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EXPERIENCES OF LONG-TERM DESTRATIFICATION IN A WATER SUPPLY IMPOUNDMENT IN CENTRAL ILLINOIS

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ABSTRACT

Lake Eureka, Illinois, was created in 1942 primarily to serve as a water supply source for the City of Eureka. Because of complaints about taste and odor in the finished waters, the city abandoned the lake and switched to groundwater as the water supply source in 1979.

A detailed taste and odor investigation indicated that high concentrations of iron and manganese, and the dominance of blue-green algae in the lake waters, contributed to the problems in the finished waters.

Lake destratification using a low-energy mechanical destratifier in the deepest part of the lake in combination with chelated copper sulfate application to control blue-green algae was tried in 1981 as a means of enhancing the lake water quality characteristics.

The aerator has been found capable of destratifying the lake and maintaining adequate oxygen levels. Iron and manganese concentrations in the deep waters have been reduced by 95 to 97% from the pre-destratification levels. Chlorine demand values have been reduced by more than half, and problem-causing blue-green algae have been brought under control.

The city has reverted back to the lake as its water supply source since April 1982, and has realized 50 to 60% savings in the water treatment plant's annual operating costs over the past three years.

INTRODUCTION

Lake Eureka, formed in 1942 by damming a branch of Walnut Creek, was created to serve as a water supply source for the city of Eureka in central Illinois. The lake has a surface area of about 14.6 ha, mean depth of 1.92 m, maximum depth of 5.5 m, and a watershed area of 688 ha.

Persistent taste and odor problems in the finished waters occurred for more than 10 years, with resultant consumer complaints. The severe taste and odor problems during the winter of 1976-1977 marked the end of local tolerance. The city sought an alternate source of raw water and switched to groundwater in November 1979.

A detailed investigation by Lin and Evans (1981), conducted during 1976-1978 to delineate the relationship between taste and odor and commonly measured water quality characteristics for Lake Eureka indicated that the threshold odor numbers (TON's) had high positive correlations with iron, manganese, and ammonia concentrations, chlorine demand, and the dominance of blue-green algae in the lake waters during summer months.

In 1981, the Water Quality Section of the Illinois State Water Survey instituted a 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, the lake could again be used as the water supply source. Aeration-destratification in combination with in-lake chemical control of algae was tried to enhance lake water quality.

A low-energy mechanical destratifier with a 1.5 hp motor, developed by James E. Garton and his associates at the Oklahoma State University, Stillwater, OK, was installed and operated since May 1981. The City switched back to the lake as its water supply source again on April 13, 1982. This paper compares the results of operation of the destratification device in Lake Eureka, with pre-operational data (1978) and describes the benefits.

MATERIALS AND METHODS

The axial flow pump destratifier used in Lake Eureka consisted of an electric motor (1.5 hp) mounted horizontally on a 90-degree gear reduction box (50:1), and a propeller with six variable pitch symmetrical blades mounted on a vertical shaft. The details of the system can be found elsewhere (Kothandaraman and Evans, 1982).

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, and it was monitored on a bi-weekly basis from May to September during 1982 and 1983. It was not monitored intensely during 1984.

The locations 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, 5.49 m.

In-situ observations of temperature, dissolved oxygen, and secchi disc depth were made at Stations 1 and 2, and water samples for chemical and biological examinations were made at Station 1. Water samples were collected at the surface and near the bottom (0.3 meter from bottom) for these purposes. Water samples for determining copper concentrations in the lake waters were taken from all three sampling sites after a lapse of approximately 24 hour following chemical application. All determination were made according to *Standard Methods* (APHA, 1981).

The chemical treatment of the lake waters involved applying copper sulfate chelated with citric acid on July 8 and August 5, 1982. There were no need to apply copper sulfate during 1983, and the chemical was applied only on June 23 during 1984. For each chemical application, 200 pounds (90.7 kg) of hydrated copper sulfate was mixed with 100 pounds (45.4 kg) of citric acid and applied. The dosage of copper sulfate was calculated at the rate of 5.4 pounds per acre (6.1 kg/ha). Fifty pounds (22.7 kg) of potassium permanganate was applied to the lake approximately 48 hours after the application of copper sulfate.

The chemicals were applied to the lake from two 30-gallon plastic containers with 0.5-inch holes drilled in their bottom halves. The buckets were floated using inflated inner tubes. The buckets were tied to a concrete block and placed in the shallow upper end of the lake. Potassium permanganate was also applied in the same manner. This method was found to be safe, economical, and effective.

RESULTS AND DISCUSSION

Temperature. Roseboom et al. (1979) reported that a thermal gradient began to develop in May 1978 when the surface temperature was 12°C. During peak stratification, the maximum temperature was 30°C at the surface of the deep station 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 1978. The lake was stratified in 1978, but was relatively isothermal in 1982 demonstrating the effectiveness of the destratifier. Selected vertical temperature profiles at station 1 for the years 1978 and 1982 are shown in Figure 2. Surface water temperatures were generally lower during summer of 1982 than in 1978, and near bottom waters experienced reverse trends. Similar results were also obtained in 1983. The effectiveness of the destratifier is clearly established by this phenomenon.

Dissolved oxygen. Roseboom et al. (1979) reported that the lake was totally devoid of oxygen six to eight feet below the water surface from June to August, 1978. Approximately 38 to 50% of the water column at Station 1 lacked oxygen. Figure 3 shows the temporal variations in dissolved oxygen at the surface and near the bottom of Station 1 in 1978 and 1982. At the lake surface, where oxygenation occurs naturally, DO concentrations were high and super-saturated conditions existed during both years. However, a marked improvement in DO conditions of the near bottom-waters was achieved in 1982. DO saturation levels at or above approximately 50% were maintained in the deep portion of the lake.

Figure 4 shows the oxygen profiles in the lake at Station 1 for 1978 and 1982. The oxic conditions of the bottom waters of the lake were greatly improved in 1982, as in all years the destratifier operated. The DO profile shown for August 18, 1982, indicates that oxygen was rapidly depleted near the bottom when the aerator shut down for a very brief period from August 14 to August 18, 1982 (Figures 3 and 4).

CHEMICAL CHARACTERISTICS

There were two distinct zones of vastly differing water quality characteristics although there was no well-defined thermocline during the summer months (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 thermal stagnation. Tables 1 and 2 indicate the means and ranges of values of chemical parameters reported by Roseboom et. al. (1979) for the surface and near-bottom waters at Station 1 of Lake Eureka during 1978.

For the surface water samples, alkalinity was higher in 1982 and 1983 than in 1978 (Tables 1 and 2), possibly indicating a decrease in algal productivity. Ammonia-nitrogen and dissolved iron were higher in 1982 and 1983 than in 1978. As the lake surface waters were well-oxygenated during these three years, changes in the values of chemical parameters monitored cannot be attributed solely to the effect of the aerator.

A marked difference in chemical quality was observed in the near-bottom waters. The minimum, mean, and maximum values for ammonia-nitrogen, iron, and manganese were reduced significantly in 1982 and 1983 due to aeration. Reductions of 91, 94, 98, and 55% in mean values of ammonia-nitrogen, iron, manganese, and chlorine demand, respectively, were achieved during 1982. Comparable results were achieved in 1983. As the raw water intake in the lake was 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. The chemical treatment was undertaken in conjunction with artificial destratification, mainly to control blue-green algal blooms. Lin and Evans (1981) reported the domination of 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. Background copper concentrations were all below detection limit of 0.03 mg/l. The 1982 samples for copper analyses were taken 24 hours after chemical application, per the Illinois Environmental Protection Agency's permit for copper sulfate in drinking water supply reservoirs. Samples obtained after a lapse of 48 hours showed a more uniform distribution of copper in the lake (Kothandaraman and Evans, 1982). Although the chemicals were applied from a single point in the shallow upper end of the lake, the results (Table 3) indicated that the copper ions are dispersed throughout the lake.

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 minimizes the chances of inadvertent overdosing of the lake waters with chemicals in local areas. Potassium permanganate was used mainly to oxidize the decaying algal cells which otherwise would exert an undue demand on the oxygen resources of the lake waters.

BIOLOGICAL CHARACTERISTICS

Phytoplankton. The total algal counts and the species distribution of algae found at the surface of Station 1 for the years 1982 and 1983 are shown in Table 4. Algal counts in the lake were of bloom proportion during the summers of 1982 and 1983; either diatoms or green algae were dominant. As expected, algal densities near the lake bottom were lower than at the surface. Although the sampling point was below the euphotic zone, high algal counts near the lake bottom reflect the phenomenon of vertical algal redistribution caused by induced mixing. The shift in algal species makeup in 1982 and 1983 to dominance of either diatoms or green algae was a welcome change from that observed in 1977 and 1978 (Lin and Evans, 1981). 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. The shift in algal species makeup was observed in 1981, 1982, and 1983 after the lake management scheme was instituted.

COST-BENEFIT ANALYSIS

The change in raw water supply source in April 1982, resulted in the alleviation of several plant 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 ground water 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), FY 1982-83, FY 1983-84, and FY 1984-85. The treatment plant operated with ground water 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.

Table 6 shows the cost savings realized by the city during fiscal years 1982-83, 1983-84, and 1984-85 because of the change in water supply source. The treatment plant operating cost (excluding manpower) was $91,730 for FY 1981-82. Knowing the quantities of energy and chemicals used in the water treatment plant's post-project period operations and using the unit costs applicable during the fiscal year 1981-82, the apparent costs of plant operation during the three years were computed (Table 6). The operating costs do not include man-power costs.

The power consumption decreased from 4300 kwh per million gallons treated in 1981-1982 to a steady value of 1200 kwh per millions gallons during 1982-83 and 1983-84. Likewise, the energy and materials costs decreased progressively from $552 to $187 (in 1981 dollars) per million gallons. Thus, the savings in operating costs increased from 51.3% in 1982-83 to 59.5% in 1984-85. Benefit cost ratios varied from 39 to 82.

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 improved in the lake during 1981. 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; anoxic conditions in the deep waters; and blue-green algae dominance) were reduced, 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 two chemical applications to control the blue-green algae, the water treatment system functioned extremely well, without any source-related consumer complaints about taste or odor.

The aerator, which has a 1.5 hp motor, destratified the lake and maintained adequate oxygen levels. Reductions of about 90, 95, 98, and 50% in the mean values of ammonia-nitrogen, iron, manganese, and chlorine demand were achieved by destratification, and blue-green algae were never dominant in the lake.

The switch in water supply resulted in a significant savings in power consumption and chemicals, particularly lime and carbon dioxide. Costs of power and chemicals amounted to $91,730 in 1981-82 when groundwater was used as the water supply source. The lake water quality management scheme resulted in a savings of 50 to 60% of the operating cost in Fiscal Year 1981-82 after the city reverted to the lake water supply. The benefit-cost ratios ranged from 39 to 82 in the three years the system was monitored by the Illinois State Water Survey.

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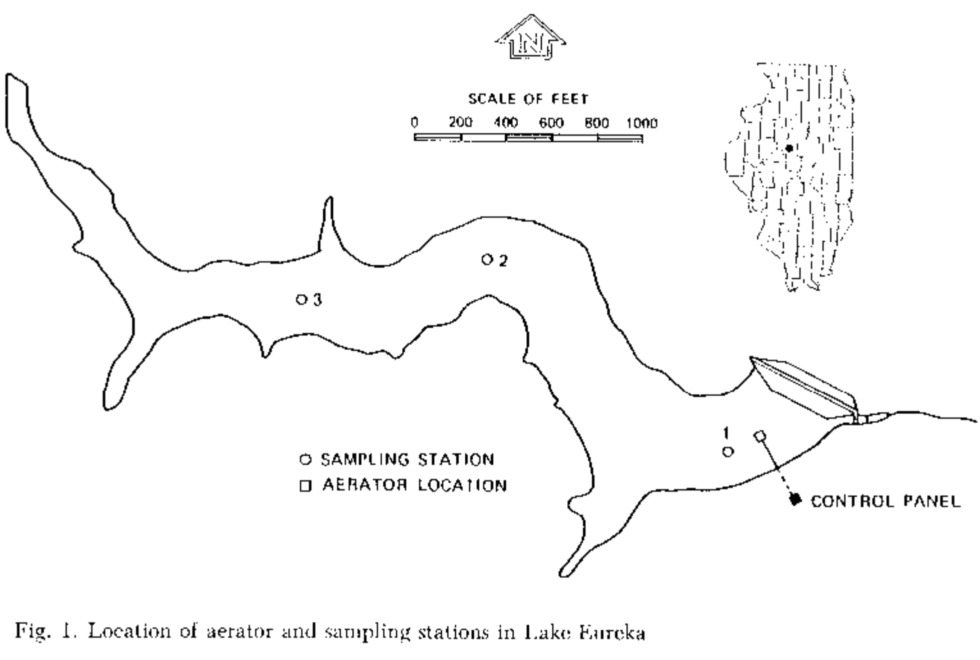

Fig. 1. Location of aerator and sampling stations in Lake Eureka

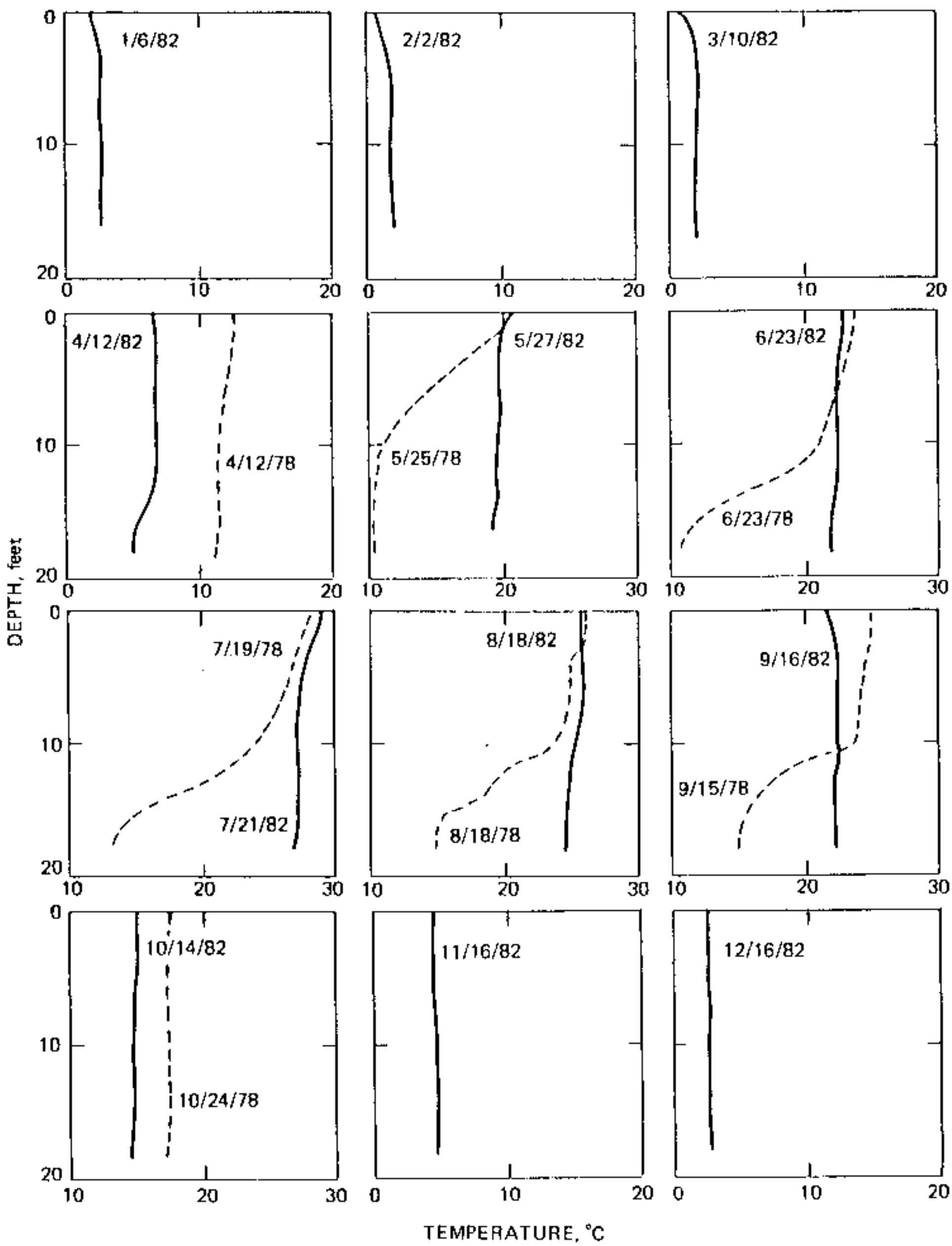

Fig. 2. Temperature profiles at station 1 in Lake Eureka (1978 and 1982)

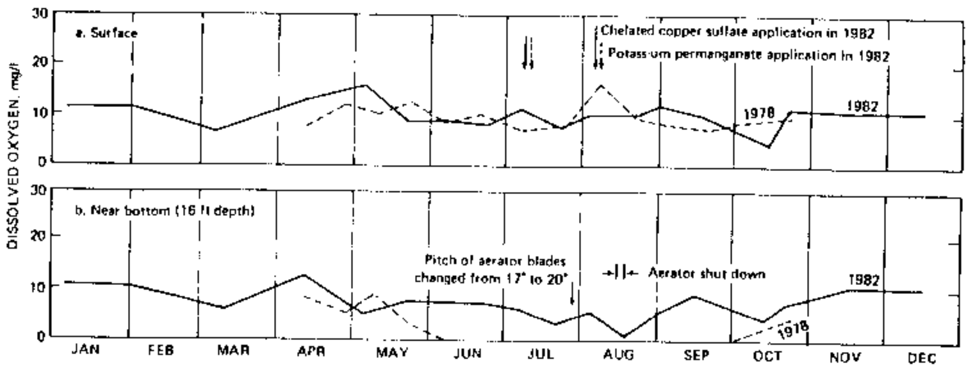

Fig. 3. Temporal variations in dissolved oxygen at the surface and near the lake bottom of station 1 in Lake Eureka (1978 and 1982)

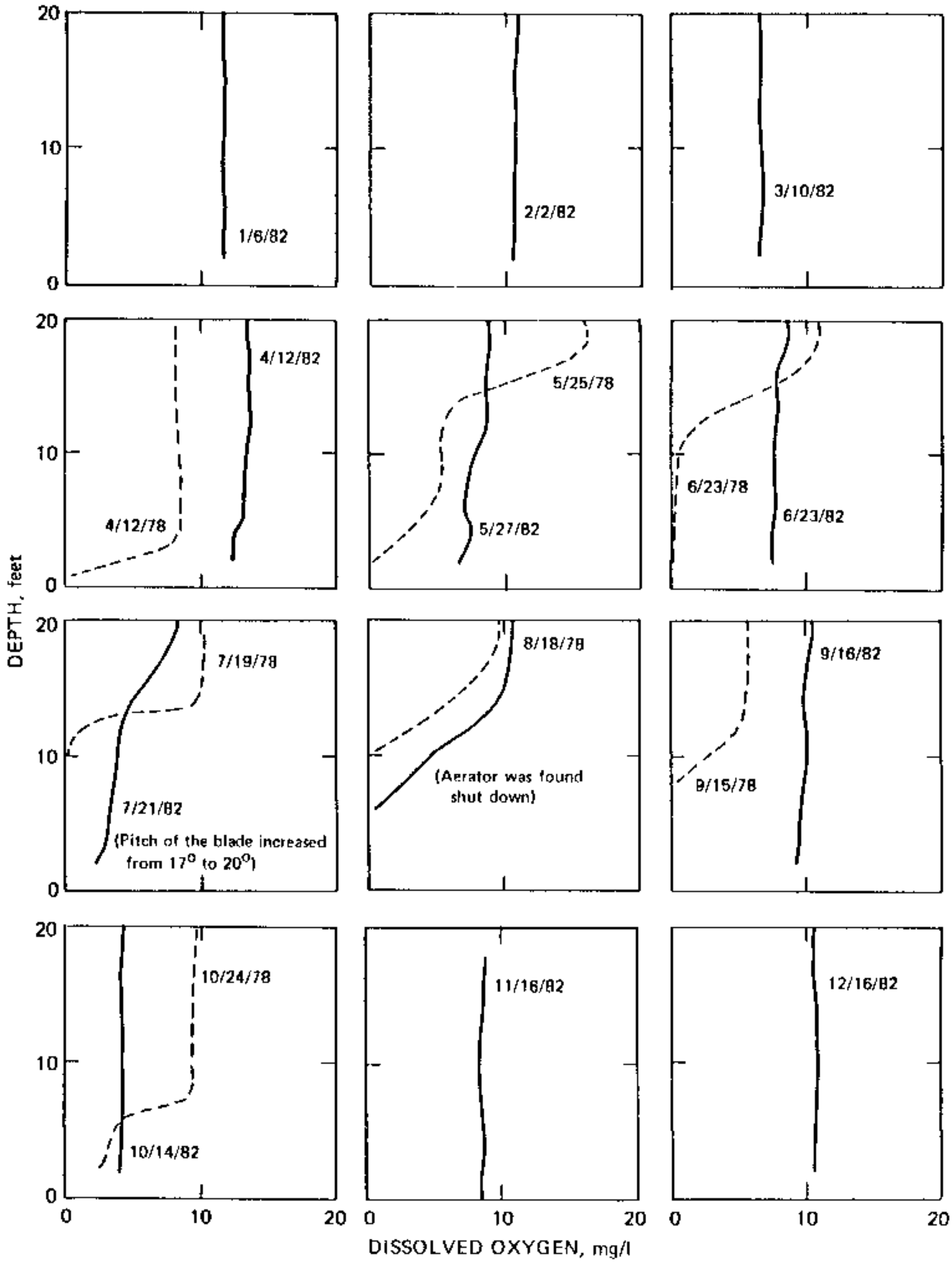

Fig. 4. Dissolved oxygen concentration profiles at station 1 in Lake Eureka (1978 and 1982)

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

	1978			1982			1983		
Parameters	No. of observa-tions	Mean	Range	No. of observa-tions	Mean	Range	No. of observa-tions	Mean	Range
Turbidity				18	13.4	1.0-60	16	27.0	4.0-60.0
Secchi disc readings	48	28	12-68	18	38	3-120	19	19	6-35
pH	50		8.0-9.2	18		7.6-9.0	18		7.7-9.4
Suspended solids				18	11	2-26	17	34	6-204
Alkalinity	50	145	94-185	18	182	129-153	18	192	126-276
Conductivity				18	374	254-480	16	416	275-560
Total ammonia-N	15	0.20	0.00-0.89	18	0.24	0.07-1.13	18	0.35	0.03-3.51
Dissolved nitrate-N				18	3.42	0.03-8.72	18	4.16	0.09-9.48
Total dissolved iron	16	0.17	0.06-0.37	18	0.27	<0.10-2.10	18	0.28	0.09-1.25
Total dissolved manganese	15	0.10	0.00-0.58	18	0.07	<0.06-0.16	18	0.06	0.03-0.11
Chlorine demand	25	4.20	1.10-8.10	18	3.41	1.33-11.21	18	5.16	1.51-18.20

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

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

Parameters	1978			1982			1983		
	No. of observations	Mean	Range	No. of observations	Mean	Range	No. of observations	Mean	Range
Turbidity				18	16.4	1.0-74.0	16	41.0	10.0-152.0
pH	50		7.2-8.3	18		7.6-8.8	18		7.5-8.5
Suspended solids				18	15	2-36	17	43	5-197
Alkalinity	50	221	150-301	18	186	145-261	18	196	124-268
Conductivity				18	382	272-500	16	423	286-580
Total ammonia-N	18	3.97	0.43-7.11	18	0.34	0.08-1.18	18	0.26	0.06-0.89
Dissolved nitrate-N				18	3.50	0.03-8.77	18	4.07	0.07-9.23
Total dissolved iron	18	5.27	0.16-10.90	18	0.30	0.10-2.13	18	0.35	0.09-1.41
Total dissolved manganese	18	3.91	0.24-9.00	18	0.08	0.06-0.18	18	0.11	0.03-0.90
Chlorine demand	25	9.20	2.50-17.1	18	4.10	1.90-11.21	18	5.19	1.39-21.90

Units of measurement: Turbidity — NTU; pH — dimensionless; conductivity — umho/cm; others — mg/l

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

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

			1982						1983		
Dates	BG	G	D	F	T	Dates	BG	G	D	F	T
5/5	0	0	4945	0	4945	5/4	0	560	60	0	620
5/27	0	20	0	10	30	5/17	0	60	60	9120	9240
6/10	0	45	60	0	105	6/8	0	90	0	0	90
6/23	0	60	60	10	130	6/22	0	390	900	0	1290
7/7	125	515	5290	680	6610	7/5	100	590	1130	0	1820
7/21	0	460	865	0	1325	7/20	30	3160	80	0	3270
8/4	650	2630	5240	0	8520	8/2	0	32760	160	370	33290
8/18	275	1145	0	210	1630	8/7	0	1970	330	70	2370
9/1	400	860	270	280	1810	8/30	0	70	80	210	360
9/16	75	160	275	25	535	9/14	0	220	60	0	280
9/30	65	45	10	30	150	9/29	0	950	10	0	960
10/14	0	25	45	0	70	10/14	0	17220	0	0	17220
11/16	0	40	60	0	100	11/11	10	90	0	0	100
12/16	0	0	40	0	40	12/13	0	40	20	0	60

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

Table 5. Power Cons::mption and Chemicals Used in Eureka Water Treatment Plant

Items	FY 1981-82	FY 1982-83	FY 1983-84	FY 1984-85
Electricity for wells, 10^3 kwh	453.7	—	—	—
Electricity for the plant, 10^3 kwh	256.5	192.7	234.6	242.0
Lime, tons	336.3	155.0	181.6	167.0
Chlorine, tons	5.0	6.4	3.8	2.6
Fluoride, tons	1.8	2.7	2.8	1.7
Carbon dioxide, tons	173.0	55.8	33.2	33.2
Alum, tons	—	27.8	37.5	20.0
Activated carbon, tons	—	0.8	—	—
Finished water, million gallons	166.5	169.0	189.0	198.0

Table 6. Comparison of the Pre- and Post Project Operations of Eureka Water Treatment System

Items	FY 1981-82	FY 1982-83	FY 1983-84	FY 1984-85
Electricity for million gallons, 10^3 kwh	4.3	1.3	1.2	1.2
*Cost of energy and chemicals used	91,730	43,400	42,060	37,106
*Cost of lake management	—	1,200	600	930
*Cost per million gallons treated	551	264	226	187
*Savings due to lake management		47,130	49,070	54,624
Savings in operating cost as percent of 1981 operating cost		51.3	53.5	59.5
Benefit/Cost ratio		39	82	59

*Cost in 1981 dollars