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*Aeration-Destratification of Lake Eureka:
Second Year Operation*

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ILLINOIS STATE WATER SURVEY

CHAMPAIGN

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AERATION-DESTRATIFICATION OF LAKE EUREKA:
SECOND YEAR OPERATION

by Raman K. Raman and Ralph L. Evans

BACKGROUND

City-owned Lake Eureka, formed in 1942 by the damming of a branch of Walnut Creek, was created to serve primarily as a water supply source for the city of Eureka, Illinois. The city owns and operates the water treatment and distribution systems.

During the early 1970s, the city began to receive consumer complaints about taste and odor problems in the finished waters. These complaints became numerous and incessant as the years progressed. 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.

However, the use of groundwater as a source resulted in increased pumping, chemical, and treatment costs. Since the water treatment plant had not been designed to treat groundwater, the change created a number of operating problems. The volume of softening sludge increased significantly, floc carry-over occurred from the settling basins to the filter beds, and the softening sludge discharge pipes frequently clogged, adding to the plant operational and maintenance loads.

A detailed investigation by Lin and Evans (1981), conducted during 1976-1978 to delineate the relationship between odor and commonly measured water quality characteristics in central Illinois impoundments, revealed that for Lake Eureka, the threshold odor numbers (TONs) had high positive correlations with iron, manganese, and ammonia concentrations and chlorine demand values of the lake waters. They found that TONs for the lake water samples obtained from near the bottom at the deep station were generally much higher than those for the samples obtained at mid-depth and at surface sampling points of the deep station. They further reported that the odors of the finished waters in the Eureka water supply systems immediately followed the odor episodes in the lake waters.

In 1981 the Water Quality Section of the Illinois State Water Survey (division of the Illinois Department of Energy and Natural Resources) instituted an in-lake water quality management program for Lake Eureka on the premise that if the factors contributing to taste and odor episodes could be controlled at the source itself, the lake could once again be used as a water supply source. Aeration-destratification in combination with in-lake chemical control of algae at appropriate intervals of time was tried as a means of enhancing the lake water quality characteristics.

A low energy mechanical destratifier with a 1-1/2-hp motor, developed by Professor James E. Garton and his associates at the University of Oklahoma, Stillwater, OK, was installed and operated from May 6 to October 8, 1981. The results of the first year of operation of the aerator in Lake Eureka have been reported by Kothandaraman and Evans (1982).

The aerator was able to destratify the lake completely and maintain adequate oxygen levels throughout, including in the near bottom waters of the deep portions of the lake. Iron and manganese concentrations in the deep waters were reduced by 97% from the pre-aeration levels. Chlorine demand values were reduced more than half. A dramatic shift in the algal species makeup was observed in the lake during 1981. Problem-causing blue-green algae were practically insignificant, and diatoms were the dominant algae during the summer months.

Encouraged by the significant improvement in the overall water quality characteristics of the lake waters, the Water Quality Section recommended to the Eureka City Council that it consider using the lake as its water supply source once again. The city switched back to using the lake water on April 13, 1982, and continues to use the lake as its raw water supply source. With the aerator in place and operating, the water supply system has performed extremely satisfactorily without any source-related taste or odor complaints from consumers.

This report presents the results of the second-year operation of the destratification device in Lake Eureka and describes the economic benefits realized by the city of Eureka due to the change from groundwater to lake water as its water supply source.

MATERIALS AND METHODS

Details regarding the axial flow mechanical destratifier installed in Lake Eureka can be found elsewhere (Kothandaraman and Evans, 1982). The aerator was run from May to October 1981 and was shut off during the first week in October when the lake underwent fall turnover, resulting in natural uniform mixing within the lake. The aerator was started again on December 11, 1981, for winter operation as soon as ice cover on the lake began to form, and was operated until April 3, 1982. The lake remained monomictic due to spring turnover until early May. The unit was started again on May 10, 1982, when the lake showed signs of thermal stratification setting in, and was again turned off from November 3, 1982, to December 20, 1982, coincident with the fall turnover period. Thus the aerator was operated for approximately nine months in 1982 except during the periods of spring and fall turnovers.

The lake was monitored for physical, chemical, and biological characteristics on a once-a-month schedule from January to April and again from October to December. It was monitored on a bi-weekly basis from May to September.

The location of the destratifier and the three sampling stations in the lake are shown in figure 1. The aerator is located at the deepest part of the lake, which has a maximum depth of 18 feet.

In-situ observations of temperature, dissolved oxygen, and secchi disc readings were made at stations 1 and 2. Water samples for chemical analyses and algal identification were obtained only at station 1. Water samples were collected at the surface and from near the bottom (1 foot from the bottom) for these purposes. Water samples for determining copper concentrations in the lake waters were taken from all three sampling sites immediately before chemical treatment of the lake and after a lapse of approximately 24 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.

Determinations for pH, alkalinity, and conductivity were made at the lake site soon after sample collections. Physical and chemical analyses were performed in the laboratory to determine turbidity, total and suspended solids, suspended volatile solids, total ammonia-nitrogen, dissolved nitrate-nitrogen, total dissolved iron, total dissolved manganese, and chlorine demand.

The procedures used for *in-situ* observations, sample collections, chemical analyses and algal identification are all detailed in an earlier report (Kothandaraman and Evans, 1982).

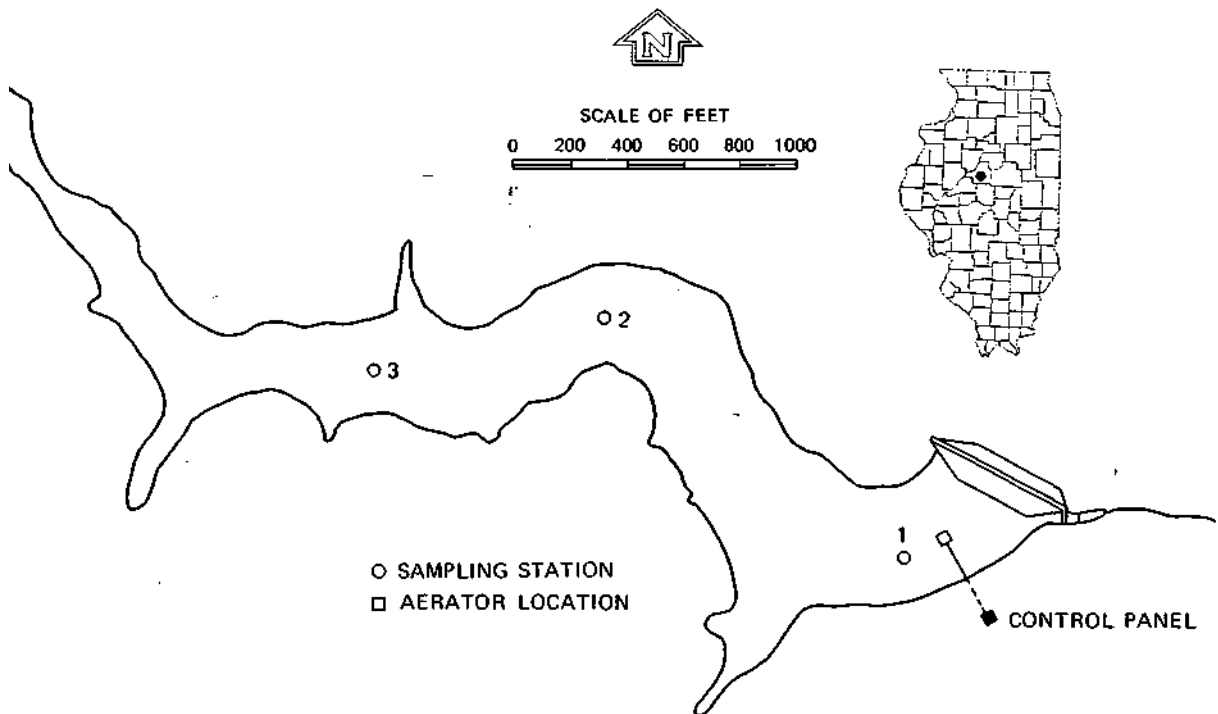


Figure 1. Location of aerator and sampling stations in Lake Eureka

The chemical treatment of the lake waters involved applying copper sulfate chelated with citric acid on two occasions: July 8 and August 5, 1982. For each chemical application, 200 pounds of hydrated copper, sulfate was mixed with 100 pounds of citric acid and applied. The dosage of copper sulfate was calculated at the rate of 5.4 pounds per acre. Fifty pounds of potassium permanganate was applied to the lake approximately 48 hours after the applications of copper sulfate.

The chemicals were applied to the lake from two 30-gallon-capacity plastic buckets with 1/2-inch holes drilled in their bottom halves. The buckets were floated using inflatable tractor inner tubes. Unlike in 1981, when the buckets were tied to the aerator raft, the buckets were tied to a concrete block and placed in the shallow upper end of the lake. Potassium permanganate was also applied using the buckets. This method of applying the chemicals was found to be safe, economical, and effective.

RESULTS AND DISCUSSION

Physical Characteristics

Temperature. Roseboom et al. (1979) reported that a thermal gradient began to develop in Lake Eureka in May 1978 at a water temperature of 10 to 12°C. During peak stratification, the maximum temperature was 30°C at the surface of the deep station in the lake and 13°C at the bottom. However, 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 1978. Isothermal plots for Lake Eureka for the pre-destratification period in 1978 are shown in figure 2.

Isothermal plots for lake stations 1 and 2 for 1982 are shown in figures 3 and 4, respectively. The maximum surface water temperature observed at station 1 was 29.0°C on July 21, 1982, and the maximum temperature differential in the lake at station 1 was 5.0°C on June 23, 1982. Except for this lone observation, the differences in observed temperatures between the surface and bottom waters were less than 2.7°C.

Figure 3, in conjunction with figure 4, clearly indicates that the aerator effectively destratified the lake not only near the unit but also at a considerable distance away from it. Selected vertical temperature profiles at station 1 for the years 1978 and 1982 are shown in figure 5. It is obvious that during summer months, surface water temperatures were generally less during 1982 than in 1978 and that the near bottom waters experienced reverse trends. The effectiveness of the destratification is clearly shown by this phenomenon.

Dissolved Oxygen. 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 (see figure 6). They

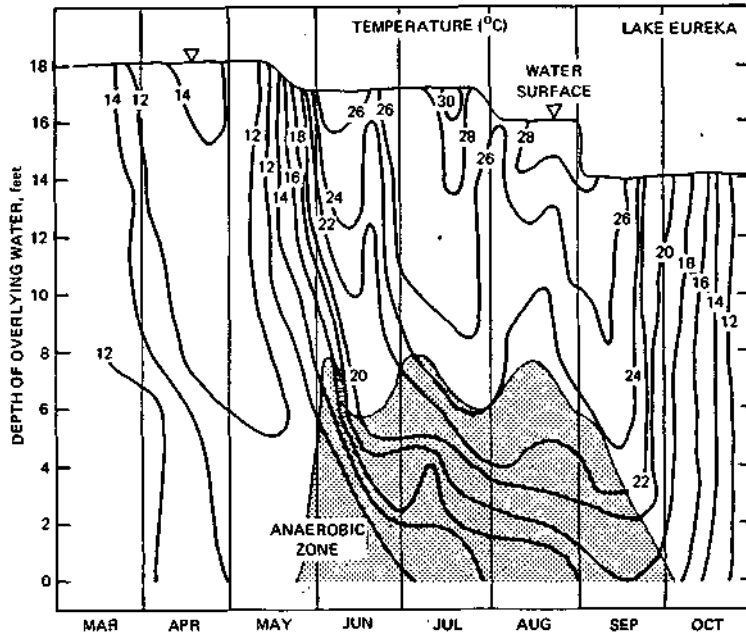


Figure 2. Isothermal plots for station 1 in Lake Eureka (1978)

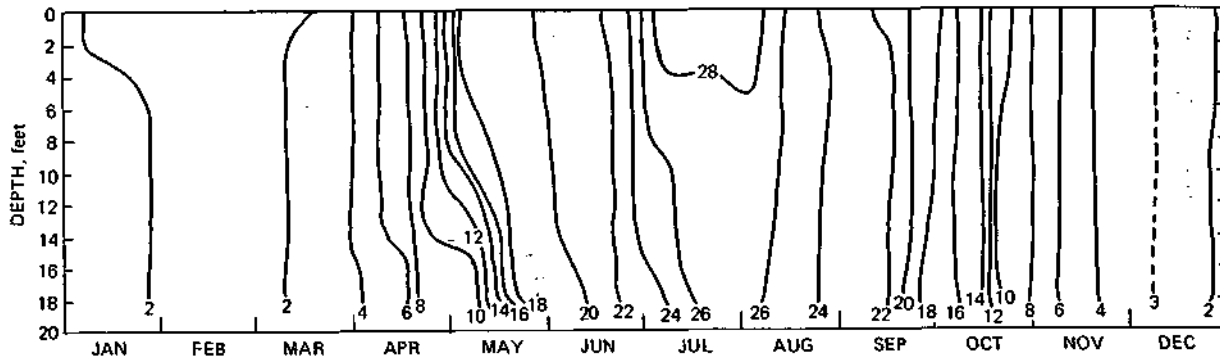


Figure 3. Isothermal plots for station 1 in Lake Eureka (1982)

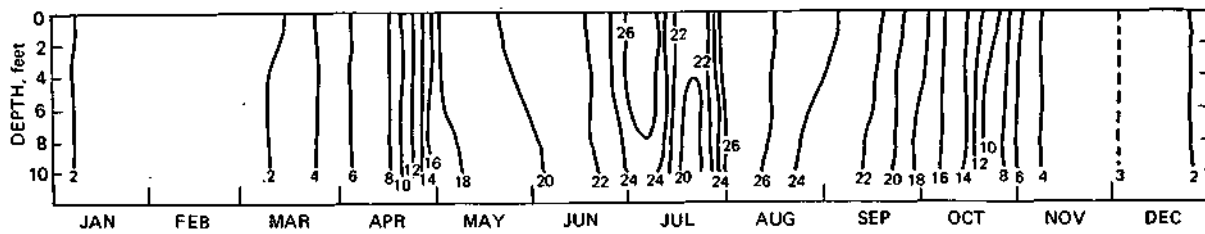


Figure 4. Isothermal plots for station 2 in Lake Eureka (1982)

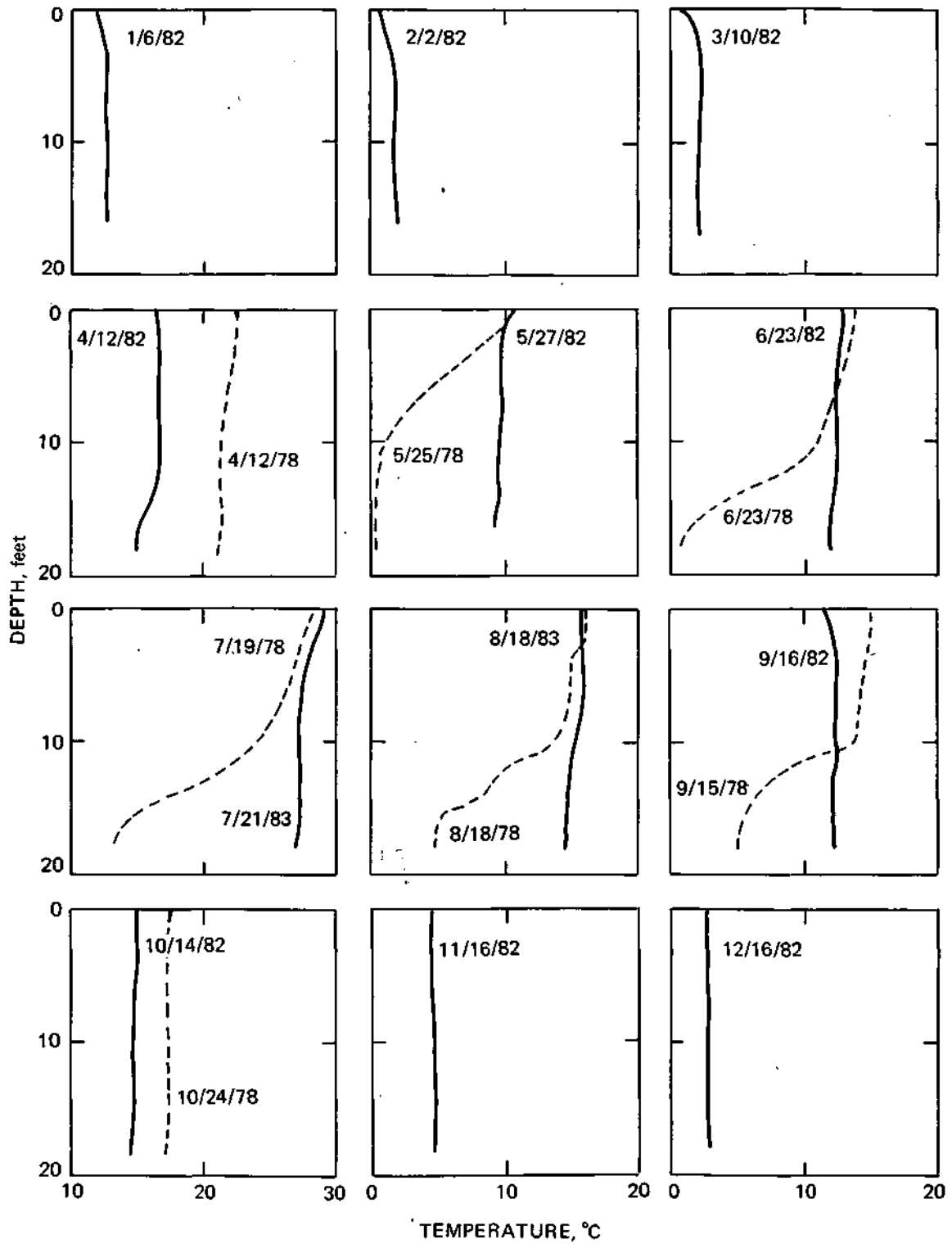


Figure 5. Temperature profiles at station 1 in Lake Eureka (1978 and 1982)

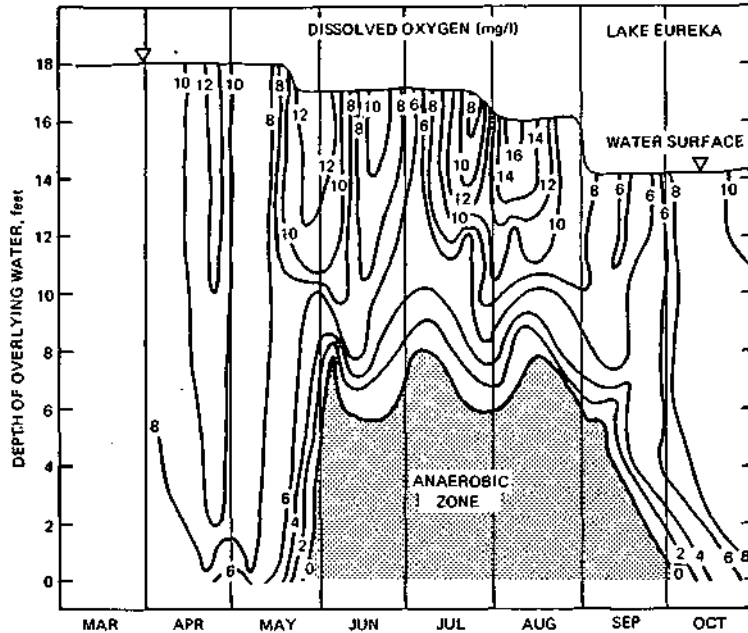


Figure 6. Isopleths of dissolved oxygen for station 1 in Lake Eureka (1978)

found that for 3 months (June 1 to August 31, 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 shown by the shaded portion of figure 6. The rate of oxygen depletion in lower strata in Lake Eureka was reported 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 (Roseboom et al., 1979).

Isopleth plots of dissolved oxygen in Lake Eureka during 1982 are shown in figures 7 and 8 for stations 1 and 2, respectively. Adequate oxygen levels were maintained throughout the summer season at station 1 except for a single episode on August 18, 1982, when oxygen was found to be depleted to a height of 4 feet from the lake bottom. The destratifier was found "shut off" on the day of field sampling and it could not be determined how long the unit had remained idle. Apparently the unit shut itself off due either to a temporary power surge or a temporary power failure. Oxygen conditions in the deep portion of the lake improved after the aerator was started again. It was possible to maintain adequate oxygen levels throughout the lake with the aerator, as evidenced by the data collected at station 2 (figure 8).

Figure 9 shows the temporal variations in dissolved oxygen at the surface and near the bottom of station 1 in 1978 and 1982, and figure 10 shows the corresponding percent saturation of dissolved oxygen values. At the

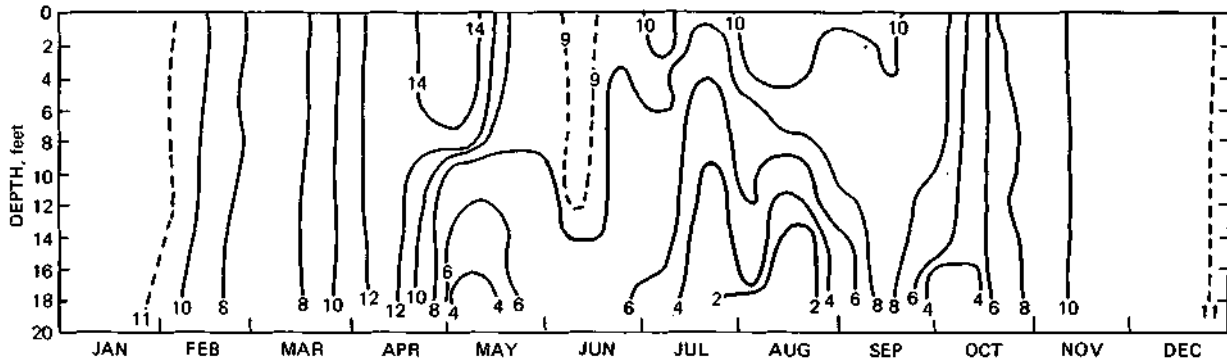


Figure 7. Isoleths of dissolved oxygen for station 1 in Lake Eureka (1982)

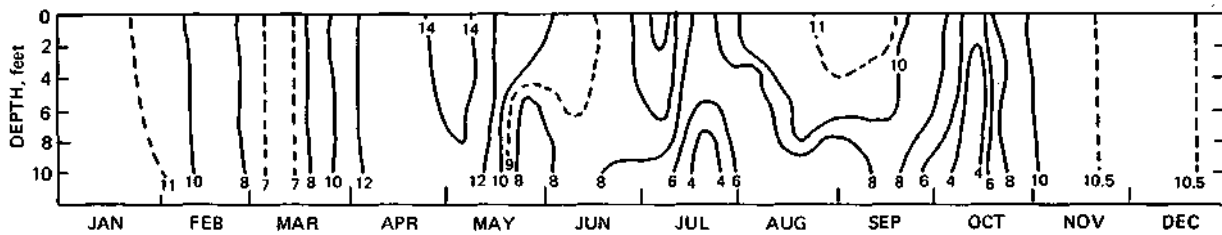


Figure 8. Isoleths of dissolved oxygen for station 2 in Lake Eureka (1982)

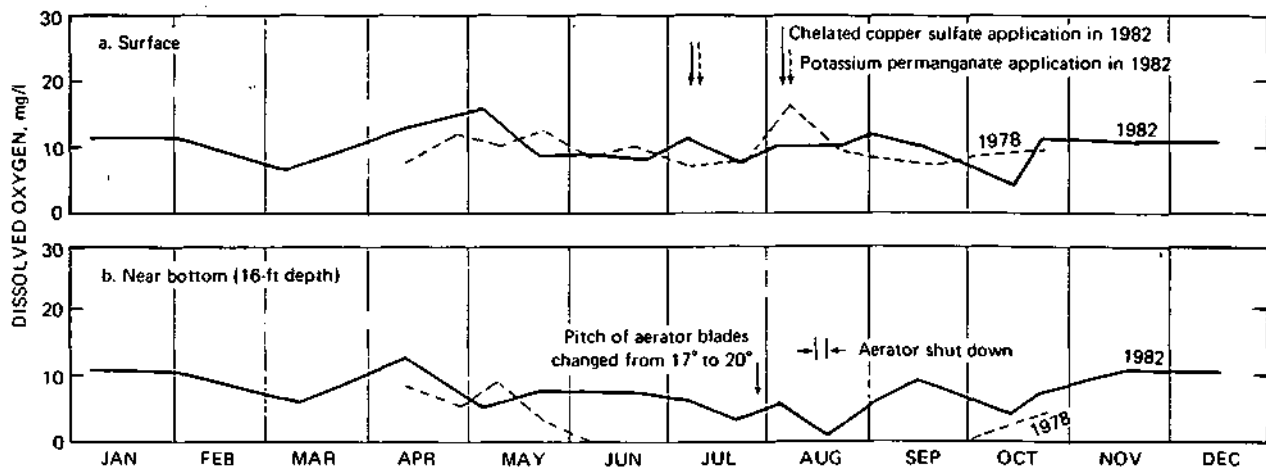


Figure 9. Temporal variations in dissolved oxygen at the surface and near the lake bottom of station 1 in Lake Eureka (1978 and 1982)

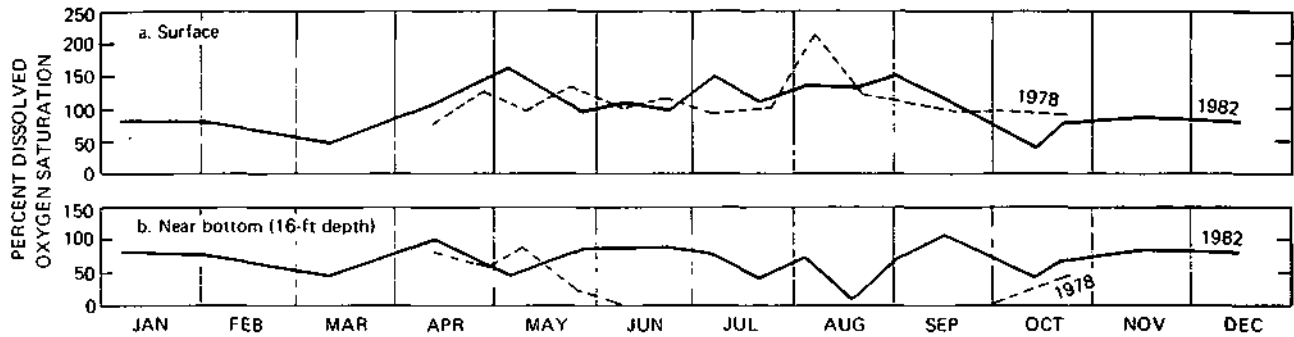


Figure 10. Temporal variations in percent DO saturation at the surface and near the lake bottom of station 1 in Lake Eureka (1978 and 1982)

lake surface, where oxygenation occurs naturally, DO concentrations were high and supersaturated conditions existed during both years. However, a marked improvement in DO conditions of the near bottom waters is obvious from figures 9 and 10. DO saturation levels at or above approximately 50% were maintained in the deep portion of the lake.

Figure 11 shows the oxygen profiles in the lake at station 1 for the years 1978 and 1982. The oxitic conditions of the bottom waters of the lake were greatly improved in 1982. The DO profile shown for August 18, 1982, clearly indicates that oxygen was rapidly depleted in the water column near the bottom when the aerator shut down. Data regarding temperature and dissolved oxygen during 1982 are included in appendix A.

Secchi Disc Transparency. The mean and range of transparency values observed during 1978 and 1982 at station 1 in Lake Eureka are shown in table 1. Plots of temporal variations in secchi disc readings for these two years are shown in figure 12. During summer months, the secchi disc values were slightly higher in 1982 than in 1978. The mean transparency in the lake during May to September 1982 was 33 inches as compared to 28 inches in 1978. This slight increase in transparency could have been a chance occurrence, and only continued operation of the aerator and monitoring of the lake in the future can establish beyond doubt the beneficial impact of aeration on lake clarity.

Chemical Characteristics

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 alkalinity values were significantly higher in the bottom waters than in the surface waters at all times during the thermal stagnation. Tables 1 and 2 indicate the means and ranges of values of chemical parameters reported by Roseboom et al. for the surface and near bottom waters at station 1 of Lake Eureka during 1978.

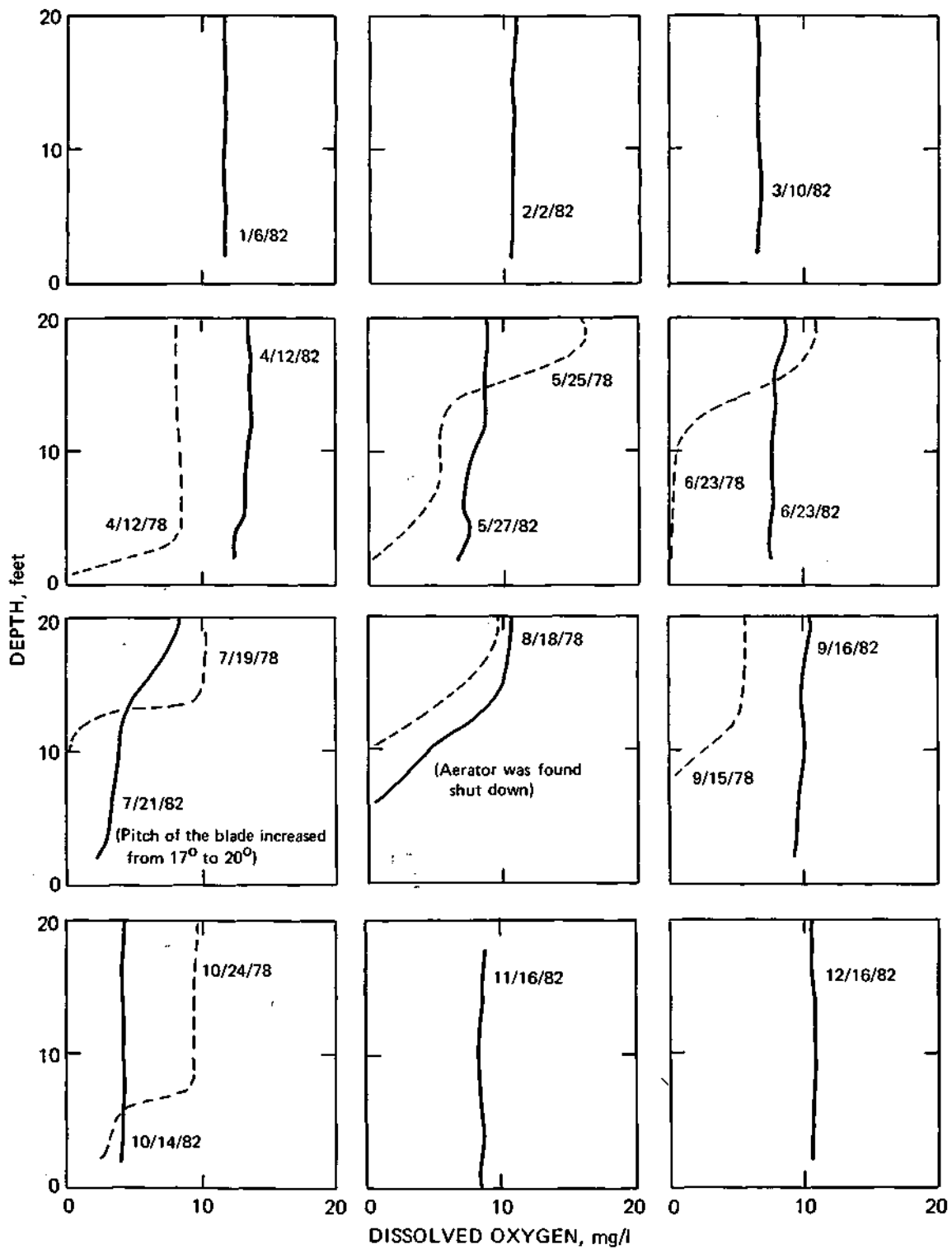


Figure 11. Dissolved oxygen concentration profiles at station 1 in Lake Eureka (1978 and 1982)

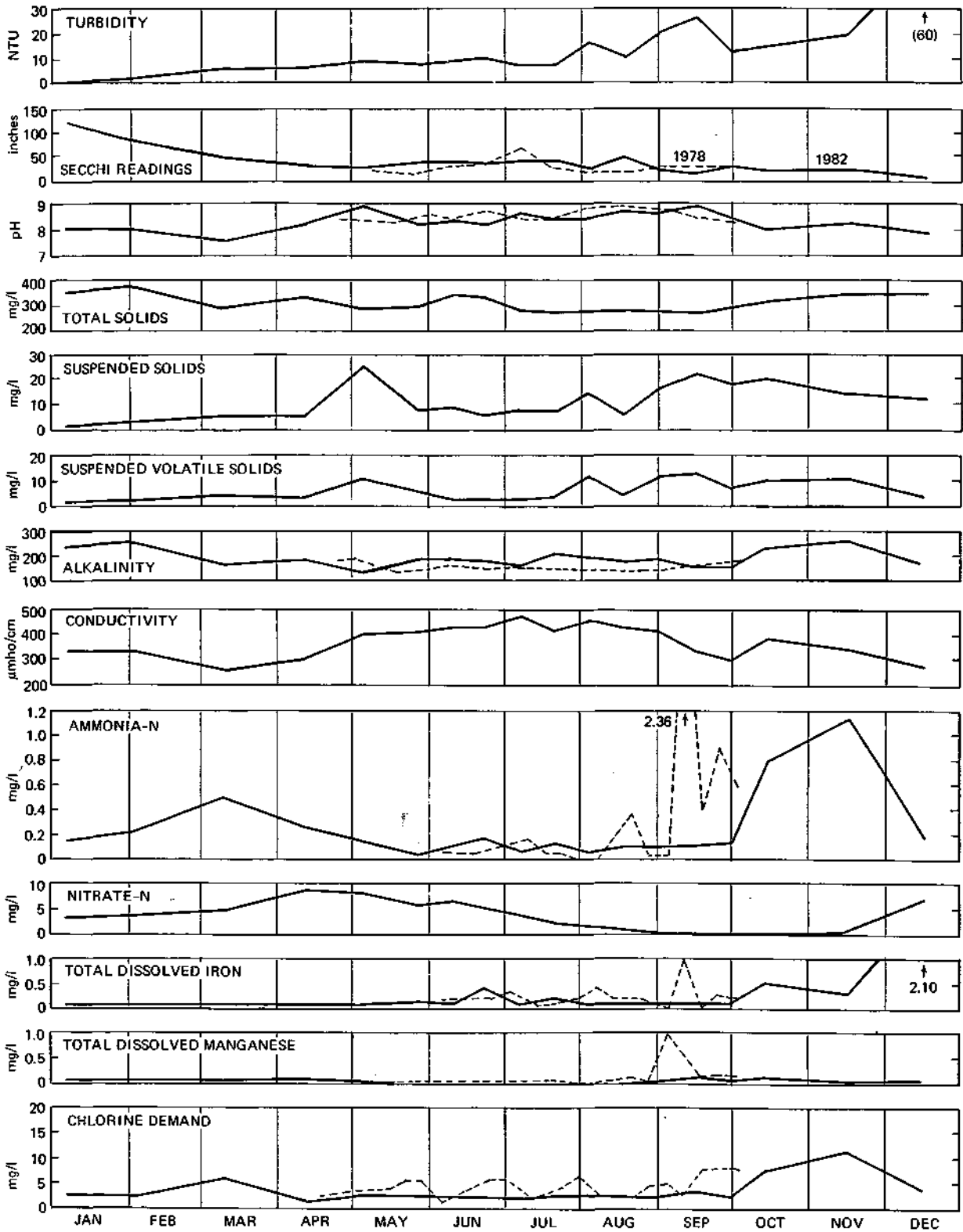


Figure 12. Physical and chemical water quality characteristics at the surface of Lake Eureka, station 1 (1978 and 1982)

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

Parameters	No. of observa- tions	1982		No. of observa- tions	1978	
		Mean	Range		Mean	Range
Turbidity	18	13.4	1.0-60			
Secchi disc readings	18	38	3-120	48	28	12-68
pH	18		7.6-9.0	50		8.0-9.2
Total solids	17	310	266-382			
Suspended solids	18	11	2-26			
Suspended volatile solids	18	6	2-12			
Alkalinity	18	182	129-253	50	145	94-185
Conductivity	18	374	254-480			
Total ammonia-N	18	0.24	0.07-1.13	15	0.20	0.00-0.89
Dissolved nitrate-N	18	3.42	0.03-8.72			
Total dissolved iron	18	0.27	<0.10-2.10	16	0.17	0.06-0.37
Total dissolved manganese	18	0.07	<0.06-0.16	15	0.10	0.00-0.58
Chlorine demand	18	3.41	1.33-11.21	25	4.20	1.10-8.10

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

Table 2. Summary of Water Quality Characteristics
of Near Bottom Waters at Station 1 in Lake Eureka

Parameters	No. of observa- tions	1982		No. of observa- tions	1978	
		Mean	Range		Mean	Range
Turbidity	18	16.4	1.0-74.0			
pH	18		7.6-8.8	50		7.2-8.3
Total solids	17	318	264-388			
Suspended solids	18	15	2-36			
Suspended volatile solids	18	6	1-12			
Alkalinity	18	186	145-261	50	221	150-301
Conductivity	18	382	272-500			
Total ammonia-N	18	0.34	0.08-1.18	18	3.97	0.43-7.11
Dissolved nitrate-N	18	3.50	0.03-8.77			
Total dissolved iron	18	0.30	0.10-2.13	18	5.27	0.16-10.90
Total dissolved manganese	18	0.08	0.06-0.18	18	3.91	0.24-9.00
Chlorine demand	18	4.10	1.90-11.21	25	9.20	2.50-17.1

Units of measurement: Turbidity - NTU; pH - dimensionless; conductivity - μ mho/cm;
others - mg/l

Tables 1 and 2 also show the means and ranges of values for observations made in 1982. All the chemical data gathered during 1982 are included in appendix B. Turbidity, various solids fractions, conductivity, and nitrate were the additional determinations made during 1982.

For the surface water samples, alkalinity was higher in 1982 than in 1978, indicating a decrease in algal productivity. Ammonia-nitrogen and dissolved iron were higher in 1982 than in 1978, while dissolved manganese and chlorine demand values were lower in 1982 than in 1978. As the lake surface waters were well oxygenated during these two years, changes in the values of chemical parameters monitored cannot be attributed solely to the effect of the aerator.

However, a marked difference in chemical quality characteristics was observed in the near bottom waters. The minimum, mean, and maximum values for ammonia-nitrogen, iron, manganese, and chlorine demand were reduced significantly in 1982 due to aeration. Percentage reductions of 91, 94, 98, and 55 in the mean values for ammonia-nitrogen, iron, manganese, and chlorine demand, respectively, were achieved.

The temporal variations in the chemical parameters monitored in the lake are shown in figures 12 and 13 for surface water samples and near bottom samples, respectively. An examination of figure 12 reveals that pH, iron, and manganese values did not differ significantly for the years 1978 and 1982 except for occasional peaks and valleys. Figure 13 indicates that the values for alkalinity, ammonia-nitrogen, iron, manganese, and chlorine demand were consistently lower in 1982 for the near bottom waters.

As the raw water intake in the lake is so constructed as to draw lake waters from the strata varying from 3'-6" to 6'-0" from the lake bottom, significant improvement in the near bottom water chemical quality characteristics assures the city of suitable raw water supply.

Chemical Treatment. Copper sulfate chelated with citric acid was applied to the lake on July 8 and August 5, 1982. Water samples for copper analyses were collected at the surface and at 2-foot depths at stations 1, 2, and 3, shown in figure 1. Water samples were collected approximately 24 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 conjunction with artificial destratification was undertaken mainly to control blue-green algal blooms. Lin and Evans (1981) reported the domination of the odor- and taste-producing algal species Ceratium hirundinella and Anacystis cyanea during their monitoring of the lake in 1977 and 1978.

The results of the copper analyses are shown in table 3. Sample analyses for copper in 1981 prior to the chemical applications indicated that copper concentrations in the lake were below detection limits (Kothandaraman and Evans, 1982). No pre-application samples were taken during 1982. The

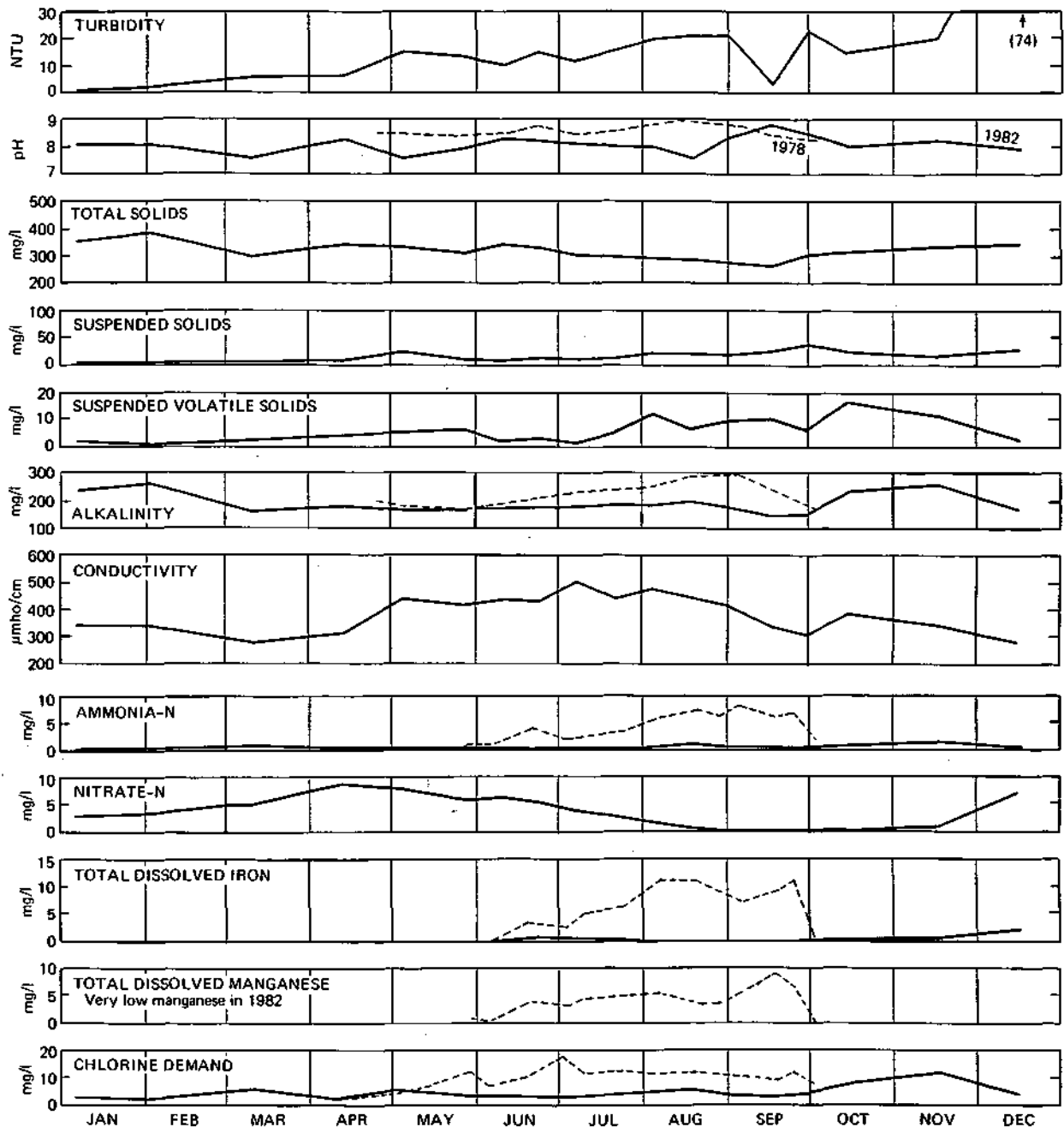


Figure 13. Physical and chemical water quality characteristics of near bottom waters of Lake Eureka, station 1 (1978 and 1982)

Table 3. Distribution of Copper Ions in Lake Eureka
 24 Hours after Chemical Application
 (Copper concentrations, mg/l as Cu⁺⁺)

Dates of sample collections	Station 1		Station 2		Station 3	
	Surface	Two feet	Surface	Two feet	Surface	Two feet
7/9/82	0.06	0.04	0.03	0.04	0.06	0.06
8/6/82	<0.03	0.03	0.06	0.10	0.11	0.04

1982 samples for copper analyses were taken 24 hours after chemical application (as per the stipulations of the Illinois Environmental Protection Agency's permit for copper sulfate applications in drinking water supply reservoirs), instead of 48 hours after application, as in 1981.

Even though the chemicals were applied from a single point in the shallow upper end of the lake, the results shown in table 3 indicate that the copper ions are dispersed throughout the lake by natural lake circulation aided by induced water movement. , Since the method of application relies on a slow release process, it appears that it takes at least 48 hours before the chemicals are completely dissolved and dispersed. The results of copper analyses of samples taken in 1981 indicate a more uniform distribution of copper ions throughout the lake in 48 hours after chemical application.

The single point, slow release method of chemical application has been found to be effective and economical, involving minimal manpower and handling of materials. Above all it eliminates or at least minimizes the chances of inadvertent overdosing of the lake waters with chemicals.

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 4. Algal counts in the lake were high and of bloom proportion during the summer months of 1982. However, either the diatoms or the green algae were the dominant species in the lake during this period. As expected, algal densities near the lake bottom were less than at the surface. (In 1981, contrary to expectations, algal densities were higher near the lake bottom.) Even though the sampling point was below the euphotic zone, high algal counts near the lake bottom reflect the phenomenon of vertical algal redistribution due to induced mixing. The blue-green algae Anacystis cyanea was previously reported to be the dominant species in the lake during the months of August and September (unpublished SWS report; 1977-1978 study). Blue-green algae in water supply impoundments have been known to cause taste and odor problems, filter clogging that reduces the duration of filter runs, etc., in water treatment systems. The shift in algal species makeup observed in 1982 with the dominance of either diatoms or green algae is a welcome change from that observed in 1977 and 1978. As the shift in algal species

Table 4. Algal Types and Densities in Lake Eureka, Station 1
(Density in counts per milliliter)

Dates	Surface samples					Near bottom samples				
	BG	G	D	F	T	BG	G	D	F	T
5/5/1982	0	0	4945	0	4945	0	0	50	0	50
5/27	0	20	0	10	30	0	5	0	20	25
6/10	0	45	60	0	105	0	10	0	5	15
6/23	0	60	60	10	130	0	140	0	15	155
7/7	125	515	5290	680	6610	0	290	1370	0	1660
7/21	0	460	865	0	1325	45	170	80	0	295
8/4	650	2630	5240	0	8520	0	3805	2375	0	6240
8/18	275	1145	0	210	1630	0	445	160	135	740
9/1	400	860	270	280	1810	0	425	270	0	695
9/16	75	160	275	25	535	0	150	130	0	280
9/30	65	45	10	30	150	0	350	0	0	350
10/14	0	25	45	0	70	0	45	55	50	150
11/16	0	40	60	0	100	0	0	30	0	30
12/16	0	0	40	0	40	0	0	15	0	15

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

makeup was observed both in 1981 and 1982 after the lake management scheme was instituted in the lake, it is postulated that elimination of the anoxic conditions in the deeper zones of the lake by destratification aided by copper sulfate application resulted in the control of blue-green algae in the lake.

COST-BENEFIT ANALYSIS

As indicated earlier, the city of Eureka reverted to the lake as its water supply source on April 13, 1982. The water treatment system operated extremely well without any source-related taste or odor complaints from consumers. There were a few consumer complaints about chlorine taste in the finished waters, which were primarily related to the operational adjustments needed when the city switched from groundwater to the lake water as the source.

The change in the raw water supply source resulted in the alleviation of several plant operational problems. The volume of softening sludge decreased significantly, resulting in a need for fewer sludge storage and handling requirements. As the treatment plant was not originally designed to treat groundwater, excessive amounts of softening sludge generated while treating groundwater resulted in poor settling characteristics in the settling basins, excessive floc carry-over to filter beds, clogging of sludge discharge conduits, and a host of other related plant maintenance and operational problems.

The use of lake water as a source resulted in reductions in power consumption and in the amount of chemicals used. There was no need to pump groundwater and run the cascade aerator for iron, manganese, and hydrogen sulfide removal. Table 5 shows the actual power consumption and the chemicals used in the treatment plant for Fiscal Year 1981-82 (May 1, 1981 to April 30, 1982) and FY 1982-83. The treatment plant operated with groundwater as the source during FY 1981-82. Significant decreases in power consumption, both in wells and plant operation, and decreases in lime and carbon dioxide usages, are evident from the table.

Table 6 shows the cost savings realized by the city during FY 1982-83 because of the change in water supply source. The treatment plant operating cost (excluding manpower) was \$91,730 for FY 1981-82 when groundwater served as the water supply source. The operating cost for FY 1982-83 was

Table 5. Power Consumption and Chemicals Used
in Eureka Water Treatment Plant

Items	FY 1981-82	FY 1982-83
Electricity for wells, 10 ³ kwh	453.65	34.33
Electricity for the plant, 10 ³ kwh	256.48	192.70
Lime, tons	336.32	155.02
Chlorine, tons	4.95	6.38
Fluoride, tons	1.80	2.65
Carbon dioxide, tons	173.03	55.77
Alum, tons		27.75
Activated carbon, tons		0.75
Finished water, million gallons	166.5	168.8

Table 6. Cost Comparison of Water Treatment
Plant Operations
(Thousands of dollars)

Items	FY 1981-82	FY 1982-83	FY 1982-83 at FY 1981-82 rates
Electricity for wells	24.75	2.53	1.88
Electricity for the plant	13.96	15.95	10.49
Lime	24.61	12.59	11.34
Chlorine	1.04	2.04	1.34
Fluoride	0.38	0.56	0.56
Carbon dioxide	26.99	8.96	8.70
Alum	-	8.53	8.53
Activated carbon	-	0.56	0.56
Total	91.73	51.72	43.40

\$51,720, resulting in a savings of \$40,010 or 43.6% of the operating cost in FY 1981-82. The table also shows the cost of power and chemicals used during FY 1982-83 at the rates that prevailed during FY 1981-82. The operating cost of the plant in FY 1982-83 would have been only \$43,400 at FY 1981-82 rates, representing an apparent savings of \$48,330 or 52.7% of the operating cost in FY 1981-82.

The operating cost of the aerator in the lake amounted to about \$650 for the year, and the cost of two chemical applications was \$550. With an operating cost of \$1200 per year for the in-lake water quality management, the city realized an actual savings of \$38,810 during FY 1982-83. The cost-benefit ratio is 1:32. In addition, most of the maintenance and operational problems within the treatment plant cited earlier have either been eliminated or minimized to a large extent.

As a consequence of the lake destratification, water temperatures of the near bottom waters in the lake increased during summer months, and consequently the intake water temperatures were much higher than under conditions without destratification. This resulted in the delivery of finished waters with temperatures in the range 25 to 30°C during summer months as opposed to the cooler groundwater.

SUMMARY

A low energy mechanical, reversible draft destratifier was installed in Lake Eureka on May 1, 1981. With the aerator in place and with in-lake chemical applications to control blue-green algae in the lake, the water quality conditions were found to be improved in the lake during 1981, the first year of operation of the aerator. Factors in the lake that had been identified as causing taste and odor problems in the finished waters (such as high levels of iron, manganese, ammonia, and chlorine demand values; anoxic conditions in the deep waters; and blue-green algae dominance) were reduced or altered, improving the lake water quality characteristics. The city of Eureka reverted to the lake from groundwater as its source of water supply on April 13, 1982.

With the aerator in place and with two chemical applications to control the blue-green algae during the summer months of 1982, the water treatment system functioned extremely satisfactorily without any source-related consumer complaints about taste or odor.

The aerator, which has a 1-1/2-hp motor, was able to destratify the lake completely and maintain adequate oxygen levels throughout, including in the near bottom waters of the deep portions of the lake. Percentage reductions of 91, 94, 98, and 55 in the mean values for ammonia-nitrogen, iron, manganese, and chlorine demand were achieved during 1982. Blue-green algae were never dominant in the lake.

The switch in water supply source resulted in a significant savings in power consumption and in chemicals used, particularly lime and carbon diox-

ide. Costs of power and chemicals amounted to \$51,720 in Fiscal Year 1982-83, as compared to \$91,730 in 1981-82 when groundwater was used as the water supply source. The lake water quality management scheme thus resulted in a savings of \$40,010, or 43.6% of the operating cost in Fiscal Year 1981-82. The costs of aerator operation and the two in-lake chemical treatments amounted to \$1200 during FY 1982-83, giving a net cost-benefit ratio of 1:32.

The change in raw water supply source alleviated several operational problems also. The volume of softening sludge decreased significantly, resulting in fewer sludge storage and handling requirements. Excessive floc carry-over to filter beds, clogging of sludge discharge conduits, and a host of other related plant maintenance and operational problems were brought under control.

ACKNOWLEDGMENTS

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Several Water Survey personnel contributed to this investigation. Special mention must be made of Davis B. Beuscher for his competent scuba diving efforts. David Hullinger, Dana Shackelford, and Brent Gregory performed chemical analyses, and Davis Beuscher performed the algal identification and enumeration. Linda Johnson typed the camera ready copy. Gail Taylor edited the report. Illustrations were prepared by William Motherway, Jr., John W. Brother, Jr., and Linda Riggins.

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Appendix A-1. Dissolved Oxygen and Temperature Observations
in Lake Eureka, Station 1

Depth (feet)	1/6/82		2/2/82		3/10/82		4/12/82		5/5/82		5/27/82		6/10/82		6/23/82		7/7/82	
	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp
0	11.6	2.0	11.5	0.3	6.6	1.0	13.2	6.2	15.1	18.5	8.7	20.0	9.3	20.8	8.4	22.9	11.3	29.0
2	11.6	2.2	11.5	1.0	6.3	2.0	13.2	6.2	14.9	18.5	8.6	20.0	9.3	20.8	8.4	22.7	11.3	29.0
4	11.6	2.6	11.2	1.8	6.3	2.0	13.2	6.2	15.0	18.0	8.7	19.8	9.3	20.8	7.9	22.2	8.2	28.0
6	11.4	2.6	11.1	1.8	6.3	2.0	13.2	6.2	14.6	17.6	8.7	19.8	9.3	20.8	7.9	22.2	8.2	26.5
8	11.2	2.7	11.1	1.8	6.3	2.0	13.2	6.2	13.4	16.2	8.4	19.7	9.3	20.8	7.9	22.1	7.5	26.5
10	11.3	2.8	11.1	1.8	6.2	2.0	13.2	6.2	7.0	12.7	7.6	19.4	9.3	20.8	7.9	22.1	7.2	25.5
12	11.3	2.8	11.1	1.8	6.2	2.0	13.2	6.2	6.3	12.0	7.4	19.4	9.2	20.7	7.8	22.1	7.2	25.5
14	11.3	2.8	11.0	1.8	6.2	2.0	13.1	6.1	4.9	10.6	7.0	19.4	8.9	20.7	7.8	22.1	6.8	25.0
16	11.3	2.8	10.9	1.8	6.1	2.0	12.7	5.0	5.1	9.3	7.8	19.0	7.5	20.2	7.4	22.0	6.2	24.5
18							12.3	5.0	3.2	9.2	6.4	19.1	5.3	19.8	7.3	22.0	4.6	24.0

Depth (feet)	7/21/82		8/4/82		8/18/82		9/1/82		9/16/82		10/14/82		10/22/82		11/16/82		12/16/82	
	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp
0	8.2	29.0	10.2	28.6	10.5	25.7	12.0	25.0	10.2	21.3	4.1	15.0	8.1	11.3	10.8	4.7	10.6	2.6
2	7.8	28.4	10.2	28.5	10.5	25.6	8.1	24.5	10.2	22.2	4.1	15.0	8.0	11.1	10.9	4.8	10.6	2.6
4	6.0	27.9	10.0	28.4	10.3	25.5	8.1	23.9	10.0	22.2	4.1	14.8	8.0	10.5	10.8	4.7	10.6	2.6
6	4.4	27.4	7.3	27.8	9.4	25.4	8.1	23.4	9.8	22.2	4.1	14.8	7.9	9.9	10.8	4.7	10.6	2.6
8	4.2	27.4	6.8	27.6	7.4	25.3	8.1	23.4	10.0	22.2	4.1	14.8	7.8	9.5	10.7	4.7	10.5	2.6
10	3.9	27.3	6.2	27.5	4.4	25.1	8.1	23.4	10.0	22.2	4.1	14.8	7.9	9.2	10.7	4.7	10.5	2.6
12	3.7	27.3	6.0	27.5	3.0	24.9	7.9	23.4	9.9	22.0	4.1	14.8	8.0	9.1	10.6	4.7	10.5	2.6
14	3.4	27.2	5.9	27.3	0.4	24.8	5.8	23.4	9.5	22.0	4.1	14.8	7.5	9.0	10.6	4.6	10.5	2.6
16	3.1	27.1	5.6	27.3	0.4	24.6	5.8	23.4	9.1	22.0	4.0	14.8	7.3	9.0	10.6	4.6	10.5	2.6
18	2.1	26.3	0.3	26.6	0.2	24.3	5.1	23.4										

D.O. - mg/l

Temperature - degrees Celsius

Appendix A-2. Dissolved Oxygen and Temperature Observations
in Lake Eureka, Station 2

Depth (feet)	2/2/82		3/10/82		4/12/82		5/5/82		5/27/82		6/10/82		6/23/82		7/7/82		7/21/82	
	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp
0	11.6	0.1	6.2	0.5	13.2	7.2	14.6	19.0	10.5	20.3	9.7	20.8	8.3	22.9	12.2	29.0	7.8	20.6
2	11.6	0.8	6.0	1.0	13.2	7.2	14.7	19.0	10.1	20.2	9.5	20.8	8.3	22.7	12.2	28.3	7.6	20.6
4	11.2	1.7	6.2	2.0	13.2	7.2	15.0	18.7	9.1	20.0	9.3	20.8	8.3	22.5	11.5	28.0	7.1	20.2
6	11.2	1.7	6.2	2.0	13.2	7.2	14.9	18.4	7.8	19.7	9.1	20.5	8.3	22.3	10.8	26.5	5.9	19.9
8	11.1	1.7	6.2	2.0	13.2	7.1	14.0	17.4	7.6	19.6	8.2	20.2	8.3	22.3	9.0	26.0	3.8	19.2
10	11.0	1.7	6.2	2.0	13.2	7.1	13.3	16.6	7.1	19.5	9.0	20.1	7.7	22.2	7.9	25.4	3.4	19.2

Depth (feet)	8/4/82		8/18/82		9/1/82		9/16/82		10/16/82		10/22/82		11/16/82		12/16/82	
	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp	D.O.	Temp
0	10.8	28.9	10.4	25.9	12.1	24.9	11.8	22.6	4.3	14.7	8.4	11.8	11.1	4.1	10.2	2.7
2	10.4	28.5	10.4	25.9	11.9	24.9	11.6	22.2	4.0	14.7	7.9	10.2	11.0	4.1	10.2	2.7
4	7.4	28.0	10.4	25.7	11.0	24.0	10.5	22.0	3.6	14.5	7.9	9.5	10.9	4.1	10.2	2.7
6	6.7	27.7	10.0	25.6	10.5	23.8	10.2	22.0	3.3	14.5	8.1	9.3	10.8	4.2	10.2	2.8
8	6.3	27.6	10.0	25.6	7.8	23.0	9.6	21.9	2.6	14.5	8.0	8.6	10.8	4.2	10.2	2.9
10	6.1	27.5	4.3	25.3	6.5	23.0	8.2	21.9			7.3	8.6	10.8	4.3	10.2	2.9

D.O. - mg/l

Temperature - degrees Celsius

Appendix B-1. Physical and Chemical Characteristics of Surface Waters
at Station 1 in Lake Eureka

Parameters	1/6/82	2/2/82	3/10/82	4/12/82	5/5/82	5/27/82	6/10/82	6/23/82	7/7/82
Turbidity	<1.0	2.0	6.1	6.2	8.8	7.1	9.0	10	7
Secchi disc readings	120	84	47	31	26	37	39	36	41
pH	8.1	8.1	7.6	8.3	9.0	8.2	8.4	8.2	8.7
Total solids	352	382	290	335	286	300	345	330	281
Suspended solids		2 4	6	6	2 6	8	9		6 8
Suspended volatile solids		2 2	4	3	1 0	5	2		2 2
Alkalinity	235	251	162	179	129	174	177	69	152
Conductivity	333	330	254	309	400	409	430	430	480
Total ammonia-N	0.15	0.22	0.48	0.26	0.14	0.04	0.11	0.17	0.07
Dissolved nitrate-N	3.13	3.58	4.84	8.72	7.92	5.78	6.40	5.25	3.70
Total dissolved iron	<0.10	<0.10	<0.10	<0.10	<0.10	0.13	<0.10	0.40	0.10
Total dissolved manganese	<0.06	<0.06	<0.06	0.09	<0.06	<0.06	<0.06	<0.06	<0.06
Chlorine demand	2.49	2.35	6.07	1.33	2.66	2.35	2.13	2.13	1.91

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Parameters	7/21/82	8/4/82	8/18/82	9/1/82	9/16/82	9/30/82	10/14/82	11/16/82	12/16/82
Turbidity	7	16	10	20	26	12	14	19	60
Secchi disc readings	39	27	48	22	18	27	18	22	3
pH	8.5	8.5	8.7	8.7	9.0	8.5	8.0	8.3	7.9
Total solids	285	-	275	270	266	291	312	337	340
Suspended solids	7	14	6	17	22	18	20	14	12
Suspended volatile solids	3	11	4	11	12	6	9	10	3
Alkalinity	198	178	163	174	145	147	227	253	163
Conductivity	415	460	430	415	335	300	382	34-	275
Total ammonia-N	0.12	0.07	0.10	0.10	0.11	0.13	0.78	1.13	0.16
Dissolved nitrate-N	2.17	1.54	0.77	0.14	0.06	0.03	0.04	0.49	7.08
Total dissolved iron	0.20	<0.10	<0.10	<0.10	<0.10	0.10	0.50	0.31	2.10
Total dissolved manganese	<0.06	<0.06	<0.06	<0.06	0.10	<0.06	0.16	<0.06	<0.06
Chlorine demand	2.57	2.66	2.35	2.26	3.23	2.39	7.35	11.21	3.85

Units of measurement: Turbidity - NTU; secchi - inches; pH - dimensionless; conductivity - $\mu\text{mho/cm}$; others - mg/l

Appendix B-2. Physical and Chemical Characteristics of Near Bottom Waters
at Station 1 in Lake Eureka

Parameters	1/6/82	2/2/82	3/10/82	4/12/82	5/5/82	5/27/82	6/10/82	6/23/82	7/7/82
Turbidity	<1.0	2.0	5.8	6.7	16.4	13.7	10.0	15.0	12.0
pH	8.1	8.1	7.6	8.3	7.6	8.0	8.3	8.2	8.1
Total solids	353	388	298	342	331	310	340	324	300
Suspended solids	2	2	3	9	22	8	9	12	9
Suspended volatile solids	2	1	2	4	10	6	2		3
Alkalinity	235	261	158	179	165	165	176	171	169
Conductivity	348	340	272	309	440	412	432	425	500
Total ammonia-N	0.14	0.26	0.56	0.22	0.29	0.13	0.09	0.25	0.10
Dissolved nitrate-N	3.22	3.58	5.20	8.77	7.76	5.71	6.40	5.42	3.78
Total dissolved iron	<0.10	<0.10	<0.10	<0.10	<0.10	0.17	<0.10	0.52	0.20
Total dissolved manganese	0.06	0.08	<0.06	<0.06	0.08	<0.06	<0.06	0.08	<0.06
Chlorine demand	2.64	1.90	5.63	1.68	5.45	2.61	2.53	2.84	2.70

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Parameters	7/21/82	8/4/82	8/18/82	9/1/82	9/16/82	9/30/82	10/14/82	11/16/82	12/16/82
Turbidity	16	20	21	21	2.6	23	15	20	74
pH	8.0	8.0	7.6	8.4	8.8	8.5	8.0	8.2	7.9
Total solids	297	-	288	272	264	305	316	335	346
Suspended solids	12	19	19	18	22	36	23	15	26
Suspended volatile solids	5	12	6	10	10	6	16	11	2
Alkalinity	183	178	194	174	145	147	227	255	164
Conductivity	435	475	440	410	335	305	387	340	272
Total ammonia-N	0.30	0.18	0.72	0.23	0.08	0.37	0.82	1.18	0.18
Dissolved nitrate-N	2.77	1.61	0.46	0.21	0.07	0.03	0.12	0.52	7.32
Total dissolved iron	0.32	<0.10	<0.10	<0.10	0.09	0.18	0.54	0.31	2.13
Total dissolved manganese	0.18	<0.06	<0.05	0.08	0.07	0.09	0.16	<0.06	<0.06
Chlorine demand	3.94	4.08	5.32	3.10	2.84	4.08	7.35	11.21	3.85

Units of measurement: Turbidity - NTU; pH - dimensionless; conductivity - $\mu\text{mho/cm}$; others - mg/l