AERATION-DESTRATIFICATION OF LAKE EUREKA USING A LOW ENERGY DESTRATIFIER

by

V. Kothandaraman and Ralph L. Evans

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EXECUTIVE SUMMARY

AERATION-DESTRATIFICATION OF LAKE EUREKA
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        The city of Eureka in Woodford County is one of several communities in
the state faced with the diminished use of city water-supply impoundments
because of water quality problems. In fact, the reservoir for the Eureka
community of 3,500 was abandoned in 1979 in favor of a groundwater source
that has proved less than satisfactory in terms of operational problems
and cost.

        The function of preserving, protecting, and deriving the maximum
potential benefits from impounded waters in Illinois resides in the State
Water Survey Division of the Department of Energy and Natural Resources.
With this mandate, the Water Survey entered into a cooperative venture with
Eureka to study their lake problems, which centered on persistent, severe
taste and odor episodes. The Water Survey's successful experience in lake
rehabilitation in other parts of the state indicated that the study could
be helpful. Funding was provided by the Department.

        The project's objective was to investigate the feasibility of improving
the lake water quality by in-lake treatment techniques so that the lake
water could once again be used as a raw water supply source.

        A low energy mechanical destratifier was operated in Lake Eureka from
May 6 to October 8, 1981, in combination with periodic chemical treatment.
Physical, chemical, and biological characteristics of the lake were monitored
during the period. The treatment techniques were able to:

  • Destratify the lake completely and maintain adequate oxygen levels
     throughout, even in the deep bottom waters

  • Reduce iron and manganese concentrations by 97% and chlorine demand
     by more than half (Manganese and chlorine demand values were
     directly correlated with the odor episodes in Lake Eureka)

  • Cause a dramatic shift in algal species, replacing problem-causing
     blue-gree algae with diatoms as the dominant species

  • Enhance the water quality in Lake Eureka to the extent that it can
     again be used as a raw water source

        The technical information developed in this investigation can be applied
not only to Lake Eureka but also to numerous other recreational and water
supply impoundments in the state.

        Cost savings to the city of Eureka in using the lake water instead of
the present groundwater source will amount to about $24,000 in power costs
and about $10,000 in chemical costs per year. Costs of operating the aerator-
destratifier and using in-lake chemical treatment are about $1,500. This
gives an operating cost-benefit ratio of 23.3 and allows payback of the
capital cost in the first year. Both the general public and the direct water
consumers will derive economic benefit from such cost savings.

ACKNOWLEDGMENTS

CONTENTS

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INTRODUCTION

City-owned Lake Eureka, formed in 1942 by damming a branch of Walnut Creek, was created to serve primarily as a water supply source for the city of Eureka. Eureka is situated 20 miles east of Peoria, Illinois. The lake and its surrounding park are used for recreational purposes such as picnicking, fishing, sail and row boating, and winter ice skating.

The lake is typical of small man-made lakes in Illinois, serpentine in configuration with a surface area of about 36 acres and a watershed area of 1700 acres. Other pertinent morphometric details are given in table 1. The watershed, which once consisted entirely of agricultural land with very few farmsteads, has changed in character within the past two decades. Residential subdivisions and lake-shore residential developments are now being constructed, even though agriculture with row crops remains the dominant land use in the watershed.

Taste and odor problems are encountered in almost all water works that use surface waters as a source. Taste and odor episodes continue to frustrate the skills of management and the patience of consumers. Lake Eureka proved to be no exception. Persistent and periodic episodes of taste and odor problems in the finished waters occurred for more than 10 years with resultant consumer complaints. The severe taste and odor problems encountered during the winter of 1976-1977 marked the end of local tolerance. The city sought an alternate source of raw water supply and switched to groundwater as the water supply source in November 1979.

Taste and odors in water can be derived from natural or man-made sources or a combination of both. The problems experienced are often associated with season, reservoir stratification and turnover, rainfall, stream flow, spring thaw, odor producing organisms, decaying vegetations, or industrial spills. Some odor episodes are predictable, while others are not.

Table 1. Morphometric Details of Lake Eureka

Surface area, acres	36
Volume, acre-feet	227
Mean depth, feet	6.3
Maximum depth, feet	18.0
Mean depth:Maximum depth	0.35
Watershed area, acres	1700

Lin and Evans (1981) conducted a detailed odor study of the raw and finished water in Lake Eureka and two other central Illinois lakes during the period of September 1976 to September 1978. They reported that high threshold odor numbers (TONs) in the lake waters occurred about the same time of year for each lake. They found that TONs for the lake water samples obtained from near the bottom were generally much higher than those for the samples obtained at mid-depth and at surface sampling points. They further reported that the odors of the finished waters in the Eureka water supply systems followed immediately the odor episodes in the lake's waters.

In an attempt to identify the relationship of TON and other commonly measured water quality constituents, Lin and Evans (1981) examined numerous parameters including pH, alkalinity, turbidity, manganese, dissolved oxygen, chlorine demand, and 15 others. For Lake Eureka, they found high correlations between TONs and 1) manganese concentrations and 2) chlorine demand values of the bottom waters. They further observed that high TONs generally occurred during the period May through October, the period of thermal stratification and the resulting anoxic conditions in the hypolimnetic waters of the impoundment.

When Lake Eureka served as a water supply source, the raw water supply intake in the lake was located about 6 feet from the bottom. It is likely that a major portion of the raw water supply during the periods of summer stagnation consisted of poorer quality hypolimnetic waters instead of the epilimnetic waters of the lake.

At present the city, with a population of approximately 3,500, spends about $2,000 each month for pumping groundwater and about $60,000 per year for lime and carbon dioxide used in the water softening process. Since the switchover to groundwater as the raw water supply source, plant operational problems such as poor floc settling, loss of pipe carrying capacity due to encrustation, and poor distribution of flows through sedimentation basins have increased. It is believed (personal communication, Benny Arbuckle, Superintendent of City Services at Eureka) that the chemical costs could be cut in half and most of the operating problems could be alleviated if lake water could again be used as the raw water source.

The primary objective of the work reported here was to investigate the feasibility of improving the lake water quality by in-lake treatment techniques so that the lake could once again be used as a raw water supply source.

Aeration/destratification or hypolimnetic aeration techniques have long been employed as an in-lake treatment method for improving lake water quality (New England Regional Commission, 1971, 1973a and b; Steichen, 1974; Symons, 1969). Brim and Beard (1980), Clair and Beck (1969), Eunpu (1973), and others have specifically dealt with the aspect of in-lake management for improving raw water supply quality characteristics.

A low energy mechanical destratifier was operated in Lake Eureka from May 6 to October 8, 1981, in combination with periodic chemical applications.

The physical, chemical, and biological characteristics of the lake were monitored during this period to determine the effects of the treatment techniques on water quality.

BACKGROUND INFORMATION ON AERATION/DESTRATIFICATION

Artificial destratification and hypolimnetic aeration are processes by which the lake waters are oxygenated and circulated. This is generally accomplished by either mechanical pumping (Symons, 1969; Steichen, 1974) or compressed air released at the lake bottom (Brim and Beard, 1980; Eunpu, 1973) or by a device which is a combination of mechanical pumping and bubbled-air aeration (Kothandaraman et al,, 1979). Symons (1969) used a pumping device by which hypolimnetic waters were lifted and discharged near the lake surface. Steichen (1974) employed an axial flow pump to move epilimnetic waters down to the hypolimnetic zone to destratify and oxygenate the anoxic zone of the lakes.

In compressed-air destratification, the rising air mass generates vertical water currents which diverge horizontally upon reaching the lake's surface. This upwelled water is much colder and denser than the surface water. The mixed water spreads out horizontally and then sinks to the level of equal density. Although the rising column of air bubbles adds oxygen directly to the upwelled water, oxygen is also gained when the oxygen-poor hypolimnetic waters come in contact with the atmosphere. As the mixing process continues, complete circulation is achieved and the lake waters approach uniform temperature and dissolved oxygen conditions.

In contrast to total aeration, several types of aeration devices have been designed to oxygenate the hypolimnetic waters without disrupting thermal stratification. Typically the aerator consists of a large diameter pipe which extends from the lake bottom to a few feet above the water surface. Water inlet ports are located near the bottom of the pipe and outlet ports are located below the thermocline. The bottom water is airlifted through the vertical tube, the rising bubbles are vented to the atmosphere, and the water is returned to the hypolimnion.

The pros and cons of artificial destratification in eutrophic lakes have been discussed in detail in the literature (Dunst et al., 1974; U.S. Environmental Protection Agency, 1973). Among the advantages of artificial destratification of eutrophic lakes are:

- With increased oxygen levels in the hypolimnion, there is a reduction in the anaerobic release of nutrients from the bottom sediments.

- Oxidation of organic and inorganic materials occurs in the water. This is particularly advantageous when the lakes serve as a raw water source, because taste, odor, and color problems caused by iron, manganese, and hydrogen sulfide are eliminated or at least minimized,

- The range of benthic populations is extended to the profundal region which was once anaerobic. An increase in the number of fish and a shift to a more favorable species can result from the greater availability of food organisms.

- Favorable changes in algal populations occur with a decrease in undesirable blue-green species.

- Evaporation rates are reduced in summer with reduction in surface water temperatures.

- There is an increase in water clarity.

- Winter fish kills may be prevented by maintaining sufficient oxygen levels under ice.

The disadvantages of artificial destratification include:

- The heat budget in the lake is increased.

- There is a temporary increase in water turbidity resulting from resuspension of bottom sediments.

- Artificial destratification may induce foaming.

- The oxygen demand of resuspended anaerobic mud may result in a decrease in oxygen concentrations, temporarily at least, that may kill fish.

MATERIALS AND METHODS

"The U.S. "Environmental Protection Agency (1973) when compiling cost data for lake aeration and destratification reported that 90% of the respondents utilized compressed air for aeration and only 4% used mechanical pumps. The axial flow, low energy, mechanical pump, developed by Quintero and Garton (1973) at Oklahoma State University, Stillwater, was reported to be very efficient (Steichen, 1974) and was shown to be capable of destratifying a 100-acre lake with a 1 1/2 hp motor. The system developed by Garton and Quintero, with minor modifications to meet site conditions, was used to destratify Lake Eureka.

The axial flow pump destratifier used in Lake Eureka consists of an electric motor (3/4 hp or 1 1/2 hp) mounted horizontally on a 90-degree gear reduction box (50:1), and a propeller with six variable pitch symmetrical blades mounted on the vertical shaft. The system was mounted on a floating platform such that the propeller was located about 5 feet below the water surface. The pitch of the individual blade can be set at any desired angle within the range of 14 to 30 degrees. As the blades are symmetrical, the pumping efficiency will remain the same whether lake water is pumped from

4

the surface toward the bottom or vice versa. An added feature of the aera-
tor system used in Lake Eureka is that a reversible switch mounted on the
motor permits the direction of rotation of the motor, and consequently the
direction of rotation of the propeller, to be reversed with ease.

Figure 1 shows the completely assembled destratifier prior to installa-
tion. Figure 2 shows a close up view of the propeller with the shroud and
protective bar grill. Figure 3 shows a view of the gearbox and the mounted
electric motor.

The assembled aerator was launched using a flatbed-mounted telescopic
crane, and was then hauled to the in-lake site and anchored. Four heavy
concrete anchors (120 to 140 pounds) with anchor ropes of lengths equal to
twice the water depth were used at each corner of the platform to anchor the
unit in place. Power (three phase, 220 volts) to the system was supplied by
means of a submersible cable laid on the lake bottom. The mechanical pump
was controlled by means of a land-based control panel which consists of a
circuit breaker, on-off switch, fuse box, indicator lamps, and a 7-day timer
with multiple "on-off" switching capability. During the first season of
aerator operation, the system was run continuously for 24 hours a day, ex-
cept for two brief interruptions. The system was shut down May 26-June 3
when the 3/4 hp motor was replaced by a 1 1/2 hp motor, and again on June
14-16 to install heavier anchors after an anchor displacement during a storm.

In order to assess the efficacy of the destratification of Lake Eureka
from the standpoint of improving lake water quality, certain physical, chemi-
cal, and biological measurements were made on a biweekly basis from May 6,
1981, until the shut down of the aerator on October 8, 1981, The location
of the destratifier and the three sampling stations in the lake are shown
in figure 4. The aerator was located at the deepest part of the lake with a
maximum depth of 18 feet.

In-situ observations of temperature, dissolved oxygen, and secchi disc
readings were made at stations 1 and 2 during the biweekly visits. Water
samples for chemical and biological examinations were made only at station
1. Water samples were collected at the surface and from near the bottom
(1 foot from bottom) for these purposes. Lake sediment samples for benthic
macroinvertebrate identification and enumeration were taken on a monthly
basis from sites 1 and 2. Water samples for determining copper concentra-
tions in the lake waters were taken from all three sampling sites immediate-
ly before chemical treatment of the lake and after a lapse of approximately
48 hours following chemical application. Samples for copper analysis were
taken at the surface and at 2 feet from the surface at all three sampling
locations.

In-situ dissolved oxygen and temperature measurements were made with a
galvanic cell oxygen analyzer equipped with a thermister. An oxygen meter,
Yellow Spring Instrument Company model 54, with a 50-foot probe was standard-
ized in lake surface water in which dissolved oxygen content was determined
by the modified Winkler method as outlined by the American Public Health
Association (1976). Temperature and dissolved oxygen measurements were ob-
tained in the water column at 2-foot intervals commencing from the surface
of the lake.

Figure   1.   Completely   assembled   aerator   prior   to   its   installation
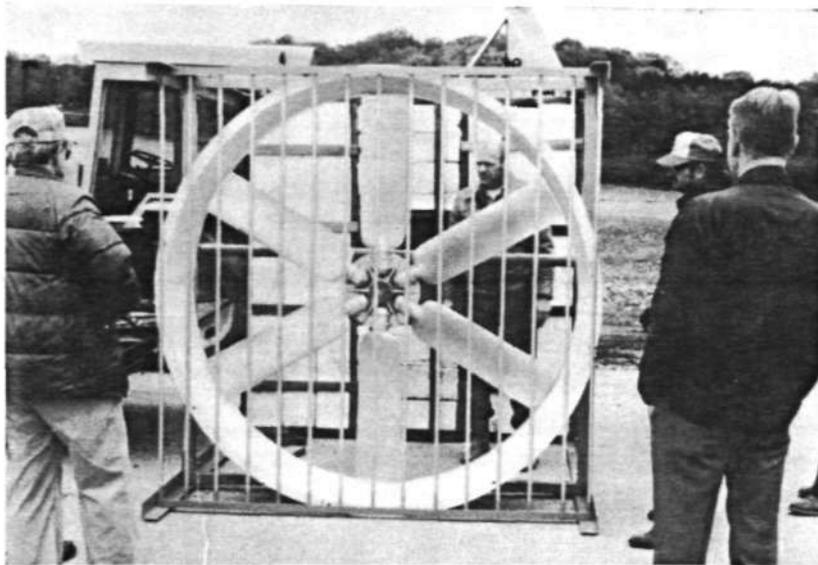

Figure   2,   View   of   the   propeller

Figure   3.   View of the platform,   motor,   and reduction gear
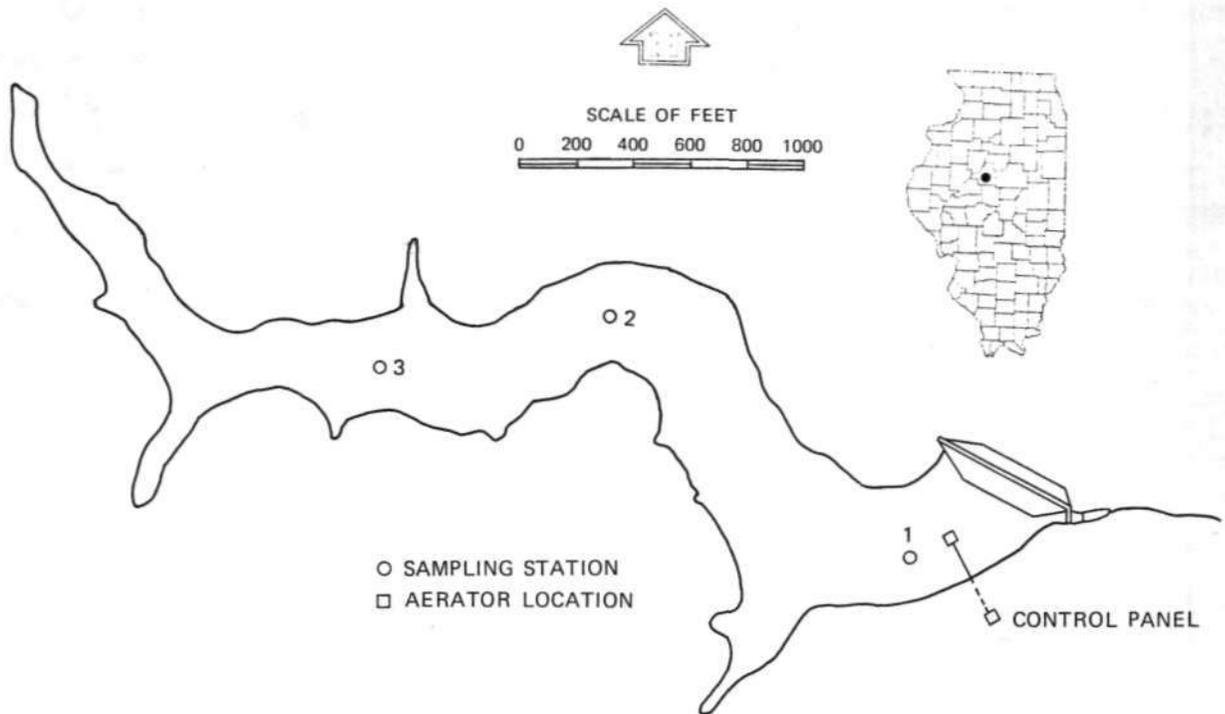

Figure 4.   Location of aerator and sampling stations in Lake Eureka

For measuring secchi disc transparencies, an 8-inch diameter secchi disc with black and white quadrant markings attached to a calibrated line was used. The disc was lowered until it disappeared from view, and the depth of immersion of the disc was noted. The disc was lowered farther and then raised slowly until it appeared. Again the depth of immersion was noted. The average of these two observations was recorded as the secchi disc reading.

Water samples for chemical and algal analyses representative of desired depths of the water column were obtained with a Kemmerer water sampler. Water samples for chlorine demand determinations were collected from surface, mid-depth, and deep locations using 300-ml BOD bottles in Juday samplers. The bottles were immediately stoppered and stored in ice along with chemical sample bottles. These sample bottles were kept refrigerated until analyses were performed. Water samples in a volume of 380 ml were collected for algal identification and enumeration. These samples were preserved with 20 ml of formalin at the time of collection and stored at room temperature until exa- mined. For ammonia determinations, samples were filtered at the lake site through 0.45 micrometer millipore filters to prevent bio-modification of the dissolved nitrogen forms.

Determinations for pH, alkalinity, and conductivity were made at the lake site, soon after sample collections. The following physical and chemi- cal analyses were performed in the laboratory: turbidity, total and suspend- ed volatile solids, total phosphorus and total dissolved phosphorus, total ammonia, dissolved nitrate, total kjeldahl nitrogen, total dissolved iron, total dissolved manganese, and chlorine demand. The methods and procedures involved in these determinations are given in table 2.

For chlorine demand determinations, a 200-ml sample was dosed with a chlorine solution to provide an initial chlorine residual concentration of 12 to 15 mg/l. After a contact period of 30 minutes at room temperature, the residual chlorine concentration of the sample was determined. The dif- ference between the initial and the residual concentrations was taken as the chlorine demand of the sample.

For algal identification and enumeration, the sample was thoroughly mixed and a 1-ml aliquot pipetted into a Sedgwick-Rafter cell, A differ- ential interference contrast microscope equipped with a 10X or 20X eyepiece, 20X or 100X objective, and a Whipple disc was used for identification and counting purposes. Five short strips were counted. The phytoplankton were identified as to species and were classified into five main groups: blue- greens, greens, diatoms, flagellates, and others. For enumeration, blue- green algae were counted by the trichomes. Green algae were counted by individual cells except for *Actinastrum*, *Coelastrum*, and *Pediastrum*, which were recorded by each colony observed, *Scenedesmus* was counted by each cell packet. Diatoms were counted as one organism regardless of their group- ing connections. For flagellates, a colony of *Dinobryon* or a single cell of *Ceratium* was recorded as a unit.

Table 2. Analytical Procedures

Turbidity	Nephelometric method, using Turner Fluorometer, model 110; Formazin was used as a standard.
pH	Glass electrode method with ?? table Metrohm-Herisau meter (model ??88).
Total solids	?? on evaporation at 103-105°C.
??pended solids	Dry weight of solids retained on go??ch crucible with fiber glass filter.
Suspended volatile solids	Loss on ignition of suspended solids at 550°C for 1 hour.
Alkalinity	Potentiometric method.
Conductivity	YSI model 33 conductivity meter.
Total phosphorus	Sample was digested with sulfuric-nitric acid mixture and determined by ascorbic acid method.
Total dissolved phosphorus	Sample was first filtered through 0.45 μm filter paper, digested with sulfuric-nitric acid mixture and determined by ascorbic acid method.
Total ammonia	Phenate method.
Dissolved nitrate	Chromotropic method after sample filtration through 0.45 μm filter paper.
Kjeldahl nitrogen	Digestion and distillation followed by endo-phenol-hypochlorite colorimetric determination.
Total dissolved iron	Atomic absorption method after filtering sample through 0.45 μm filter paper.
Total dissolved manganese	Atomic absorption method after filtering sample through 0.45 μm filter paper.
Chlorine residual	Iodometric method.

Benthic samples were obtained at monthly intervals covering the period June through September from stations 1 and 2, Three grabs with an Ekman dredge (6 × 6 inches) were taken at each station.. The samples were then washed in a 30-mesh screen bucket, placed in quart jars, and preserved in 95 percent ethyl alcohol. In the laboratory, the samples were washed again and the organisms were picked from the bottom detritus. They were then identified, counted, and preserved in 70 percent ethyl alcohol.

In conjunction with lake destratification, chemical treatment of the lake waters was also instituted. Copper sulfate chelated with citric was applied to the lake four times during May through August, Kothandaraman et al. (1980) reported that copper sulfate application with a chelating agent results in higher copper ion concentration and better distribution through-out the lake.

The chemicals were applied to the lake using two 30-gallon capacity plastic buckets with 1/2-inch holes drilled in the bottom half of the buckets. The buckets were floated using inflatable tractor inner tubes and tied to the aerator raft. For each chemical application, 200 pounds of copper sulfate was mixed with 100 pounds of citric acid and equal amounts were placed in the plastic containers. Flow of water past the perforated container, caused by the aerator currents, dissolved the chemicals gradually. The slowly released

chemicals subsequently were dispersed throughout the lake by natural circulation aided by the induced water movement in the lake. Fifty pounds of potassium permanganate was applied to the lake similarly on the second day after applying copper sulfate. Dosage of copper sulfate was calculated at the rate of 5.4 lbs per acre.

RESULTS AND DISCUSSION

Physical Characteristics

Temperature. The thermal stratification of deep lakes, impoundments, and reservoirs in the temperate zone is a natural phenomenon. Even very shallow lakes (5 to 10 feet) under certain conditions are known to exhibit thermal gradients of 6°C in 5 feet of water (Hill et al., 1981; Kothandaraman et al., 1977). Most of the physical, chemical, and biological characteristics of impounded waters are functions of temperature. Closely related to temperature variation in lake water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. Together, these two interrelated forces are capable of creating strata of water of vastly differing characteristics. Lake Eureka is no exception to this phenomenon.

Roseboom et al. (1979) report that in Lake Eureka, based on their observations during 1978, a thermal gradient began to develop in May at a water temperature of 10 to 12°C. The maximum temperature was 30°C at the surface and 13°C at the bottom. Bottom waters did not maintain a constant temperature typical of a firmly stratified lake. Water temperatures near the bottom varied from 10°C in April to 18°C in September of 1978. Isothermal plots for Lake Eureka pertaining to the pre-destratification period in 1978 are shown in figure 5.

Isothermal plots for lake stations 1 and 2 for 1981 are shown respectively in figures 6 and 7, The maximum surface water temperature observed at station 1 was 28.2°C on July 15, and the maximum temperature differential in the lake at station 1 was 9.2°C on June 4, 1981. This occurred just after an aerator breakdown during May 26 to June 3, 1981. However, when the aerator functioned without interruption in July, the maximum temperature difference was only 2.3°C, as contrasted to a difference of 17°C during July of 1978. Generally, the difference in water temperatures between the surface and near bottom waters was less than 2.5°C during the operation of the aerator.

Figure 7, in conjunction with figure 6, clearly indicates that the aerator effectively destratified the lake not only near the unit but also at a considerable distance away from the aerator. Figure 8 shows the temporal variations in temperature at the surface and near lake bottom at station 1. Surface water temperatures were generally lower and the near bottom water temperatures significantly higher than usual with destratification.

Selected vertical temperature profiles at station 1 for the years 1978 and 1981 are shown in figure 9. It is obvious that during summer months,

10
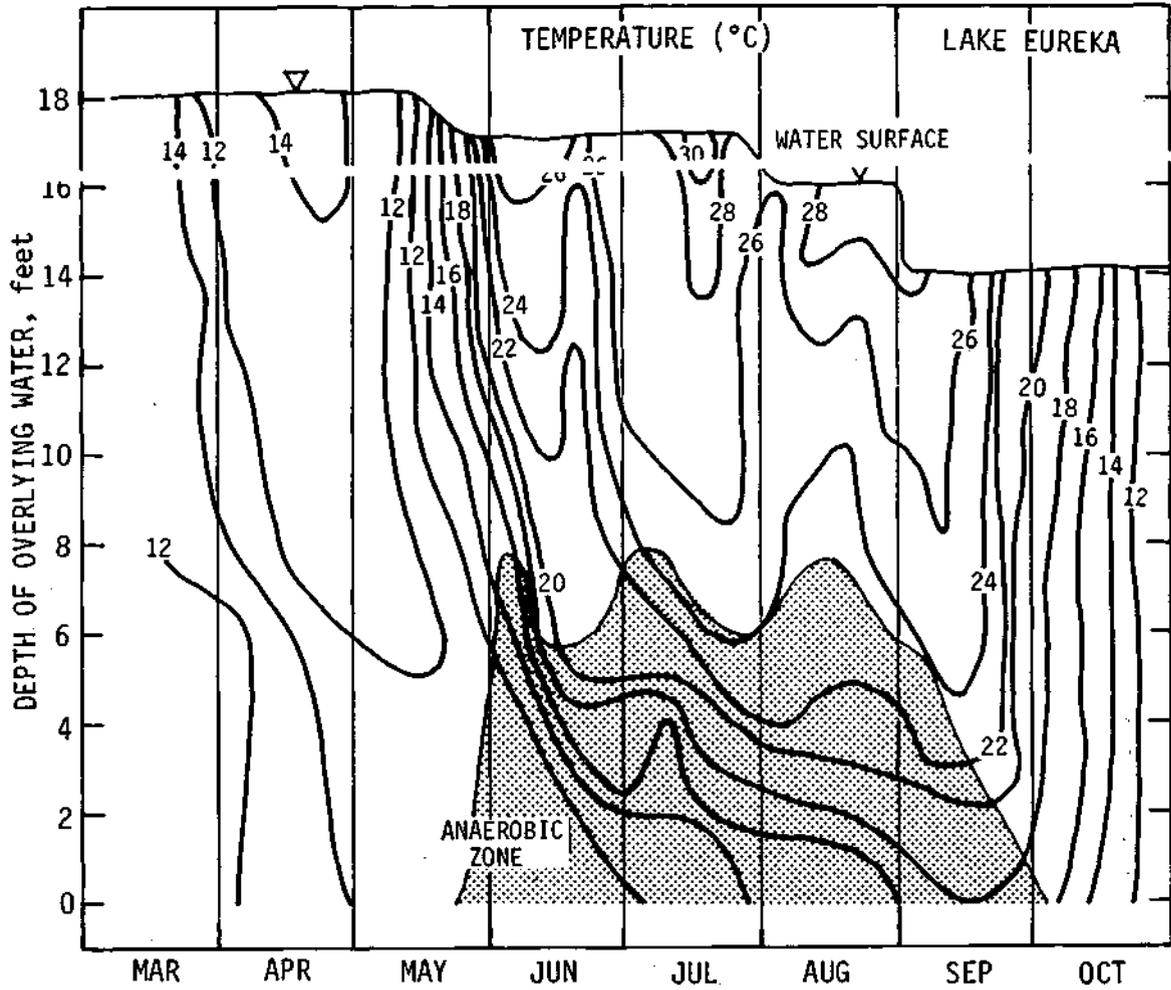
Figure 5. Isothermal plots for station 1 in Lake Eureka (1978)
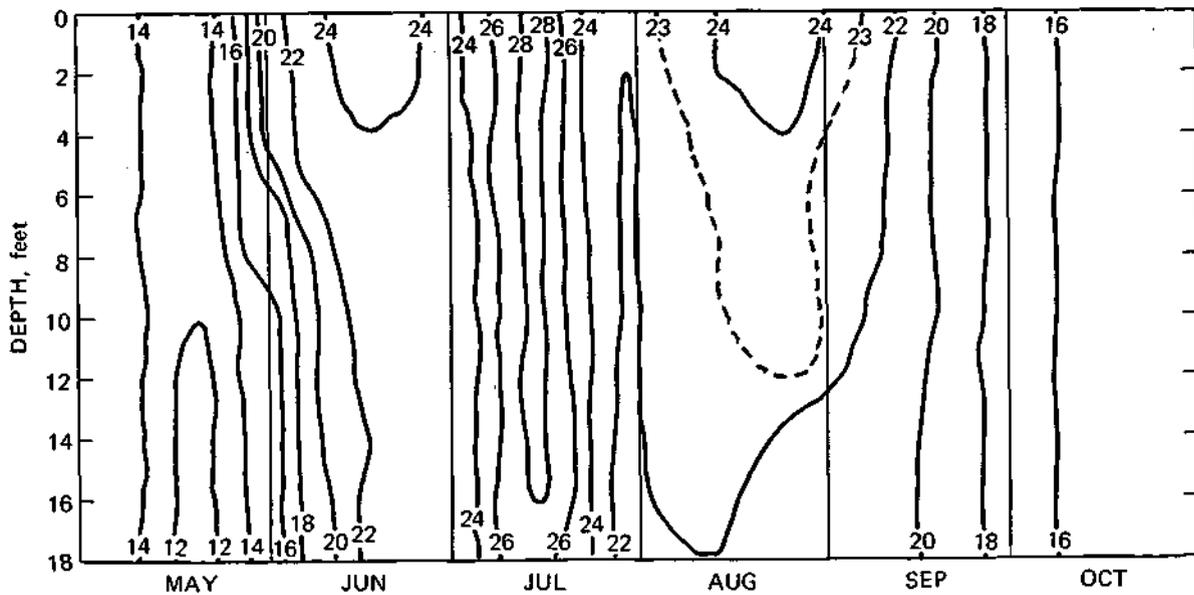
Figure 6. Isothermal plots for station 1 in Lake Eureka (1981)

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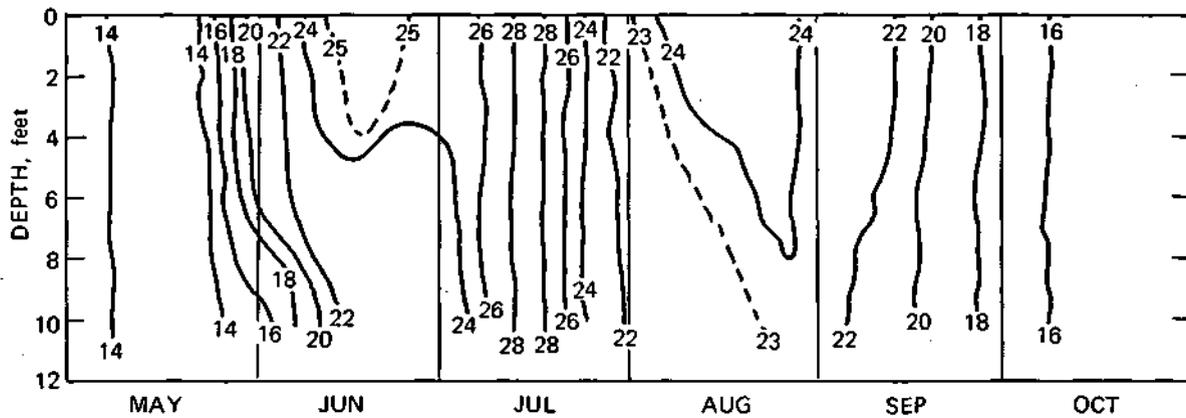
Figure 7. Isothermal plots for station 2 in Lake Eureka (1981)
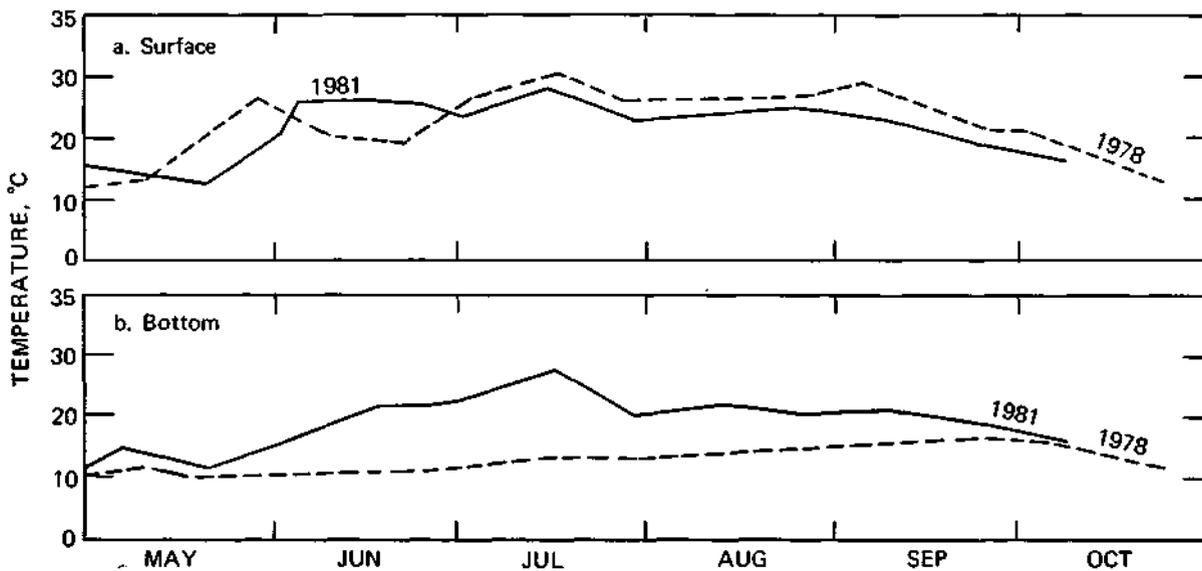
Figure 8. Temporal variations in temperature at the surface and near the lake bottom at station 1 in Lake Eureka

surface water temperatures were less during 1981 than in 1978 and the near bottom waters experienced a reverse trend. The effectiveness of the destratifier is clearly established by this phenomenon.

Dissolved Oxygen. Where the depth of an impoundment or a lake is significant, the thermal stratification acts as an effective barrier for wind-induced mixing. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion mechanism. As a result, when the benthic sediments exert a high demand, the oxygen resources of the hypolimnetic zone are quickly exhausted. Anoxic conditions prevail in the lake bottom waters during the warm summer months. Hill et al. (1981) reported this to be true even in a lake with a 5-foot depth.

12
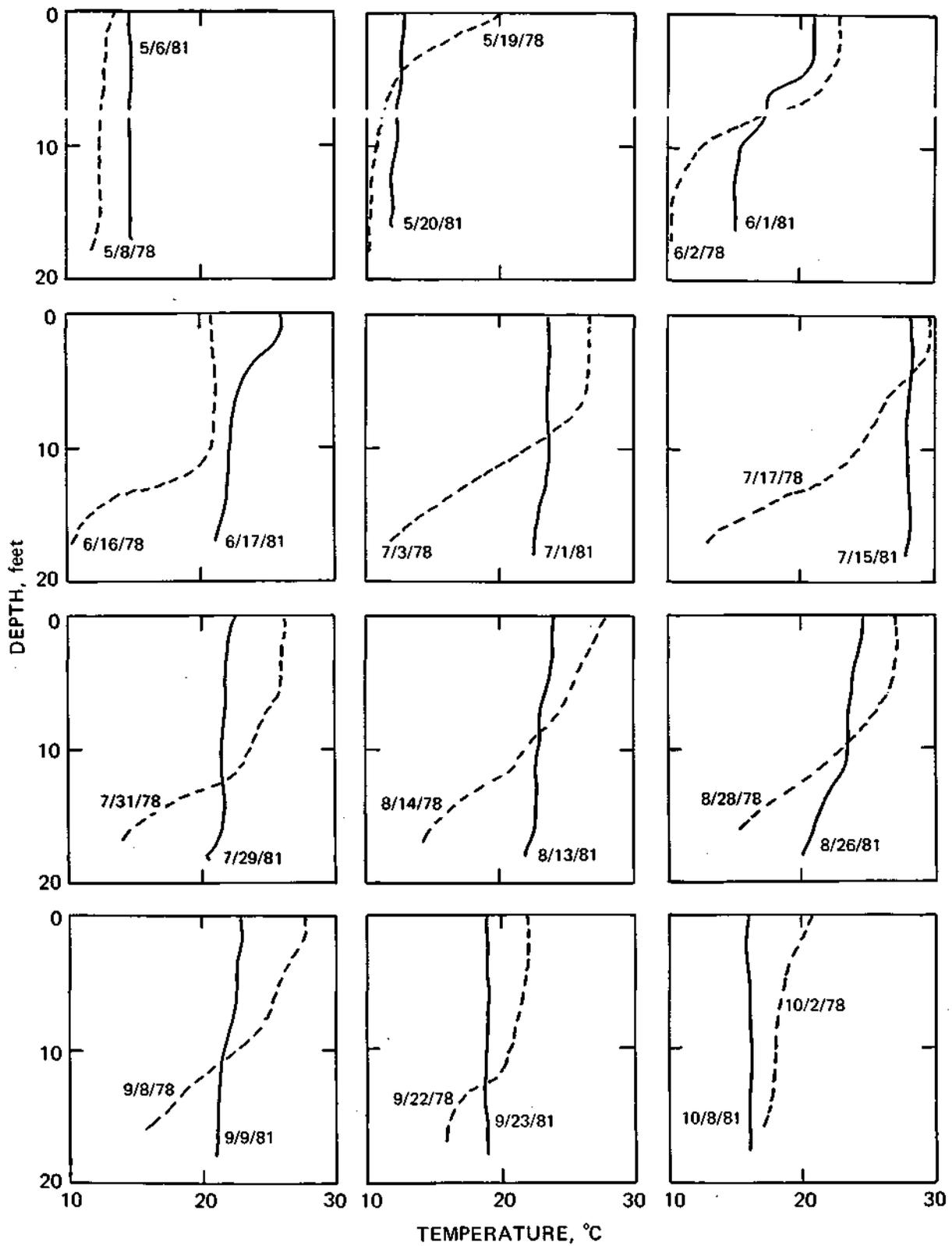
Figure   9.   Temperature   profiles   at   station   1   in   Lake   Eureka

13

Roseboom et al. (1979) reported that during 1978, dissolved oxygen was totally depleted in the water column of Lake Eureka at station 1, to a height of 8 feet from the bottom. They found that for 3 months (June 1 to August 30, 1978) the layers of water extending from 6 to 8 feet from the lake bottom were devoid of oxygen. Approximately 38 to 50% of the water column at station 1 lacked oxygen. The extent and duration of the anaerobic zone observed during 1978 with respect to the total water depth at station 1 is depicted as the shaded portion of figure 10. The rate of oxygen reduction in lower strata of Lake Eureka was reported in 1978 to be 0.40-0.50 mg/l/day which is nearly twice the rate of 0.22-0.34 mg/l/day for Lake Canton, another water supply impoundment in central Illinois.

Isopleth plots of dissolved oxygen in Lake Eureka during 1981 are shown for stations 1 and 2, respectively, in figures 11 and 12. Adequate oxygen levels were maintained throughout the summer season at station 1 except for a single episode of anoxic condition on August 26, 1981. This happened because
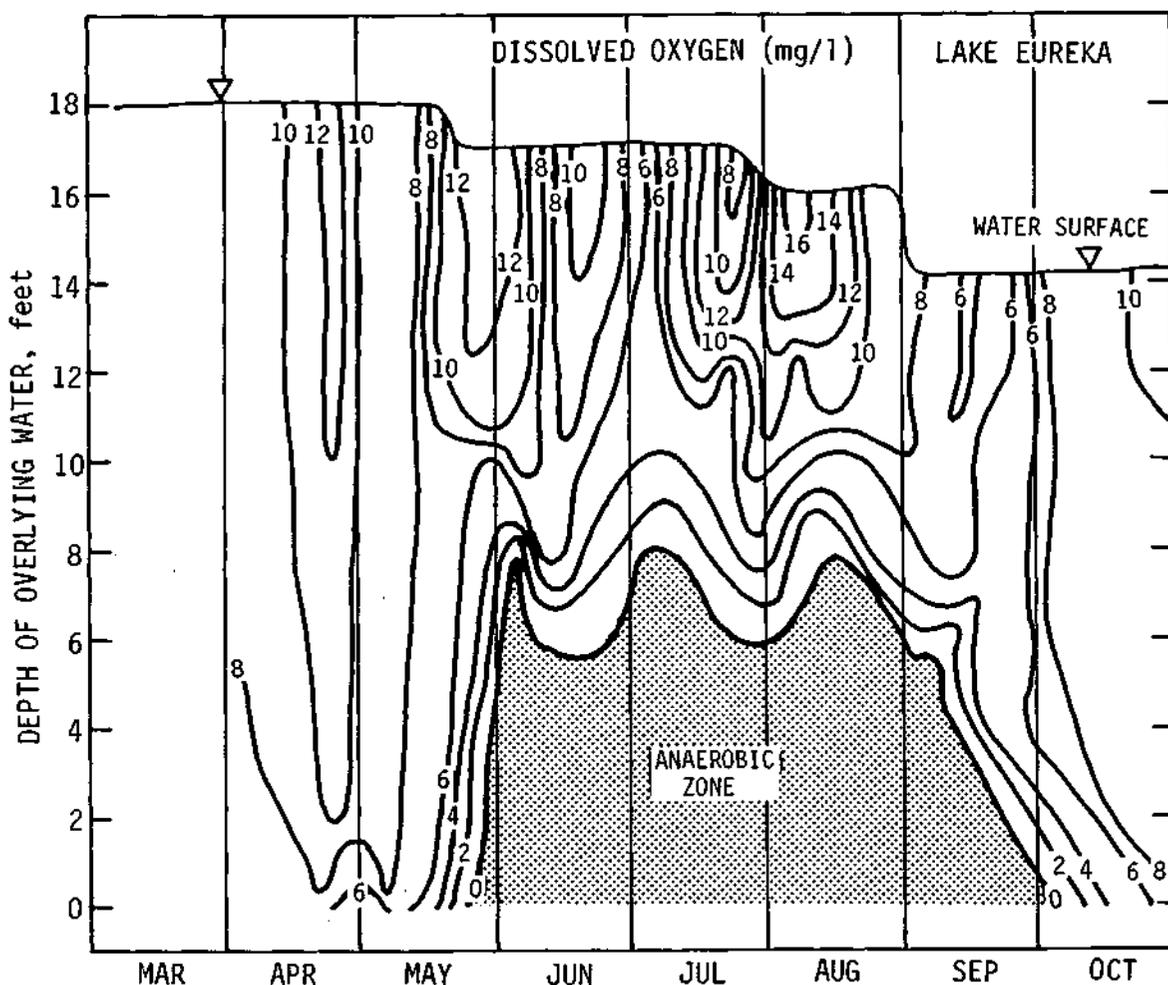
Figure 10. Isopleths of dissolved oxygen at station 1 in Lake Eureka (1978)

14
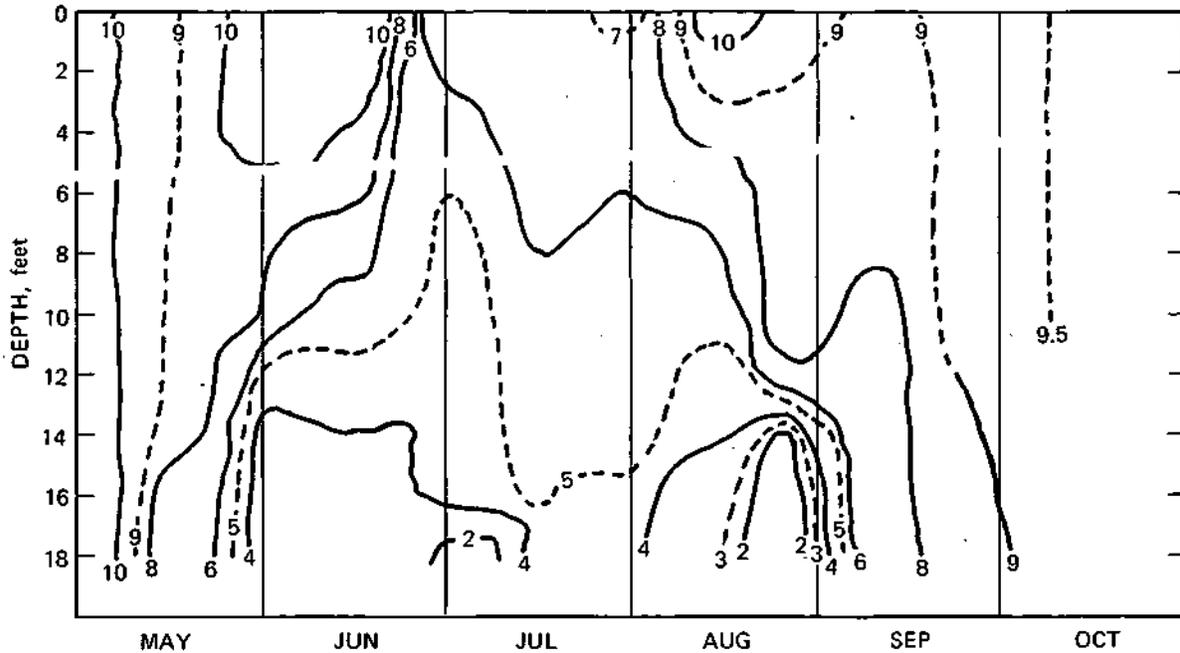
Figure 11. Isopleths of dissolved oxygen at station 1 in Lake Eureka (1981)
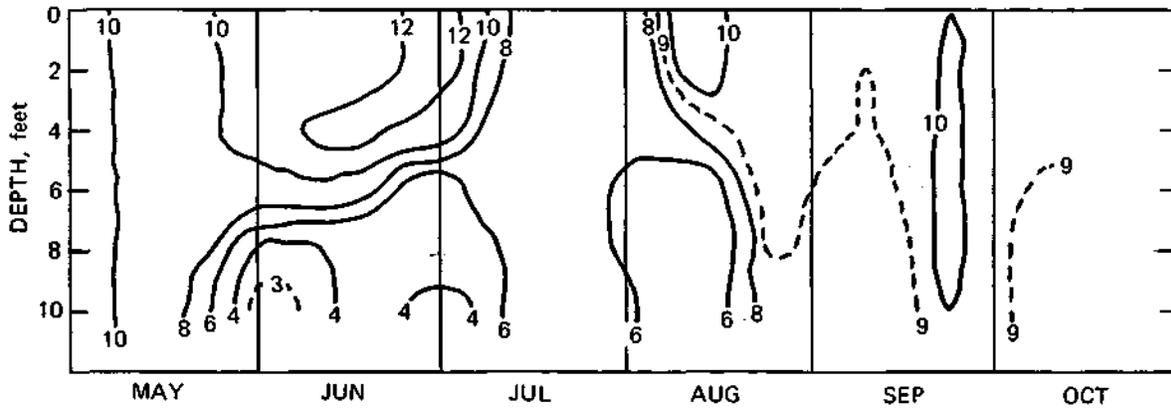
Figure 12. Isopleths of dissolved oxygen at station 2 in Lake Eureka (1981)

the propeller was operated with the blades set at the minimum pitch of 14 degrees until that time. The depth of water jet penetration and induced cir- culation provided by the pump became inadequate to satisfy the higher sedi- ment oxygen demand rate caused by the increased water temperature resulting from the artificial destratification. The blade pitch was set at 20 degrees soon afterwards and the DO conditions of the near bottom waters improved dramatically. It must be pointed out that the DO concentrations near the lake bottom at station 1 were never less than 2.0 mg/l even during the periods of aerator shut down (May 26 to June 3, and June 14 to June 16, 1981). It was possible to maintain oxygen levels throughout the lake with the aerator as evidenced by the data collected at station 2 (figure 12).

15

Figure 13 shows the temporal variations in dissolved oxygen at the surface and near the bottom of station 1, and figure 14 shows the corresponding percent saturation of dissolved oxygen values. At the lake surface, the DO concentrations and the percent saturation values were generally less from June through August of 1981 except for the periods of aerator shut down in
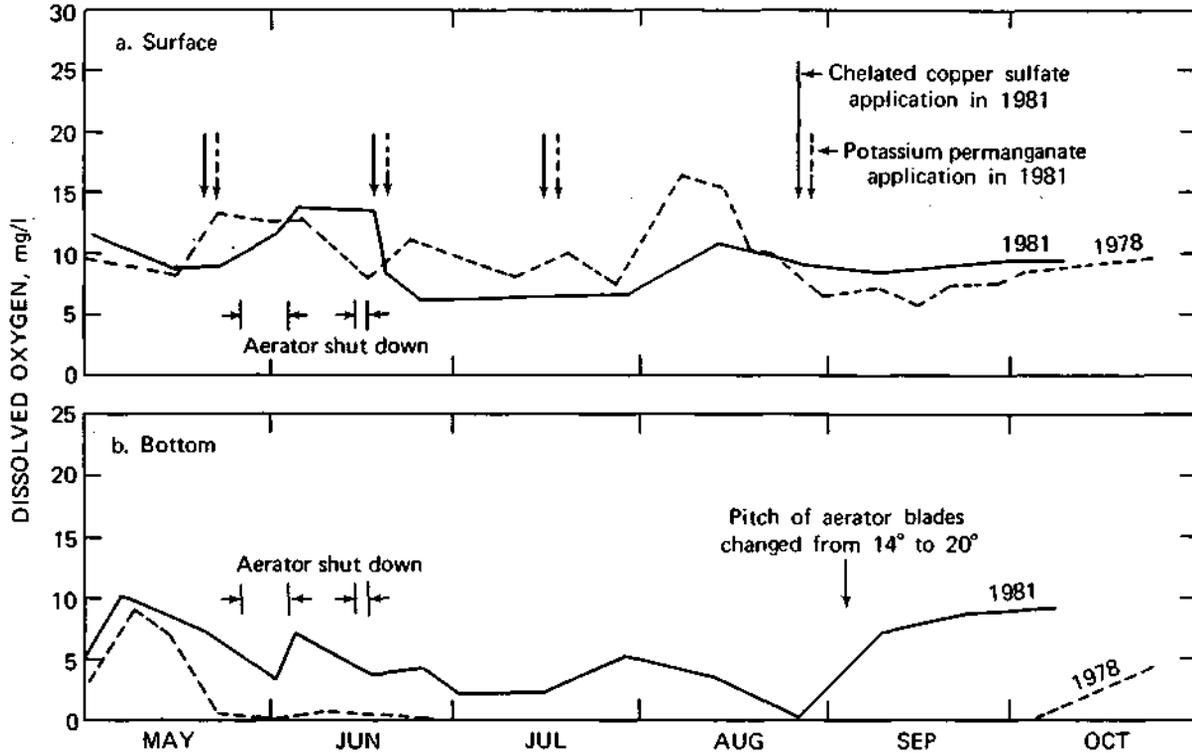
Figure 13. *Temporal variations in dissolved oxygen at the surface and near the lake bottom of station 1 in Lake Eureka*
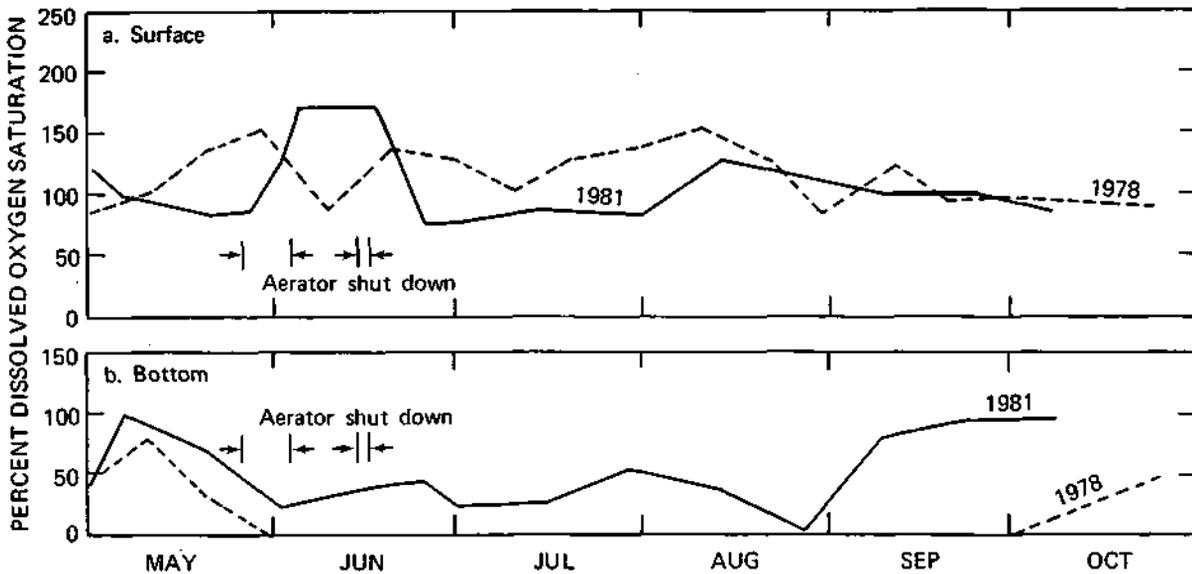
Figure 14. *Temporal variations in percent DO saturation at the surface and near the lake bottom of station 1 in Lake Eureka*

16

June. Near the bottom it was possible to maintain at least 4 mg/l of oxygen, or 50% saturation level, with adequate pitching of the propeller blades.

Figure 15 shows the oxygen profiles in the lake at station 1 for the years 1978 and 1981. The oxic conditions of the bottom waters of the lake were greatly improved with the destratifier.   The profiles ?? ?? ?? 1, June 17, and August 26 1981, clearly indicate that oxygen was rapidly depleted in the water column near the bottom when the aerator was shut down or when its mixing capacity was inadequate. Data for temperature and dissolved oxygen collected during 1981 are included in the appendix.

Secchi Disc Transparency. Secchi disc transparency is a measure of the lake water clarity or its ability to allow light transmission. Transparency is related to water color, suspended sediment consisting of silt and clay, and algae. The mean and range of values for transparency observed during 1978 and 1981 for Lake Eureka station 1 are shown in table 3, Plots of the temporal variations in secchi disc readings for these two years are shown in figure 16. The mean and range of values for 1981 are slightly higher than for 1978 but not significantly enough to attribute the improvement to the artificial aeration. This increase could have been a chance occurrence, and only continued operation of the aerator in the future can establish beyond doubt the beneficial impact of aeration on lake clarity.

Chemical Characteristics

The thermal stratification occurring in deep lakes and impoundments creates generally three distinct zones with widely differing physical, chemical, and biological characteristics. In the epilimnetic zone, the water is of chemical quality comparable to other surface waters in the area. On the other hand, the waters of the hypolimnetic zone deteriorate in quality after thermal stratification is established. The middle transition zone, or thermocline, did not usually exist in Lake Eureka.

The concentrations of reduced substances such as iron (Fe^{++}) , manganese (Mn^{++}), ammonia, hydrogen sulfide, phosphorus, and silica increase in the oxygen-deprived layers of the impounded waters. These substances, particularly the nutrients, are dispersed to the entire water column during autumnal overturn and become available for algal growth in spring and summer months.

In Lake Eureka, even though there was no well-defined thermocline during summer stratification, there were two distinct zones of vastly differing water quality characteristics (Roseboom, et al,, 1979). Phosphorus, ammonia nitrogen, iron, manganese, and alklinity values were significantly higher in the bottom waters at all times during the thermal stagnation compared to the values for surface waters. Tables 3 and 4 indicate the mean and range of values of chemical parameters reported by Roseboom et al. for the surface and near bottom waters of Lake Eureka during 1978.

Tables 3 and 4 also show the means and ranges of values for observations made in 1981. All the chemical data gathered during 1981 are included in the appendix. Turbidity, various solids fractions, conductivity, and nitrate and
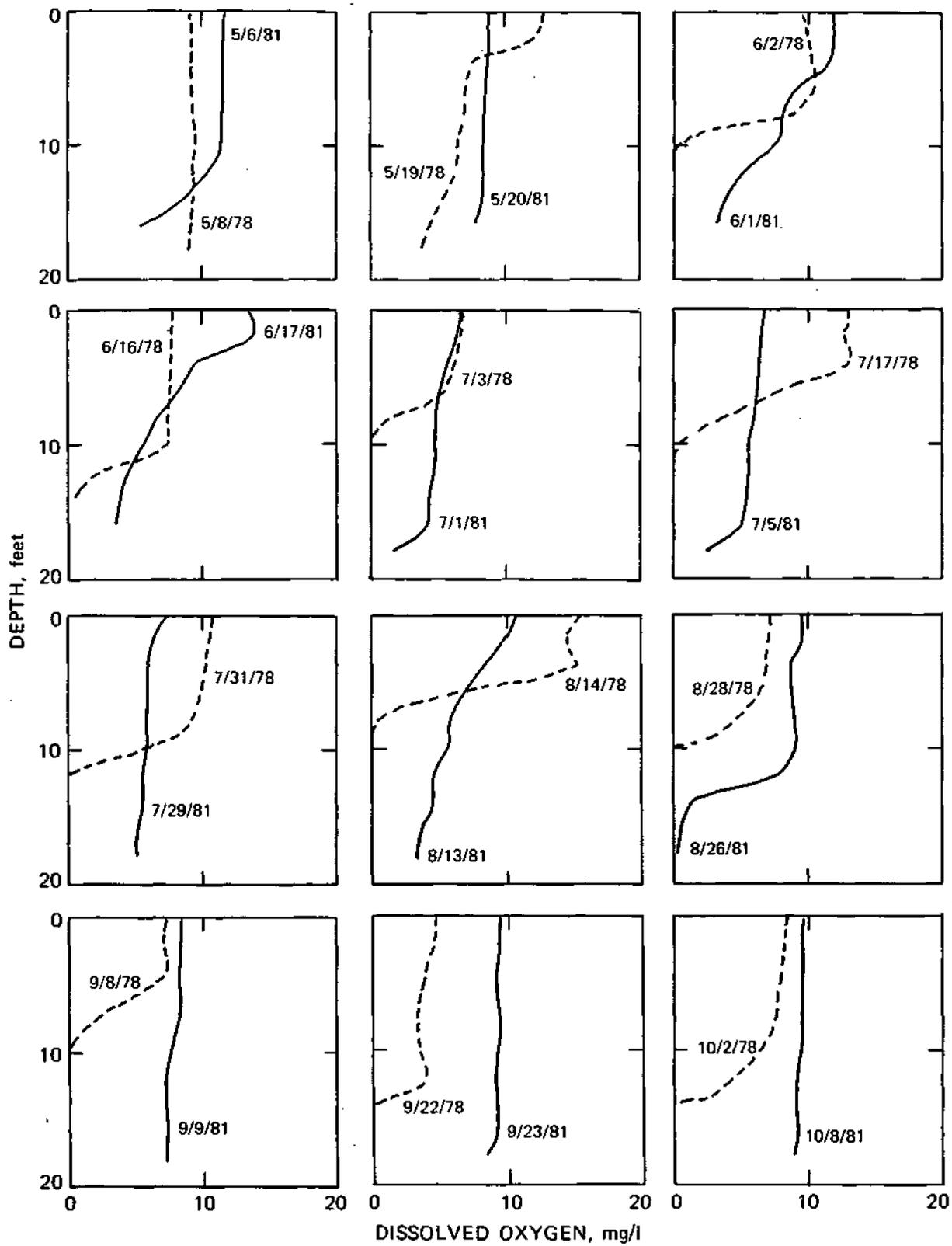
Figure 15. Dissolved oxygen concentration profiles at station 1 in Lake Eureka
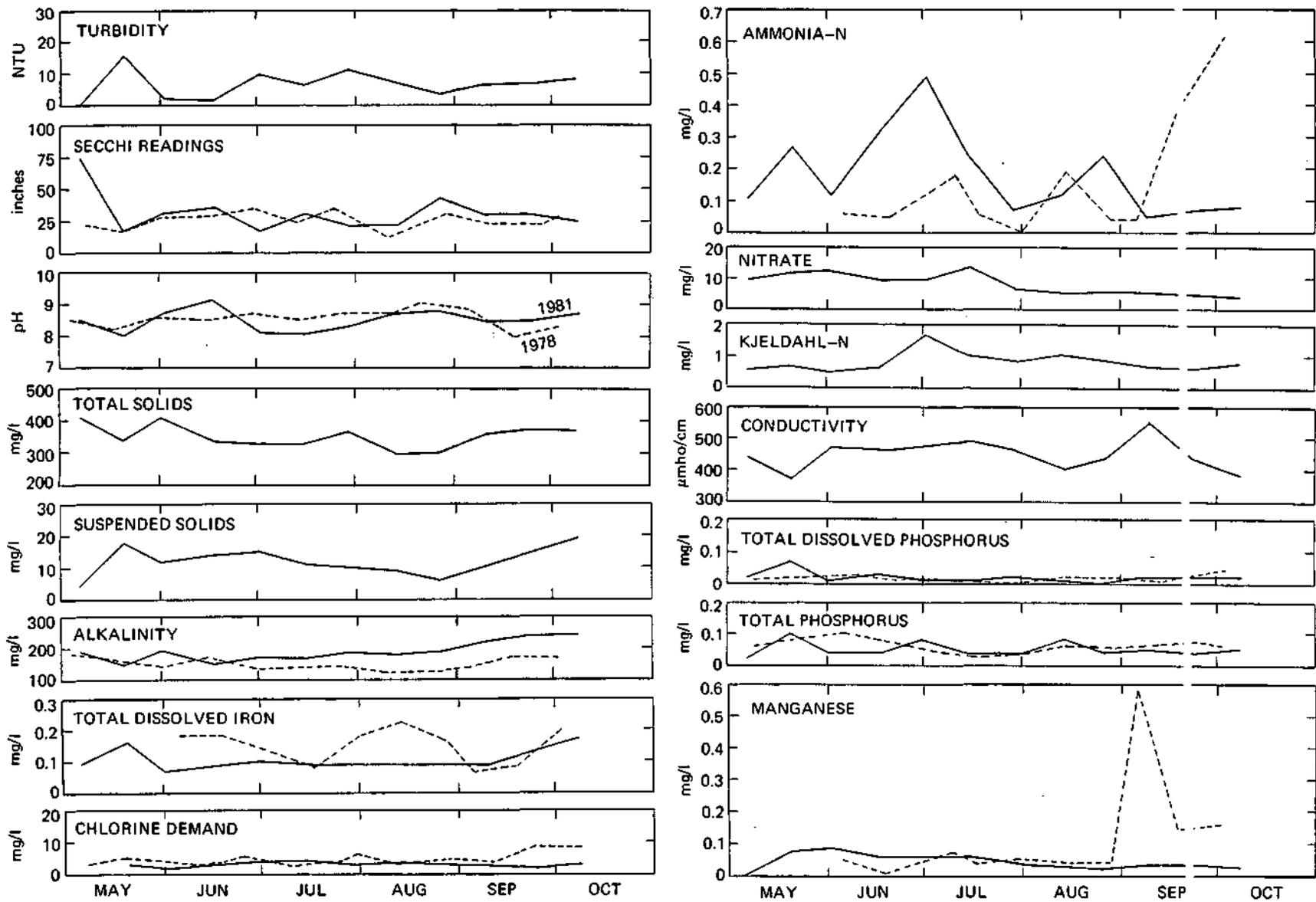
Figure 16. Physical and chemical water quality characteristics at the surface of Lake Eureka, station 1

Table 3. Summary of Water Quality Characteristics at the Surface of Lake Eureka, Station 1

Parameters	1981			1978		
	No. of observations	Mean	Range	No. of observations	Mean	Range
Turbidity	12	6.5	0.0-15.5			
Secchi readings	12	31	19-75	48	28	12-68
pH	12	–	8.0-9.1			8.0-9.2
Total solids	12	351	294-412			
Suspended solids	12	12	4-19			
Suspended volatile solids	12	6	2-13			
Alkalinity	12	185	146-233	50	145	94-185
Conductivity	12	447	370-550			
Total phosphorus-P	12	0.05	0.02-0.10	25	0.06	0.02-0.11
Total dissolved phosphorus-P	12	0.02	0.00-0.07	25	0.02	0.00-0.06
Total ammonia-N	12	0.18	0.05-0.49	15	0.20	0.00-0.89
Dissolved nitrate-N	12	8.13	3.76-13.50			
Kjeldahl-N	12	0.81	0.49-1.69			
Total dissolved iron	12	0.10	<0.08-0.17	16	0.17	0.06-0.37
Total dissolved manganese	12	0.05	<0.02-<0.10	15	0.10	0.00-0.58
Chlorine demand	11	2.94	1.86-4.56	25	4.20	1.10-8.10

Units of measurement: Turbidity-NTU; secchi-inches; pH-dimensionless; conductivity-umho/cm; others-mg/l.

Table 4. Summary of Water Quality Characteristics of Near Bottom Water Samples of Lake Eureka, Station 1

Parameters	1981			1978		
	No. of observations	Mean	Range	No. of observations	Mean	Range
Turbidity, NTU	12	18.8	5.2-84.5			
pH	12	--	7.5-8.6			7.2-8.3
Total solids	12	392	308-464			
Suspended solids	12	50	12-254			
Suspended volatile solids	12	11	1-44			
Alkalinity	12	195	160-227	50	221	150-301
Conductivity	12	466	380-590			
Total phosphorus-P	12	0.12	0.05-0.38	25	0.12	0.06-0.28
Total dissolved phosphorus-P	12	0.02	0.01-0.05	25	0.02	0.00-0.08
Total ammonia-N	12	0.31	0.07-0.95	18	3.97	0.43-7.11
Dissolved nitrate-N	12	8.27	3.66-12.31			
Total Kjeldahl-N	12	1.08	0.69-1.70			
Total dissolved iron	12	0.17	<0.08-0.34	18	5.27	0.16-10.90
Total dissolved manganese	12	0.13	<0.02-0.74	18	3.91	0.24-9.00
Chlorine demand	11	4.41	1.86-9.21	25	9.20	2.50-17.1

Units of measurements: Turbidity-NTU; pH-dimensionless; conductivity-µmho/cm; others-mq/l

kjeldahl nitrogen forms were additional determinations made during 1981 which were not made earlier. The mean, minimum, and maximum concentrations of total and dissolved phosphorus in the surface water samples were similar during both years. However, a significant reduction in the concentrations of iron and manganese and the chlorine demand values in surface samples were noticed during 1981 when compared to 1978 values. As the lake surface waters were well oxygenated during both years of monitoring, the reduction in these values cannot be attributed solely to the effect of the aerator.

The temporal variations of the chemical parameters monitored in the lake are shown in figures 16 and 17 for surface water samples and near bottom samples, respectively. An examination of figure 16 reveals that pH, phosphorus, iron, manganese, and chlorine demand values did not differ significantly for the years 1978 and 1981 except for occasional peaks and valleys. Ammonia-N concentrations ?? and July of 1981 and lower in September 1981 than the values for 1978. Surface alkalinity values were consistently higher in 1981.

However, a marked difference in chemical quality characteristics was observed in the near bottom samples. The minimum, mean, and maximum values for iron, manganese, and chlorine demand were reduced significantly in 1981 due to aeration/destratification. Reductions in the 'mean values of 97, 97, and 53% respectively for iron, manganese, and chlorine demand were achieved. Temporal variations of these parameters shown in figure 17 indicate this consistent trend. Likewise ammonia-N concentration in the bottom waters was found to be reduced to the extent of 92% in 1981. There was practically no difference in the phosphorus values. The pH and alkalinity values were less in 1981 compared to 1978 as would be expected under oxic conditions which prevailed during 1981.

As the chemical quality characteristics of the near bottom waters represent the worst case, the quality of the mid-depth waters at station 1 (the deepest part of the lake) should at least be as good or better than those reported for station 1 deep location.

The chemical quality characteristics of the lake, during 1981 monitoring with the aerator in place, were found to be of acceptable quality for the lake to serve as a raw water supply source.

Chlorine demand analysis is not usually applied to assess the quality of lake water. Its application is mainly limited to determining the required dosage of chlorine for potable water supplies and wastewater effluents. Because chlorine demand of water is dependent on the concentration of such inorganic reductants as ferrous iron, manganous manganese, and sulfide in water, it is an indirect measure of the oxidizing potential of these substances. Lin and Evans (1981) reported that the odor episodes of the Eureka finished water supply followed immediately the odor episodes of the lake bottom water samples. They found the TONs of lake bottom water samples to be well correlated with the manganese and chlorine demand values. No other water quality parameter among the 20 or so parameters they examined revealed any significant correlation. Since significant reductions in manganese and chlorine demand values were achieved in the bottom waters by the artificial destratification, it is highly probable that the odor episodes could be handled at the lake source more economically and efficiently than at the water treatment plant.

Chemical Treatment. Copper sulfate chelated with citric acid was applied to the lake on four different occasions, May 20, June 17, July 15, and August 26, 1981, Surface and 2-foot depth water samples for copper analyses were collected at stations 1, 2, and 3 shown in figure 4. Water samples
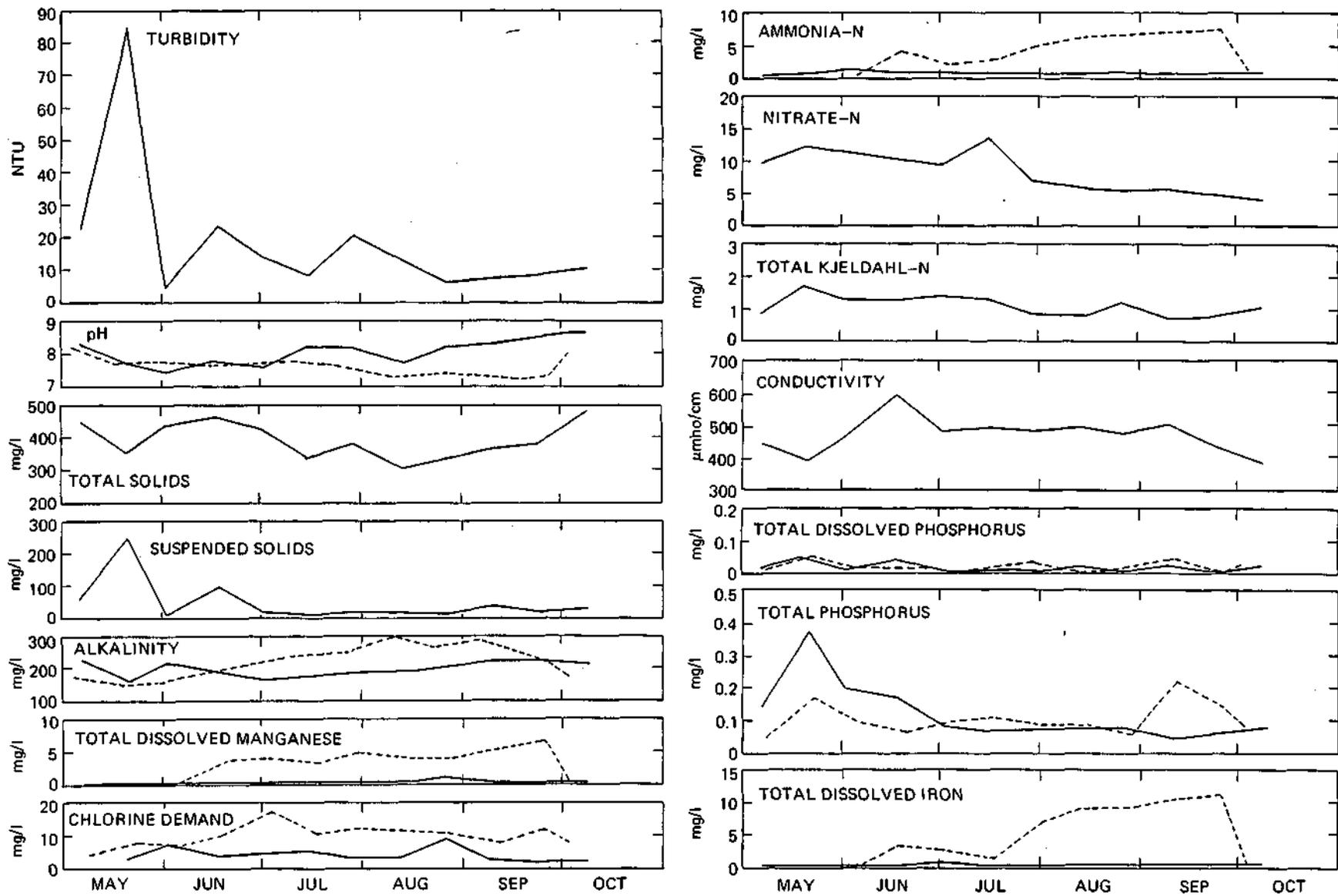
Figure 17. Physical and chemical water quality characteristics of near bottom' water samples of Lake Eureka, station 1

were collected immediately before the. chemical application and approximately 48 hours after application. Potassium permanganate was applied two days after the copper sulfate application mainly to oxidize the decaying algal cells which otherwise would exert a demand on the oxygen resources of the water column. Potassium permanganate is also considered an algicide. The chemical treatment in coniunction   with   ??   was under-Laken mainly to control algal blooms in the lake. Roseboom et al. (1979) and Lin and Evans (1981) reported algal growth of bloom proportions in the lake during the summer months, Lin and Evans (1981) reported the domination of the odor and taste producing algal species *Ceratium hirundinella* and *Anacystis cyanea* in the lake when they monitored the lake in 1977 and 1978,

The results of,copper analyses are shown in table 5, The pre-chemical application copper concentrations were all below the detection limit. After the chemical application, copper was found to be dispersed uniformly through-out the lake. The single point application of the chemicals and subsequent dispersal with the aid of the aerator appears to be effective, and this mode of application is economical. A similar approach taken in Lake Catherine (Kothandaraman et al., 1980) yielded comparable results.

Biological Characteristics

Phytoplankton. The total algal counts and the species distribution of algae found at the surface and near the bottom of station 1 are shown in table 6. Algal counts were less than bloom proportion during May, September, and October. Densities were high and of bloom proportion during the warm summer months of June through August. However, diatoms were the dominant algae in the lake during this period. The reasons for higher algal densi-ties near the lake bottom than at the surface during the summer months (table 6) are not known unless they are due to induced circulation. The drama-tic shift in the species makeup of the phytoplankton community is a welcome change from that observed in 1977 and 1978 (Roseboom et al., 1979). This could have been brought about by destratification, chemical treatment of the lake waters, above normal rainfall in the region resulting in decreased hy-draulic residence time and the consequent higher flushing rate, and myriad other factors.

Table 5. Distribution of Copper Ion in Lake Eureka
after Chemical Application

Dates of sample collections	Copper concentrations, mg/l					
	Station 1		Station 2		Station 3	
	Surface	Two feet	Surface	Two feet	Surface	Two feet
*5-20-81	--	--	--	--	--	--
5-22-81	0.04	0.13	0.06	0.15	0.03	0.12
*6-17-81	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
6-19-81	0.07	0.06	0.06	0.05	0.05	0.05
*7-15-81	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
7-17-81	0.06	0.06	0.06	0.07	0.06	0.06
8-26-81	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
8-28-81	0.07	0.07	0.07	0.07	0.07	0.07

* Dates of copper sulfate application.

Table 6. Algal Types and Densities in Lake Eureka
(Density in counts per milliliter)

Dates	Surface					Near bottom samples				
	BG	G	D	F	T	BG	G	D	F	T
5-6-1981	60	5	105		170	4	19	23	2	48
5-20	90	5	80		175	13	4	48	0	65
6-1	180	390	905	40	1515	6	0	340	2	348
6-17	200	420	3390	10	4020	0	0	4940	60	5000
7-1	0	600	3880	120	4600	0	420	3640	60	4120
7-15	0	490	3395	0	3885	0	305	5	80	5060
7-29	95	0	3575		3670	0	0	6605	0	6605
8-13	430	0	3510		3940	0	115	720	20	2855
8-26	0	95	375		470	0	95	0	990	1085
9-9	0	60	210		270	0	220	270	0	490
9-23	0	0	80		80	0	8	135	0	143
10-8-1981	0	60	160		220	0	86	23	4	113

Note: BG - Blue Greens; G - Greens; D - Diatoms; F - Flagellates;
       T - Total

No attempt was made to catalog the type and areal extent of macrophytes
and attached algae that were found in the shallow bay areas and along the
shores. Another unusual phenomenon noticed in the lake during the spring
months was that over 70% of the lake bed (estimated by scuba diving exami-
nation at several locations in the lake) was found to be covered with at-
tached algae. These were predominately *Spirogyra communis, S. majuscula,*
and other unidentified species of Spirogyra. The impact of these algal
mats and their life cycles on the lake water quality could not be assessed.
No known practical in-lake treatment technique, except dredging or mechani-
cal scraping of lake bottom and removal of sediments, exists to control this
type of growth.

Benthic Macroinvertebrates. The population of the benthic macroinverte-
brate communities in sediments from stations 1 and 2 are given in table 7.
Oxic conditions prevailed in the overlying waters at both the stations.
However, the species diversity at station 2 was much higher than at station
1. *Chaobovus* was the dominant organism at the deep station. Significant
numbers of Chironomidae with respect to the total number of organisms were
found in the well oxygenated shallow station.

CAPITAL COST AND O & M

The total cost of the aerator system was $8,400 (1981 dollars) which
included $6,900 for the design, fabrication, transportation, and installa-
tion of the aerator system; $350 for 3-wire #8 submersible cable; and $1,150
for fabrication and installation of the control panel. Vandal-proofing the
aerator system, adding the backup motor, adding flexibility to the operation
of the system by providing an "on-off" timer switch on the control panel,
and providing more than adequate protective controls-, all added to the total
cost of the system.

Table 7. Benthic Macroinvertebrates in Lake Eureka
(Individuals per square meter)

	Station 1			
Taxon	6-18-81	7-15-81	8-13-81	9-9-81
Chaoborus (Phantom midge)	6832	3818	29	1493
Chironomidae (Midges)	144	0	72	14
Total	6976	3818	101	1507
	Station 2			
Ceratopogonidae (Biting midge)	129	101	14	29
Chaoborus (Phantom midge)	5038	1866	0	115
Chironomidae (Midges)	1091	574	287	258
Oligochaeta (Aquatic worms)	718	0	129	43
Sphaerium (Fingernail clams)	129	0	0	29
Unionidae (Fresh-water mussels)	43	0	0	0
Total	7148	2541	430	474

Once the proper pitch for the rotor blades was determined, the system
proved to be reliable and trouble free. The only periodic maintenance re-
quired in operating the system was the changing of gear oil at about three-
month intervals. The power cost for 5 1/2 months operation of the aerator
was about $325. The cost of chemicals was about $800,

RECOMMENDATIONS

The operation of the aerator during the summer months indicates that
the lake water quality can be greatly enhanced. The aerator should be oper-
ated during winter months also, and the lake should be monitored to investi-
gate whether the odor problems in finished waters can be controlled. The
macrophytes and attached algae in bay areas and along the shoreline should
be mechanically harvested and removed from the lake. During the first year,
two or three harvestings will be needed, but less frequent harvestings would
be needed in subsequent years. In the past, raw water supply from the lake
was drawn from an inlet located 6 to 8 feet from the bottom. The inlet
should be modified in such a way that water will be drawn from within the
top 2 to 3 feet of the lake surface.

SUMMARY

A low-energy, mechanical, reversible draft, destratifier was- installed
in Lake Eureka and operated from May 6 to October 8, 1981, The primary
purpose of the aeration/destratification was to investigate whether the lake
water quality could be improved by in-lake management techniques so that
the lake could once again serve as a possible source of raw water supply to
the city of Eureka. The lake had served as a water supply source for nearly

40 years when the city switched to a groundwater source because of persistent and severe odor problems in the finished water during summer months and occasionally in winter months.

Destratification in combination with periodic application of chelated copper sulfate followed by potassium permanganate was tried in an attempt to improve the lake water quality. Physical, chemical, and biological characteristics of the lake were monitored at its deepest station.

The aerator with a 1 1/2 hp motor was able to destratify the lake completely and maintain adequate oxygen levels throughout, including the near bottom waters of the deep portions of the lake. Iron and manganese concentrations in the deep waters were reduced by 97% compared to the pre-aeration levels. Chlorine demand values were reduced more than half. An earlier study (Lin and Evans, 1981) had indicated that the odor episodes in the finished water were directly correlated with manganese and chlorine demand values.

Also with the destratification procedures, dramatic shift in the algal species makeup was observed in the lake. Problem causing blue-green algae were practically insignificant, and diatoms were the dominant algae during the summer months.

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Appendix   A-1.   Dissolved   ox??   temperature   ??
in Lake Eureka, station 1

Depth feet	5-1-81 D.O.	Temp.	5-6-81 D.O.	Temp.	5-20-81 D.O.	Temp.	5-22-81 D.O.	Temp.	6-1-81 D.O.	Temp.	6-4-81 D.O.	Temp.
0	11.9	15.8	10.1	14.8	8.8	12.9	8.9	15.1	11.9	21.0	13.7	26.2
2	11.9	15.8	10.1	14.8	8.8	12.5	8.2	14.9	11.9	21.0	15.2	26.2
4	11.9	15.8	10.1	14.8	8.8	12.5	8.1	14.2	11.9	21.0	15.6	25.2
6	11.9	15.8	10.1	14.8	8.7	21.3	8.2	14.0	8.4	17.2	10.4	20.2
8	11.8	15.7	10.1	14.8	8.5	12.1	8.2	14.0	8.0	17.2	9.6	18.8
10	11.8	15.0	10.1	14.8	8.3	12.0	8.2	13.9	8.0	15.2	9.0	18.0
12	10.3	13.2	10.1	14.8	8.2	11.9	8.0	13.8	4.6	15.2	7.8	17.6
14	9.0	11.9	10.1	14.8	8.2	11.8	8.1	13.6	3.2	15.2	7.5	17.2
16	5.2	11.6	10.1	14.8	7.5	11.4	8.1	13.2	3.2	15.2	7.0	17.0
18	--	--	--	--	7.3	11.4	7.2	12.9	--	--	--	--

Depth feet	6-17-81 D.O.	Temp.	6-19-81 D.O.	Temp.	6-25-81 D.O.	Temp.	7-1-81 D.O.	Temp.	7-15-81 D.O.	Temp.	7-29-81 D.O.	Temp.
0	13.6	26.0	8.1	23.3	6.0	25.0	6.5	23.7	6.6	28.2	7.1	22.5
2	14.2	26.0	8.0	23.2	5.7	24.0	6.1	23.6	6.6	28.2	6.3	22.0
4	9.6	23.5	8.0	23.1	5.5	23.9	5.3	23.1	6.4	28.2	6.2	22.0
6	8.2	23.0	7.9	23.0	5.5	23.7	5.0	23.1	6.4	28.2	6.0	22.0
8	6.4	22.5	7.7	23.0	5.3	22.4	4.8	23.1	6.0	28.2	5.8	22.0
10	5.8	22.5	7.5	22.9	5.1	23.0	4.6	23.1	5.6	28.2	5.9	21.9
12	4.8	22.2	7.4	22.9	4.3	22.1	4.5	23.1	5.4	28.2	5.7	21.9
14	4.0	22.0	7.4	22.9	4.0	21.9	4.3	23.0	5.4	28.2	5.4	21.9
16	3.6	21.2	7.2	22.8	4.0	21.7	4.2	22.9	5.1	28.2	4.8	21.3
18	--	--	6.4	22.5	4.1	21.0	1.9	22.8	2.1	27.9	5.1	20.2

Depth feet	8-13-81 D.O.	Temp.	8-26-81 D.O.	Temp.	9-9-81 D.O.	Temp.	9-23-81 D.O.	Temp.	10-8-81 D.O.	Temp.
0	10.6	24.0	9.3	24.7	8.5	22.9	9.3	18.9	9.5	16.0
2	9.6	24.0	9.1	24.5	8.5	22.9	9.3	18.9	9.5	16.0
4	8.3	23.6	8.8	24.0	8.3	22.7	9.1	18.9	9.5	16.0
6	6.4	23.2	8.8	23.8	8.4	22.5	9.1	18.9	9.5	16.0
8	5.7	23.0	9.1	23.8	8.1	22.0	9.1	18.9	9.5	16.0
10	5.3	23.0	9.5	23.5	7.5	21.5	9.1	18.9	9.5	16.0
12	4.6	22.9	7.9	23.0	7.2	21.3	9.0	18.9	9.2	16.0
14	4.2	22.8	0.3	21.1	7.3	21.2	8.9	18.9	9.2	16.0
16	3.4	22.4	0.1	20.8	7.1	21.0	9.0	18.9	9.2	16.0
18	3.2	22.0	0.1	20.1	7.1	21.0	8.6	18.9	9.2	16.0

D.O. - mg/1
Temperature - degrees Celsius

Appendix A-2. Dissolved oxygen, temperature observations
in Lake Eureka, station 2

Depth	5-6-81		5-20-81		5-21-81		6-1-81		6-4-81		6-17-81	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	10.4	14.8	9.3	13.0	9.1	16.0	11.9	21.0	16.2	26.0	11.5	26.0
2	10.4	14.8	9.3	13.1	8.9	15.0	11.9	21.0	16.6	25.0	11.4	25.8
4	10.4	14.8	8.5	12.2	8.6	14.9	11.9	21.0	19.2	23.0	13.2	25.0
6	10.4	14.8	8.5	11.9	8.6	14.2	8.6	21.0	12.5	19.8	9.2	23.0
8	10.4	14.6	8.4	11.7	8.5	14.2	3.2	16.6	11.5	18.2	5.4	22.8
10	10.4	14.2	7.9	11.7	8.5	14.0	2.4	15.2	10.8	18.0	4.4	22.4

Depth	6-19-81		6-25-81		7-1-81		7-15-81		7-29-81		8-13-81	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	9.5	23.4	5.4	24.0	12.8	24.6	7.7	28.8	7.3	22.9	10.4	25.1
2	9.4	23.4	5.3	24.0	12.7	24.4	7.7	28.8	7.1	22.1	10.6	24.9
4	9.2	23.4	5.2	23.5	10.7	24.0	7.6	28.8	6.4	22.0	8.9	23.5
6	9.0	23.4	4.8	22.8	5.1	23.7	7.2	28.6	5.8	22.0	4.5	23.0
8	8.8	23.3	4.4	22.2	4.6	23.7	6.8	28.5	5.8	21.9	4.4	22.8
10	8.4	23.1	4.2	22.1	3.8	23.0	6.6	28.4	6.3	21.9	4.2	22.8
12	--	--	3.9	20.5	--	--	--	--	6.0	19.3	--	--

Depth	8-26-81		9-9-81		9-23-81		10-8-81	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	9.1	24.2	9.1	23.7	10.0	18.9	9.5	16.0
2	9.3	24.2	9.0	23.0	10.1	18.9	9.5	16.0
4	9.3	24.2	9.0	22.2	10.2	18.9	9.2	16.0
6	9.3	24.2	8.5	22.0	10.2	18.9	8.9	16.0
8	9.3	24.0	7.6	21.9	10.1	18.9	8.9	16.0
10	8.9	23.5	7.2	21.6	10.0	18.9	8.9	16.0
12	5.8	22.9	7.3	21.4	10.0	18.8	--	--

D.O. - mg/l
Temperature - degrees Celsius

30

Appendix A-3.   Physical and chemical quality characteristics of surface waters
at station 1 in Lake Eureka

Parameters	5-6-81	5-20-81	6-1-81	6-17-81	7-1-81	7-15-81
Turbidity	0.0	15.5	2.6	1.7	9.4	6.2
Secchi disc readings	75	18	30	36	19	30
pH	85	8.0	8.7	9.1	8.1	8.1
Total solids	412	338	412	334	328	329
Suspended solids	4	18	12	14	15	11
Suspended volatile solids	2	13	6	4	4	5
Alkalinity	187	146	183	147	164	162
Conductivity	440	370	470	460	468	493
Total phosphorus - P	0.02	0.10	0.04	0.04	0.08	0.04
Total dissolved phosphorus - P	0.02	0.07	0.01	0.03	0.01	0.01
Total ammonia-N	0.11	0.27	0.12	0.33	0.49	0.24
Dissolved nitrate-N	9.72	11.56	12.5	9.63	9.28	13.50
Total kjeldahl-N	0.52	0.67	0.49	0.69	1.69	1.03
Total dissolved iron	<0.10	0.16	<0.08	<0.10	0.10	<0.10
Total dissolved manganese	<0.02	<0.09	<0.10	<0.07	<0.07	<0.07
Chlorine demand	--	3.15	1.95	2.92	4.25	1.56

Parameters	7-29-81	8-13-81	8-26-81	9-9-81	9-23-81	10-3-81
Turbidity	11.0	6.3	3.4	6.6	6.9	8 5
Secchi disc readings	22	21	42	30	30	24
pH	8.3	8.7	8.8	8.5	8.5	8 7
Total solids	362	294	302	356	374	367
Suspended solids	10	9	5	10	14	19
Suspended volatile solids	8	2	3	4	7	10
Alkalinity	185	174	187	218	231	233
Conductivity	460	405	435	550	437	380
Total phosphorus, P	0.05	0.08	0.04	0.05	0.04	0 05
Total dissolved phosphorus, P	0.02	0.01	Tr	0.02	0.02	0 02
Total ammonia-N	0.07	0.12	0.24	0.05	0.07	0 08
Dissolved nitrate-N	6.55	5.32	5.25	5.60	4.90	3 76
Total kjeldahl-N	0.81	1.07	0.84	0.63	0.58	0 74
Total dissolved iron	<0.10	<0.10	<0.10	<0.10	0.13	0 17
Total dissolved manganese	<0.05	<0.04	<0.03	<0.04	<0.04	<0 04
Chlorine demand	3.01	3.45	2.39	2.13	1.86	2 66

Units of measurements: Turbidity - NTU; Secchi - inches; pH - dimensionless; Conductivity -
umho/cm; others - mg/1

Appendix A-4. Physical and chemical quality characteristics of near bottom waters at station 2 in Lake Eureka

Parameters	5-6-81	5-20-81	6-1-81	6-17-81	7-1-81	7-15-81
Turbidity	22.6	84.5	5.2	23.7	14.8	8.6
pH	8.4	7.7	7.5	7.8	7.6	8.2
Total solids	456	356	436	464	422	336
Suspended solids	64	254	17	102	20	12
Suspended volatile solids	14	44	6	12	4	6
Alkalinity	227	160	218	183	168	172
Conductivity	440	385	460	590	481	490
Total phosphorus-P	0.14	0.38	0.20	0.17	0.09	0.07
Total dissolved phosphorus-P	0.02	0.05	0.02	0.03	0.01	0.01
Total ammonia-N	0.26	0.44	0.95	0.51	0.46	0.30
Dissolved nitrate-N	9.79	12.31	11.50	10.2	9.53	13.3
Total kjeldahl-N	0.80	1.70	1.30	1.26	1.41	1.25
Total dissolved iron	<0.10	0.16	<0.08	<0.10	0.34	0.22
Total dissolved manganese	<0.02	<0.09	0.24	0.08	<0.07	0.18
Chlorine demand	--	3.23	7.11	4.43	5.18	5.49

Parameters	7-29-81	8-13-81	8-26-81	9-9-81	9-23-81	10-8-81
Turbidity	21.0	12.6	6.1	7.2	8.3	10.6
pH	8.2	7.7	8.2	8.3	8.5	8.6
Total solids	380	308	330	360	378	478
Suspended solids	22	15	12	36	19	27
Suspended volatile solids	12	1	4	11	6	17
Alkalinity	183	187	202	218	221	202
Conductivity	480	490	470	499	432	380
Total phosphorus-P	0.08	0.08	0.07	0.05	0.06	0.08
Total dissolved phosphorus-P	0.01	0.02	0.01	0.02	0.01	0.02
Total ammonia-N	0.11	0.18	0.30	0.07	0.07	0.10
Dissolved nitrate-N	7.00	5.96	5.61	5.65	4.83	3.66
Total kjeldahl-N	0.85	0.79	1.16	0.69	0.75	1.01
Total dissolved iron	0.22	0.24	0.14	0.16	0.14	0.17
Total dissolved manganese	<0.05	<0.04	0.74	<0.04	<0.04	<0.04
Chorine demand	3.23	3.41	9.21	2.70	1.86	2.66

Units of measurements: Turbidity - NTU; pH - dimensionless; Others - mg/l