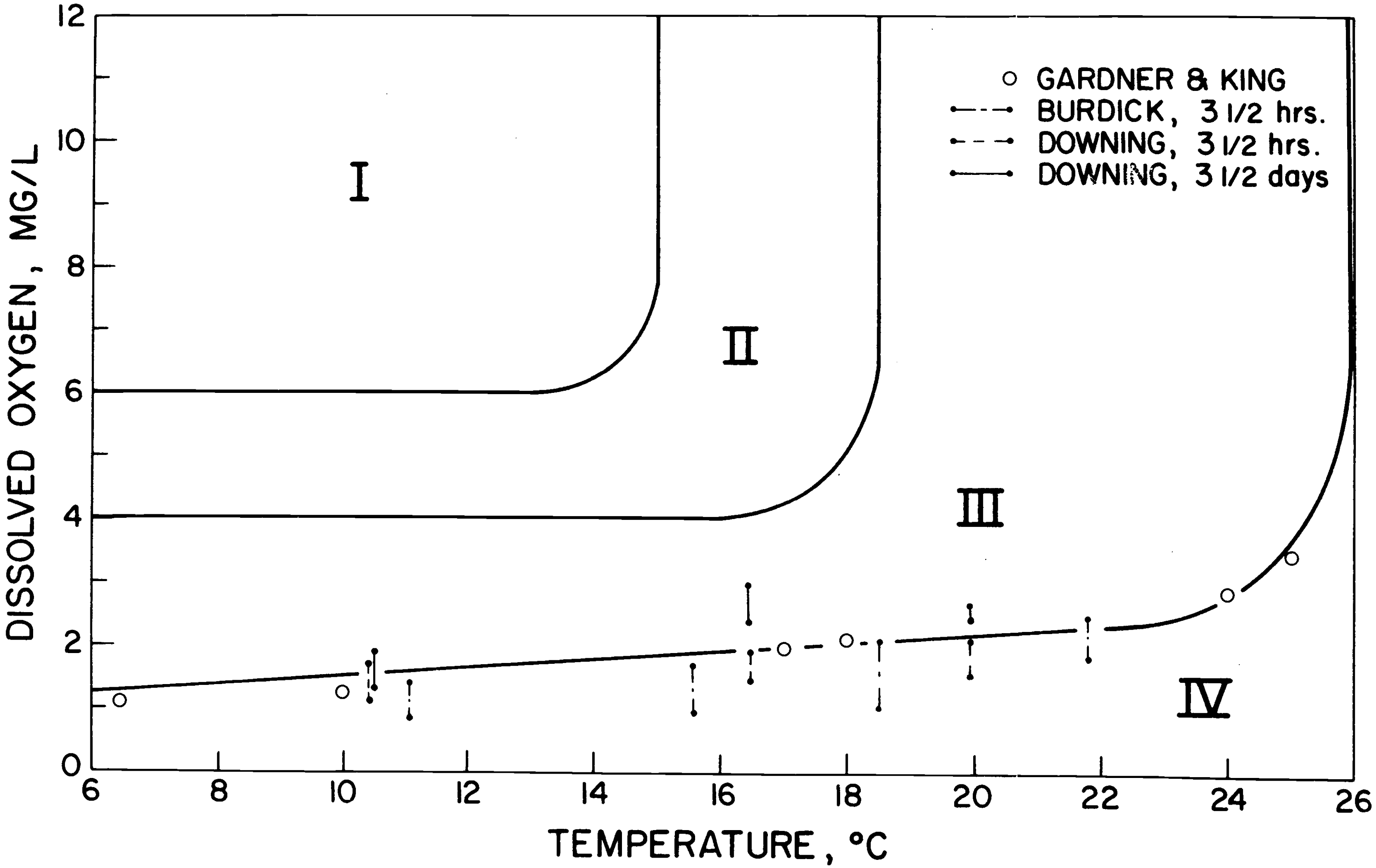

Figure 13. Various livability zones for Rainbow Trout. Zone I represents most favorable combinations of DO and temperature while Zone IV represents lethal combinations. Fish exposure time during laboratory experiments are given for Burdick (3) and Downing (6).

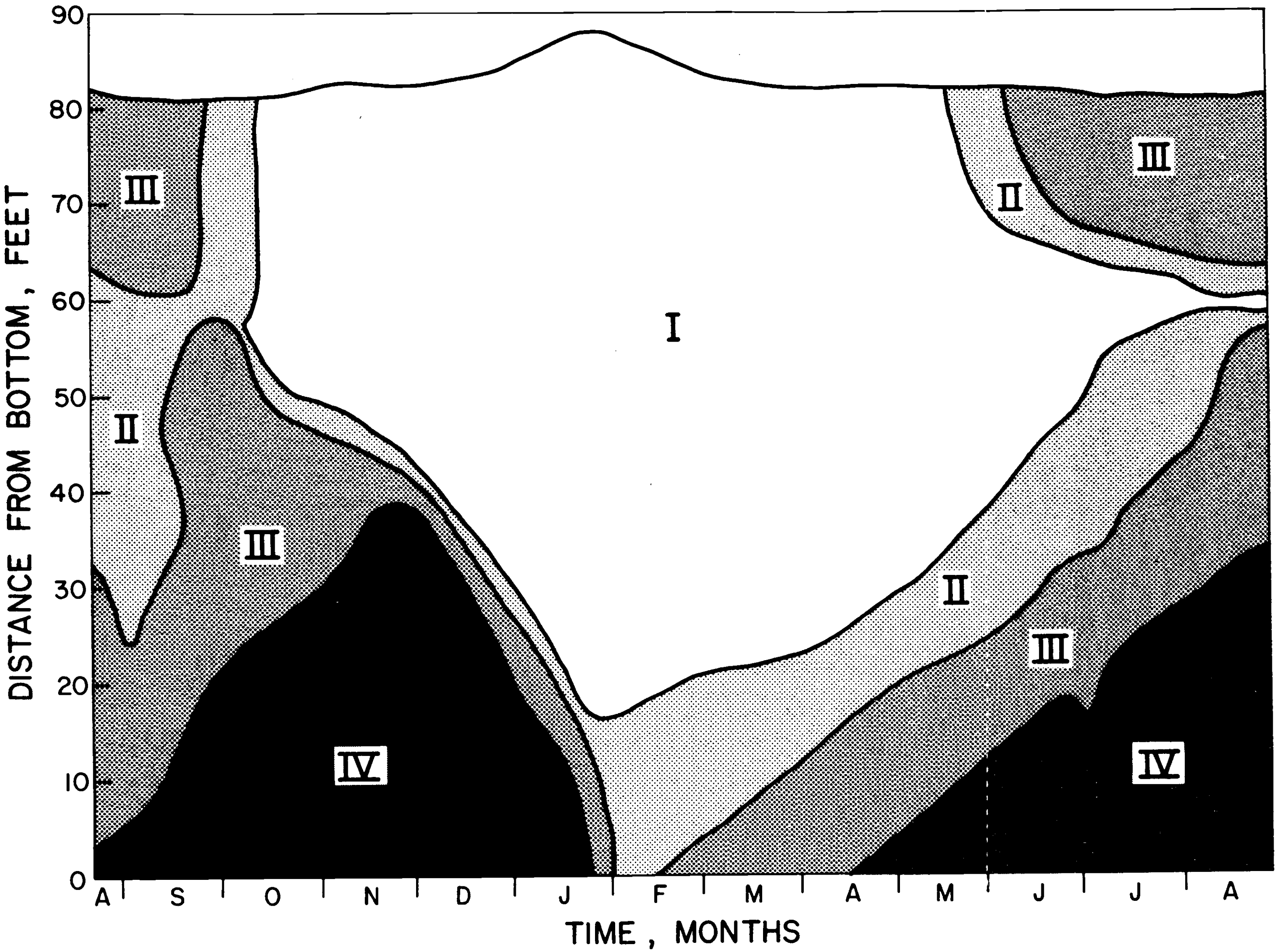

Figure 14. Variations in livability zones within Triangle Lake over a period of one year, 1969-1970.

1970. The hypolimnion was undesirable as a fish habitat during the fall and summer months due to low DO even though the water temperature within the hypolimnion was favorable. Only during the winter does the majority of the lake meet the requirements of Zone I. It can be seen that during the late summer the preferred zones are restricted to a thin strata at a depth near the thermocline with undesirable warm temperatures above and undesirable low concentrations of DO below. Fish kills have been reported in instances where this strata was eliminated during summer stratification and the combination of low DO and high temperatures proved lethal (4).

Other Parameters Within Triangle Lake

During July 1970 a dense bloom of *Spirogyra* within the littoral waters made that green algae the predominate genus in Triangle Lake. The algae was a definite nuisance near the shore as it grew as a mat supported by the waterweed *Elodea densa*. The algae hindered the rowing of boats and handicapped fishermen trying for bass in the shallow water along the shoreline. At a depth of about 15 feet, with the disappearance of the waterweed, the algae was no longer visible.

By August the dense bloom of *Spirogyra* had disappeared and the predominant algae genus became *Anabena*. *Anabena* is a blue-green algae and one of the algae groups commonly associated with euthropic lakes (12). Appearing concurrently with the *Anabena* was

Gleotricia, another blue-green algae. These were clearly visible with the unaided eye and distracted from the aesthetic quality of the lake. During the morning while the water was calm, the *Gleotricia* appeared to be most abundant near the surface and appeared similar to a layer of pollen which commonly blows onto water surfaces during the spring.

A summary of data collected on June 12, 1970 appears in Table 1. Chlorophyll measurements for two dates are shown in Table 2.

Table 1. Summary of water quality analysis on samples collected from Triangle Lake.

Parameter	Depth, feet			
	10	30	50	80
Temperature, ^{o}C	17.9	9.0	7.0	6.5
Dissolved oxygen, mg/l	9.3	7.1	4.0	0.1
pH	7.0	6.4	6.1	5.9
Alkalinity, mg/l	17.7	15.0	14.5	15.7
Acidity, mg/l	3.8	4.0	4.5	5.7
Suspended solids, mg/l	1.8	1.7	1.6	3.9
BOD_5, mg/l	0.7	0.8	0.7	0.9
Turbidity, JTU	2.0	2.6	6.0	19.5
Ammonia-N, mg/l	0.06	0.04	0.02	0.12
Nitrite-N, mg/l	0.001	0.001	0.001	0.012
Nitrate-N, mg/l	0.022	0.078	0.198	0.168
Kjeldhal-N, mg/l	0.3	0.3	0.3	0.3
Total phosphorus-P, mg/l	0.015	0.014	0.017	0.04
Ortho phosphorus-P, mg/l	0.003	0.002	0.004	0.002

Table 2. Chlorophyll a concentrations in Triangle Lake.

Depth	Chlorophyll a, mg/m^3 5 ft.	14 ft.	24 ft.
Date			
June 11, 1970	1.5	4.2	4.2
July 29, 1970	6.5	7.7	6.7

Effect of the Winter of 1968-1969

One of the interesting observations made during the study of seasonal variations in temperature and DO was the recording of the incomplete winter overturn. It has been demonstrated that meteorological conditions during a winter can influence the following cycle of summer stratification and winter overturn (22). It is believed meteorological conditions were responsible for incomplete overturn in the winter of 1969-1970.

The winter of 1968-69 was one of the most severe in Oregon's history. Climatological data for Noti, the weather station nearest to Triangle Lake, reflected the severe weather conditions in January 1969. The weather station, located nine miles south of Triangle Lake, recorded 28 inches of snow and an average temperature of 35.6°F. Sixteen inches of snow remained on the ground through early February when normally only a trace is recorded (17).

The winter of 1969-70 was considerably milder with very little snow and the average temperatures for January and February were approximately 7°F warmer than in the previous winter.

As a result of the cold winter of 1968-69, the temperature of the hypolimnion during August 1969 was only 5.3°C. Although the hypolimnion did warm during the fall and winter of 1969-70, isothermal conditions from surface to bottom did not develop. It is believed that stratification remained because temperatures during the winter of 1969-70 were too mild to sufficiently cool the surface waters to produce overturning over the complete depth. During the spring and summer of 1970 the temperature of the hypolimnion gradually warmed and a complete overturn did occur in the following December. After the overturn the lake became isothermal and DO was restored throughout the depth of the lake.

SUMMARY AND CONCLUSIONS

Temporal and spatial variations of temperature and DO were measured in Triangle Lake, Oregon. The lake was found to be relatively uniform in the horizontal direction while being significantly stratified in the vertical direction during the summer months.

Diel DO variations were found to be less than 0.5 mg/l within the surface regions. Diel temperature variations resulted in a nocturnal density overturning that extended to a depth of approximately 8 to 12 feet. It appeared the depth of diel overturning defined the lower boundary of the epilimnion and the upper boundary of the metalimnetic DO maxima.

Seasonal variations of temperature and DO indicated that it was likely that complete overturning did not occur during the winter of 1969-70. The low hypolimnetic DO values which occurred during the following summer may have been a result of the incomplete overturn.

Using temperature and DO as parameters, the regions of desirable habitat for game fish varied considerably throughout the year. During the summer months desirable fish habitats were restricted due to high temperatures above and low DO below.

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APPENDICES

Appendix A. Variations in temperature measured at central sampling station. Temperature is expressed in °C.

Depth,	Date									
feet	8-26-69	9-4-69	9-10-69	9-16-69	9-28-69	10-5-69	10-19-69	11-9-69	11-29-69	12-30-69
Surface	21.5°	20.7°	20.5°	20.0°	18.2°	16.9°	13.40°	12.4°	8.6°	7.26°
2	21.5	20.7	20.7	20.0	18.2	16.9	13.50	12.1	8.5	7.28
5	21.6	20.6	20.7	20.0	18.2	16.9	13.50	11.9	8.4	7.28
10	21.6	20.7	20.7	20.0	18.2	16.9	13.51	11.8	8.4	7.28
12	21.6	20.6	20.7	20.0	18.2	16.9	13.51	---	8.4	7.28
14	21.6	20.6	20.7	20.0	18.2	16.9	13.51	11.7	8.4	7.28
16	21.3	20.6	20.7	20.0	18.2	16.9	13.51	11.6	8.4	7.28
18	19.5	20.6	20.2	20.0	18.2	16.9	13.50	11.5	8.4	7.28
20	17.1	18.1	18.3	18.2	17.7	16.9	13.49	11.2	8.4	7.28
22	14.4	14.7	15.6	16.0	16.0	16.6	13.40	11.1	8.4	7.28
24	12.8	12.8	13.7	14.5	14.5	14.6	13.17	11.0	8.4	7.28
26	11.0	11.3	11.7	13.1	12.8	13.3	12.62	10.9	8.4	7.28
28	9.8	10.3	10.1	11.2	11.7	11.9	11.50	10.8	8.4	7.27
30	9.0	9.8	9.1	9.8	9.9	10.1	11.50	10.8	8.4	7.26
35	7.7	7.7	8.0	8.0	8.1	8.0	10.29	10.1	8.3	7.25
40	6.6	6.9	7.3	6.7	6.7	6.9	8.89	8.0	7.8	7.19
45	6.2	6.4	6.6	6.3	6.1	6.3	7.72	7.0	7.3	7.12
50	5.9	6.0	6.3	6.0	5.8	6.0	6.87	6.5	6.2	7.00
55	5.6	5.7	6.0	5.7	5.7	5.8	6.51	6.2	5.9	6.82
60	5.5	5.5	5.8	5.7	5.6	5.7	6.25	6.1	5.7	6.30
65	5.4	5.5	5.7	5.6	5.5	5.6	6.08	5.9	5.5	5.88
70	5.3	5.4	5.6	5.6	5.5	5.5	6.00	5.8	5.4	5.72
75	5.3	5.3	5.5	5.5	5.5	5.5	5.92	---	5.4	5.66
80	5.3	5.3	5.4	5.5	5.4	5.4	5.88	5.8	5.3	5.65
85										5.65
90										

Appendix A. Variations in temperature measured at central sampling station. Temperature is expressed in °C. (Cont.)

Depth,	Date												
feet	1-24-70	2-21-70	3-27-70	5-1-70	6-11-70	6-25-70	6-30-70	7-7-70	7-16-70	7-29-70	8-7-70	8-17-70	8-26-70
Surface	8.61°	8.72°	10.48°	12.5°	18.18°	24.48°	20.07°	24.13°	22.90°	23.08°	21.90°	22.47°	21.42°
2	8.61	8.05	10.32	11.3	18.18	24.15	19.99	23.96	23.00	22.95	21.92	22.50	21.27
5	8.61	7.78	10.28	10.94	18.08	23.00	19.70	23.73	23.00	22.10	21.90	22.46	21.15
10	8.60	7.69	10.21	10.12	17.19	19.60	19.58	21.15	22.90	21.88	21.70	22.24	21.06
12	8.58	---	---	9.92	17.15	18.00	19.50	20.14	21.62	21.80	21.65	22.18	21.05
14	8.58	7.65	10.17	9.72	15.48	16.68	17.00	17.70	19.09	21.25	21.60	21.93	21.03
16	---	7.63	---	9.58	14.20	14.86	14.95	15.72	16.74	18.55	19.32	20.23	21.01
18	8.49	7.61	9.39	9.45	12.18	13.42	13.50	14.58	14.86	15.76	16.86	17.40	18.58
20	8.49	7.40	9.05	9.34	10.61	12.26	12.21	12.50	13.33	13.95	14.61	15.93	16.25
22	8.45	---	---	9.23	10.18	---	11.23	11.06	12.21	12.90	12.14	14.17	13.84
24	---	7.27	8.65	9.02	9.82	10.69	10.35	10.50	11.00	11.71	10.95	12.00	11.99
26	8.40	---	---	8.92	9.52	---	9.88	10.07	9.62	10.82	10.11	10.80	10.90
28	---	7.23	8.38	8.84	9.21	9.55	9.45	9.42	9.22	9.90	9.30	10.05	10.14
30	7.72	7.20	8.12	8.78	8.98	9.22	9.10	9.14	8.81	9.25	9.00	9.29	9.54
35	7.60	7.18	7.70	8.28	8.49	8.36	8.47	8.32	8.11	8.38	8.32	8.34	8.63
40	7.42	7.15	7.40	8.14	7.88	7.80	7.93	7.88	7.68	7.80	7.81	7.69	8.01
45	6.32	7.09	7.05	7.35	7.48	7.38	7.60	7.57	7.31	7.40	7.47	7.30	7.64
50	6.08	6.91	6.69	7.12	7.14	7.10	7.22	7.08	7.11	7.15	7.22	7.15	7.22
55	5.91	6.58	6.60	6.94	6.91	6.92	7.00	6.92	6.96	6.99	7.10	7.00	7.00
60	5.90	6.22	6.52	6.78	6.76	6.82	6.89	6.81	6.81	6.87	6.92	6.87	6.87
65	5.88	6.03	6.44	6.70	6.70	6.76	6.80	6.77	6.75	6.78	6.82	6.79	6.77
70	5.82	5.98	6.40	6.61	6.60	6.68	6.72	6.67	6.65	6.70	6.73	6.71	6.70
75	5.80	---	6.30	6.54	---	---	6.66	6.63	6.60	6.67	6.64	6.65	6.63
80	5.79	5.88	6.29	6.52	6.51	6.59	6.58	6.56	6.57	6.59	6.58	6.60	6.59
85	5.79	5.87											
90	5.79												

Appendix B. Variations in dissolved oxygen measured at central sampling station. Dissolved oxygen concentrations are expressed in mg/l.

Depth, feet	Date 8-26-69	9-4-69	9-10-69	9-16-69	9-28-69	10-5-69	10-19-69	11-9-69	11-29-69	12-30-69
Surface	8.20	8.35	8.20	8.50	9.20	9.20	9.30	9.05	9.00	9.50
2	8.35	8.45	8.20	8.55	9.15	9.15	9.35	9.00	9.00	
5	8.35	8.45	8.25	8.60	9.20	9.20	9.35	9.00	8.90	
10	8.40	8.50	8.30	8.55	9.15	9.25	9.30	8.90	8.80	9.45
12	8.40	8.50	8.30	8.55	9.15	9.15	9.30			
14	8.40	8.50	8.35	8.55	9.05	9.15	9.30	8.90	8.80	
16	8.70	8.50	8.25	8.50	9.20	9.20	9.25	8.90		
18	9.80	8.60	7.50	8.50	9.00	9.20	9.10	8.75	8.80	
20	9.40	8.50	7.70	8.20	7.30	9.20	9.00	7.85	8.80	9.45
22	6.95	6.30	6.25	6.30	4.88	7.45	8.45	7.70	8.80	
24	5.00	4.85	4.70	4.85	3.00	3.30	8.25	7.40	8.70	
26	4.80	4.60	4.60	4.80	3.15	2.20	8.05	7.50	8.70	
28	4.50	4.75	4.00	4.20	2.65	2.45	7.00	7.30	8.65	
30	5.00	5.15	3.90	4.15	3.45	2.35	6.00	7.20	8.60	9.40
35	4.40	5.00	4.40	3.70	3.00	2.75	2.30	5.15	8.30	9.35
40	5.65	5.75	4.45	4.20		3.15	2.75	1.95	6.40	8.95
45	5.05	5.50	4.00	4.40		3.20	2.55	1.65	1.30	8.10
50	4.00	5.35	3.65	3.80		2.05	1.65	1.75	0.30	7.00
55	3.30	4.35	3.25	3.15		1.70	1.30	0.85	0.30	5.30
60	3.25	3.45	2.40	---		0.65	0.35	0.40	0.10	2.10
65	2.35		1.75	1.60		0.25		.	0.10	
70	2.40	2.90	1.00	1.20		0.25	0.15	0.10	0.05	0.00
75										
80			0.65	0.35					0.05	
85										
90										

Appendix B. Variations in dissolved oxygen measured at central sampling station. Dissolved oxygen concentrations are expressed in mg/l.

Depth, feet	Date												
	1-24-70	2-21-70	3-27-70	5-1-70	6-11-70	6-25-70	6-30-70	7-7-70	7-16-70	7-29-70	8-7-70	8-17-70	8-26-70
Surface	10.00		11.50	11.00	9.20	8.40	9.10	8.40	8.35	8.80	8.90	8.90	8.90
2		10.20	11.65	11.05	9.20	8.40	9.10	8.40	8.35	8.90	8.90	8.90	8.90
5			11.70	11.00	9.20	8.40	9.10	8.40	8.35	8.90	8.90	8.90	8.90
10	9.90	10.30	11.60	10.70	9.10	9.75	9.00	9.00	8.30	8.90	8.90	8.80	8.90
12					9.10	10.50	9.00	9.60	9.50	8.90	8.90	8.80	8.90
14			11.30	10.50	9.20	10.50	10.40	10.00	10.20	9.20	8.85	8.80	8.90
16					9.75	10.30	10.15	9.65	10.00	10.30	10.10	10.20	8.85
18					9.30	9.20	8.90	9.25	10.10	10.00	10.70	11.60	10.40
20	9.80	9.95	10.15	10.20	8.50	8.00	7.85	7.60	8.85	8.50	9.50	11.50	11.00
22					7.70		7.40	7.75	7.45	7.20	6.60	8.00	8.40
24			9.80	10.00	7.35	7.60	6.95	6.80	6.60	5.60	5.40	5.10	4.45
26							6.60	6.25	5.90	5.05	4.90	4.20	3.05
28					7.20	7.00	6.60	5.90	5.85	4.55	4.60	3.40	3.15
30	9.55	9.90	9.30	9.50	7.20	6.40	6.50	5.85	5.40	4.55	4.50	3.65	3.15
35			9.15	8.90	6.80	5.90	5.90	5.60	5.10	4.80	4.25	3.85	3.20
40	9.40	9.95	9.00	8.00	5.90	5.30	5.20	5.10	4.65	3.60	3.50	3.00	2.85
45				7.30	5.20	4.60	4.45	4.50	3.65	3.20	2.45	1.70	1.90
50	8.45	8.90	8.10	6.80	4.60	3.60	3.70	3.85	2.60	2.40	1.90	1.10	1.10
55			7.25		4.00	2.85	3.15	2.60	1.75	1.10	0.95	0.55	0.20
60	8.00	6.20	6.00	4.50	2.65	2.15	1.90	1.55	0.65	0.20	0.80	0.05	0.05
65				3.10	1.60	0.80	1.55	1.30	0.15	0.10	0.10	0.05	0.05
70	7.40	4.50	4.50	3.30	0.40	0.15	0.85	0.40	0.15	0.10	0.05	0.05	0.05
75			3.35	2.10	0.10	0.10	0.25	0.40	0.15	0.10	0.05		
80			2.25	0.80	0.00	0.10	0.15	0.40	0.10	0.05	0.05	0.00	0.00
85													
90													