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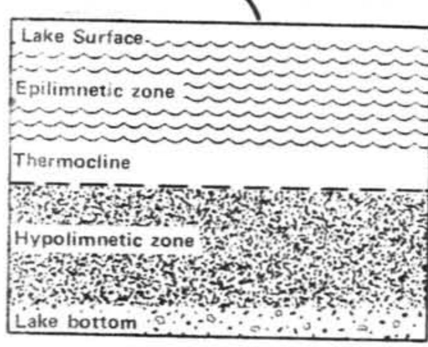
ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

Pilot Lake Restoration Investigations in the Fox Chain of Lakes

by RAMAN K. RAMAN and RALPH L. EVANS



ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1984

REPORT OF INVESTIGATION 99

Pilot Lake Restoration Investigations in the Fox Chain of Lakes

by RAMAN K. RAMAN and RALPH L. EVANS

Title: Pilot Lake Restoration Investigations in the Fox Chain of Lakes.

Abstract: Pilot lake restoration schemes were implemented in the Fox Chain of Lakes, Illinois, in an attempt to improve the water quality of the Chain. A detailed study had determined that the deep lakes in the system developed distinct summer stratification and became totally anoxic below the thermoclines, with marked increases of end products of anaerobic decomposition of bottom sediments. High densities of algae, primarily blue-greens and diatoms, were common. Three different in-lake restoration techniques were tried in three parts of the lake system: nutrient inactivation by alum precipitation in Bluff Lake; copper sulfate application in Mineola Bay, Fox Lake; and aeration-destratification combined with chemical treatment in Lake Catherine. The alum and copper sulfate applications in small portions of the lake system were found ineffective because of the interconnection of the Chain's waters. However, chemical treatment combined with aeration proved to be worthwhile in Lake Catherine. The aeration system demonstrated its capability to destratify the thermal regime and induce oxygenation of lake waters down to its location level. There is also evidence that increased water temperatures and allied dissolved oxygen partially stabilized the organic content of bottom sediments. The full potential of aeration and chemical treatment would probably be realized if a comprehensive water quality management scheme were implemented.

Reference: Raman, Raman K., and Ralph L. Evans. Pilot Lake Restoration Investigations in the Fox Chain of Lakes. Illinois State Water Survey, Champaign, Report of Investigation 99, 1984.

Indexing Terms: Aeration, algal control, chemical treatment, destratification, dissolved oxygen, Fox Chain of Lakes (Illinois), lake management, lake restoration, nutrient inactivation, water quality, water quality control.

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PILOT LAKE RESTORATION INVESTIGATIONS IN THE FOX CHAIN OF LAKES

by Raman K. Raman and Ralph L. Evans

INTRODUCTION

The Fox Chain of Lakes, located in the northeastern part of Illinois (figure 1), is one of the few glacial lake systems in the state. The Chain consists of nine interconnected bodies of water with a total surface area of 6850 acres. Its natural shorelines, picturesque beauty, and proximity to the city of Chicago combine to make the Chain a popular area for swimming, boating, fishing, waterskiing, picnicking, and resort development. The economy of the region is firmly founded on recreation-oriented enterprises such as marinas, tackle and bait shops, restaurants, hotels, and motels.

The Fox Chain is in an advanced stage of eutrophication and experiences recurring problems of luxuriant nuisance algal blooms, periodic fish kills, and offensive odors. These and other symptoms of advanced lake eutrophy impair and interfere with the aesthetic and recreational enjoyment of the Chain's waters. These undesirable eutrophic symptoms have been a source of citizens' complaints for more than 35 years. Apprehension has been expressed regarding the curtailment of swimming and fishing, the lowering of property values, the cancellation of resort trade, and the impairment of the picturesque beauty of the Chain.

A detailed 18-month investigation of the Chain was conducted by the Illinois State Water Survey and the Illinois State Geological Survey (Kothandaraman et al., 1977) to delineate the physical, chemical, and biological characteristics of the lake waters; the geology and geochemistry of the lake bottom sediments; and the hydrodynamics of the lake waters. It was determined that the deep lakes in the system developed distinct summer stratification and became totally anoxic below the thermoclines. Marked increases of ammonia, phosphorus, silica, iron, and other end products of anaerobic decomposition of bottom sediments occurred. Algal densities of 10,000 counts/ml or more were not uncommon in each of the lakes.

The types of algae that predominated (primarily blue-greens and diatoms) were found to be related to the physical characteristics of the lakes. The northern lakes in the system are relatively deep (20 to 40 feet), and their lesser expanse of water surface makes them less exposed to wind action than the large shallow lakes in the system. The deep lakes support similar algal types, mainly blue-greens, whereas in the shallow lakes, diatoms are the dominant species.

A detailed nutrient budget developed for the lake system (Kothandaraman et al., 1977) indicated that tributaries to the lake system introduce

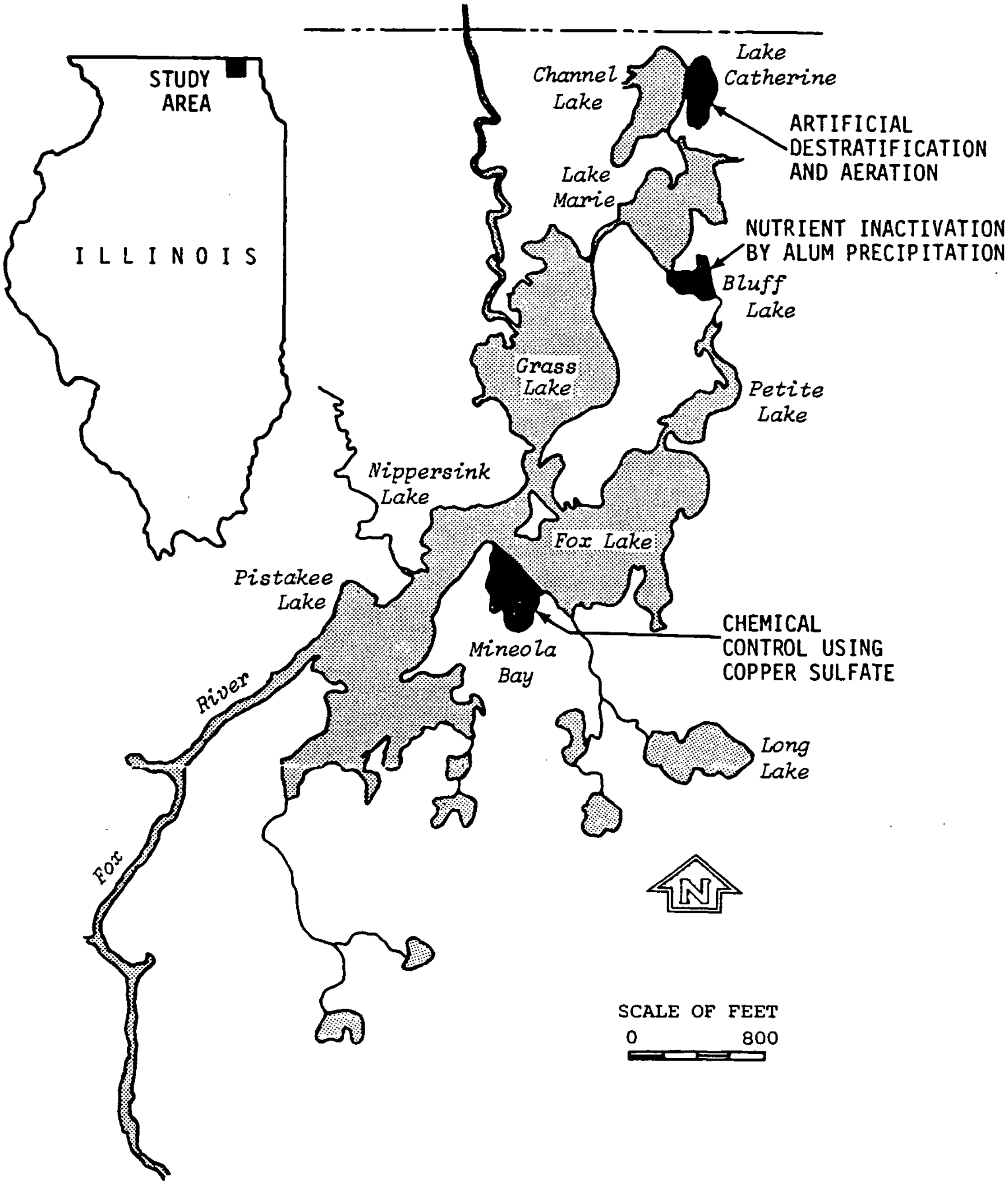

Figure 1. Pilot demonstration schemes in the Fox Chain of Lakes

nutrients, particularly nitrogen and phosphorus, far in excess of limits that are likely to be assimilated without giving rise to nuisance algal blooms. Total annual phosphorus and total nitrogen loading rates to the lake system were estimated to be, respectively, 10.3 and 86.0 g/m^2. Guidelines for relating nutrient influx to water quality in lakes were first proposed by Vollenweider (1968). According to Vollenweider, for lakes with mean depths of 5 meters (16.4 feet) or less, permissible annual loading levels of biochemically active phosphorus and nitrogen are, respectively, 0.07 and 1.0 g/m^2. For the same average depth, loading rates greater than 0.13 g/m2/yr for phosphorus and 2.0 $g/m^2/yr$ for nitrogen are considered excessive. These guidelines are applicable to the Fox Chain of Lakes, which has an overall mean depth of 5.7 feet.

Limiting the nutrient influx to the lakes is an essential step in reversing the eutrophic trend in the Fox Chain. Regional plans for pollution abatement in the Fox River watershed, including phosphorus emission control, are in various developmental stages in Illinois and Wisconsin. Illinois has taken a major stride by removing phosphorus from municipal waste discharges affecting the Fox Chain, as well as by diverting waste discharges around the lake system where feasible. It is unlikely that nutrient influx into the Fox Chain of Lakes can be curbed to subcritical levels within the next few decades. In the interim, use of in-lake treatment techniques to enhance the Chain's water quality is justified.

On the basis of the limnological studies of the Fox Chain and the recommendations of the Water Survey (Kothandaraman et al., 1977), the Illinois Institute for Environmental Quality sponsored and funded pilot demonstration schemes for improving the water quality in the Chain. Three different in-lake restoration techniques were tried in three different parts of the lake system (figure 1). In 1977 nutrient inactivation by alum precipitation was attempted in Bluff Lake, and copper sulfate application to control algae was tried in Mineola Bay of Fox Lake. Aeration-destratification in combination with chemical treatment was employed in Lake Catherine in 1978 and again in subsequent years. The results of these demonstration schemes were reported in separate documents as yearly progress reports to the sponsoring agency, the Illinois Institute for Environmental Quality (Kothandaraman et al., 1978, 1979, 1980).

The purpose of this report is to consolidate the results of all the treatment techniques tried in the Fox Chain of Lakes in a single document. The report also provides more recent data on the aeration-destratification attempts in Lake Catherine than were included in the previous reports. Finally, the report details an overall water quality management plan for the entire Fox Chain of Lakes system that was developed on the basis of the pilot investigations.

Acknowledgments

The pilot lake restoration investigations were sponsored and financially supported by the Illinois Institute for Environmental Quality, which is now a part of the Illinois Department of Energy and Natural Resources. The investigations were carried out under the general supervision of Dr. William C. Ackermann, Chief Emeritus, Illinois State Water Survey.

Mr. Clem Haley of the Grass Lake Marina loaned a pontoon tank barge with an outboard motor to the Water Survey free of charge for applying alum in Bluff Lake.

The wholehearted support and assistance given by Mr. Robert Palm of Bob's Marina on Lake Catherine is gratefully acknowledged. He very generously allowed the installation of the aerator, the power cable, and the control panel and transformer concrete platform on his property at no cost to the Water Survey. He loaned heavy equipment and tools and provided year-round storage for chemicals and Water Survey equipment at no cost to the Survey. Without his support, accomplishing the tasks would have been much more difficult, time consuming, and expensive.

Several Water Survey staff members participated in the investigations in various capacities. Donald Roseboom was actively involved in all the field operations related to the copper sulfate application, alum application, aerator installation, and modifications to the aerator. Special mention must be made of Davis Beuscher for his competent and voluntary scuba diving efforts to start the aerator system in the spring and to winterize it in the fall. Others who assisted in the field operations were Jack Williams, Thomas E. Hill, and Scott Bell. David Hullinger, Dana Shackleford, Curtis Pulliam, and Diana Shaw performed chemical analyses; and David Hullinger performed copper and manganese - analyses and the tests to characterize lake bottom sediments. Davis Beuscher performed the algal identification and enumeration, and Tom Hill and Scott Bell identified and counted benthic organisms. Linda Johnson typed the initial draft of this report, and the camera copy was typed by Marilyn Innes. Illustrations were prepared by the graphic arts staff under the supervision of John W. Brother, Jr. Editorial assistance was provided by Gail Taylor.

NUTRIENT INACTIVATION IN BLUFF LAKE

Materials and Methods

As a preliminary step to alum application in Bluff Lake, laboratory "jar tests" were performed with lake surface and deep water samples to determine the desirable alum dosage rate. The jar tests were run with water samples on a six-place Phipps and Bird variable speed paddle mixer. The alum dosage rates ranged from 50 to 150 mg/l, as $Al_2(SO_4)_3$, at 25 mg/l increments. A control without the addition of alum was included in each of the experiments. A 30-second rapid mix at 100 rps was followed by 10 minutes of gentle mixing at 30 rpm and then 1 hour of quiescent settling. At the end of the settling period, the clear supernate was syphoned and analyses were performed for alkalinity, pH, turbidity, and dissolved and total phosphorus. In addition, qualitative observations on floc size and settleability were made and recorded.

The results of the jar tests are shown in table 1 for the Bluff Lake surface water sample and deep water sample (collected 1 foot above lake bottom). The surface sample was collected on June 6 and the deep sample on June 13, 1977. Summer stratification had set in by then, and the lake had begun to

Table 1. Bluff Lake Surface and Deep Water Sample Jar Tests

	Raw sample	*Alum dosage (mg/l)* 0	50	75	100	125	150
Surface water sample							
Total phosphorus (mg/l)	0.07	0.05	0.05	0.04	0.03	0.03	0.07
Total dissolved phosphorus (mg/l)	0.08	0.05	0.03	0.03	0.03	0.02	0.07
Turbidity (FTU)	11	5	4	4	3	2	2
pH	8.69	8.70	7.87	7.71	7.37	7.33	7.31
Alkalinity (mg/l)	162	162	152	136	126	111	101
Settleability			**least rapid** →				**most rapid**
Deep water sample							
Total phosphorus (mg/l)		0.46	0.19	0.16	0.14	0.11	0.08
Total dissolved phosphorus (mg/l)		0.31	0.03	0.02	0.02	0.03	0.01
Turbidity (FTU)		4	3	3	3	3	2
pH		7.53	7.12	6.97	6.81	6.86	6.74
Alkalinity (mg/l)		197	172	162	152	146	131
Settleability			**least rapid** →				**most rapid**

experience algal growth of bloom magnitude. Because of the utilization of nutrients by the standing algal crop, the phosphorus concentration in the surface water sample was only 0.07 mg/l, whereas in the deep water sample, the total phosphorus was 0.46 mg/l. Alkalinity and pH decreased progressively with increased alum dosage and tended to level off at high dosage rates. Floc sizes were large, and settleability was good in all cases. On the basis of the phosphorus reduction by precipitation and the turbidity data, a dosage rate of 100 mg/l as aluminum sulfate (15.8 mg/l as Al^{3+}) was chosen for application to Bluff Lake. It was decided to apply alum to the volume of lake water contained in the top 2 feet, as had been done in a study conducted by the Wisconsin Department of Natural Resources (Peterson et al., 1973).

Although it is ideal to apply alum to the lake soon after the winter thaw and prior to the onset of any algal blooms, a decision was made to apply alum as early as practicable during the summer in which the study was conducted. It was anticipated that after the alum application the phosphorus concentration in the photic zone would be reduced, minimizing subsequent algal blooms, and that the settling floc would remove particulate phosphorus and dissolved phosphorus by sorption and entrapment in the process of settling to the bottom. It was also anticipated that the alum floc blanket formed over the lake sediments would tend to reduce the anaerobic release of phosphorus from the lake sediments. Above all, the clarity of the lake could be improved immediately, enhancing the aesthetic attractiveness of the lake.

An attempt was made to apply alum to the lake on July 19, 1977. This effort had to be abandoned because of a malfunctioning outboard motor. The pontoon barge employed in the operation proved to be inadequate and unsafe. However, the task was successfully completed on August 10, 1977, with the aid of better-designed equipment and facilities.

Alum was applied from a tank barge with a 3 hp gasoline-powered centrifugal pump (figure 2). The barge, which was loaned to the Survey by Mr. Clem Haley, owner-operator of the Grass Lake Marina, was ordinarily used to transport sanitary waste from the Blarney Island tavern and restaurant in Grass Lake to the main shore for final disposal. Prior to the use of the barge for alum application, the tank was flushed four times with lake water, and the rinse waters were transferred to a tank truck hauling sanitary waste. The barge tank was then treated with 5 pounds of high test hypochlorite, allowing a 30-minute contact time.

Alum was applied by means of a center feed underwater sprayer of galvanized iron pipe 20 feet long and 1.5 inches in diameter with 5/16-inch diameter holes at 12-inch intervals. The flow of fluid through the system was monitored by a Fischer and Porter variable area flow meter, capable of registering a flow of 20 gpm of water. Nomographic charts are available for estimating flows of fluids of different densities from the permanent graduations on the flow meter. The pump and flow meter are shown in figure 3.

The spray header was held by means of "U" bolts to vertical struts which were structurally fastened to the barge pontoons. Holes were drilled in the vertical struts so the header could be fixed at three different positions

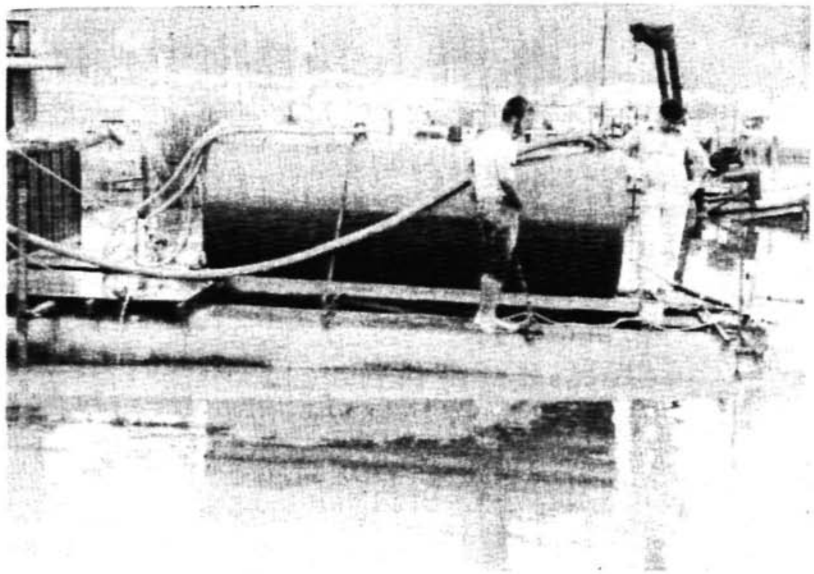

Figure 2. Pontoon tank used in alum application

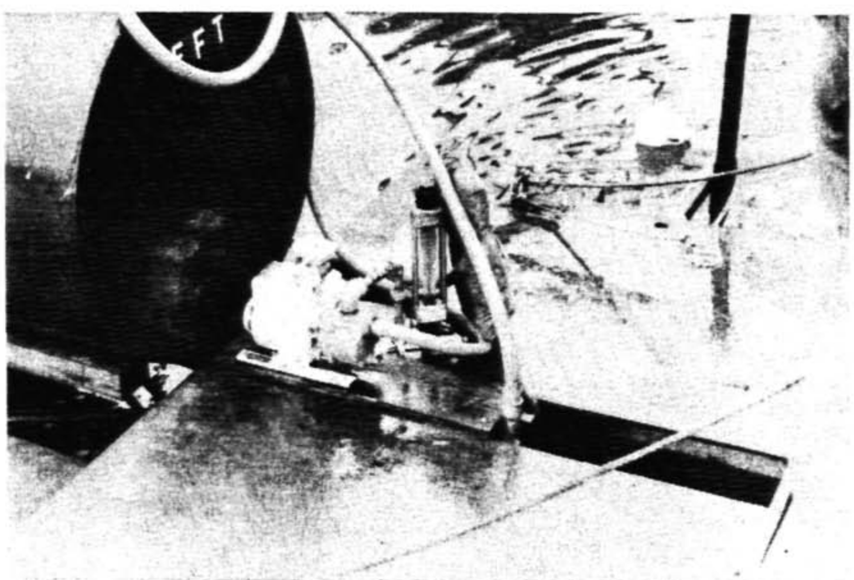

Figure 3. View of the pump, flow meter, and work platform

approximately 15, 21, and 27 inches below the water surface. The working platform and spray header support system were designed and fabricated by Donald Roseboom of the Water Survey. Details of the working platform, the sprayer-supporting structures, and the center feed unit of the sprayer are shown in figures 3 and 4.

Bulk alum was stored in a semi-trailer tank (figure 5) for the duration of the lake work. The charge for this storage facility was less than the cost of a 15-foot-diameter, 3-1/2-foot-high portable swimming pool initially considered. Alum was transferred by gravity flow from the storage tank to the barge tank.

The barge was powered by a 25 hp outboard motor. The steering mechanism of the outboard was modified to enable the operator of the barge to look ahead over the tank (figure 6). The barge is shown loaded to the maximum extent. Although the tank has a capacity of 940 gallons (4-foot diameter, 10 feet long), the barge can safely carry only about 5000 pounds of liquid.

The speed of the barge was determined by noting the time of traverse between two fixed points at a known distance in Grass Lake. The tank was filled with water to its safe limit, and the outboard was operated with the throttle fully open. The contents of the tank were discharged through the header at the same time. This very nearly simulated the operating conditions in Bluff Lake - during alum application. The barge covered a distance of 6600 feet in 19 minutes, giving an average speed of 3.95 miles per hour.

Because the alum applicator length was 20 feet, the alum dosage rate was 100 mg/l, the commercial liquid alum contained approximately 50 percent aluminum sulfate, and the speed of the barge was 347.4 feet/minute, it was computed that the system should deliver alum at the rate of 15.73 gallons/minute. The flow meter reading of 18 was determined from a nomograph supplied by the manufacturer, on the basis of the density of alum (11 pounds/gallon). The flow rate could be controlled by adjusting a gate valve on the delivery line, adjusting the speed of the gasoline engine, or combining these two techniques. A calibrated float gage (shown in figure 7) was used to indicate the liquid level in the tank. The gage was inserted into the tank through one of the plug holes located on top of the tank.

As shown in figure 8, Bluff Lake was divided into two sections by use of regulatory buoys in an east-west orientation. While one segment of the lake was being treated, general boat traffic was diverted through the other segment. Alum was applied in 20-foot wide strips (figure 8), beginning from the central dividing line. To demarcate the edges of the treated lanes, floats consisting of 1-gallon jars tied to bricks with 35-foot nylon cords wound around them (figure 9) were dropped at frequent intervals from a boat following behind the barge. The cords were longer than the water column, which was necessary to keep the floats from drifting away. By this arrangement, irrespective of the depth of water column, the cord would unwind until the brick reached the bottom, thus anchoring the float in place. The ends of the spray header were marked by plastic bottle floats, one of which is visible in figure 3.

Consecutive 20-foot-wide strips of the lake surface were treated, working from the center toward the north and then the south end of the lake. After two

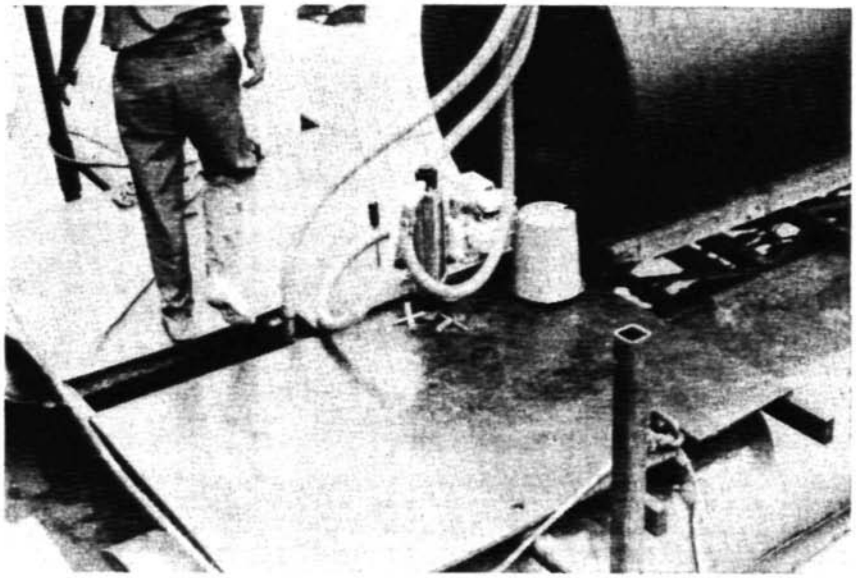

Figure 4. View of the spray header supports

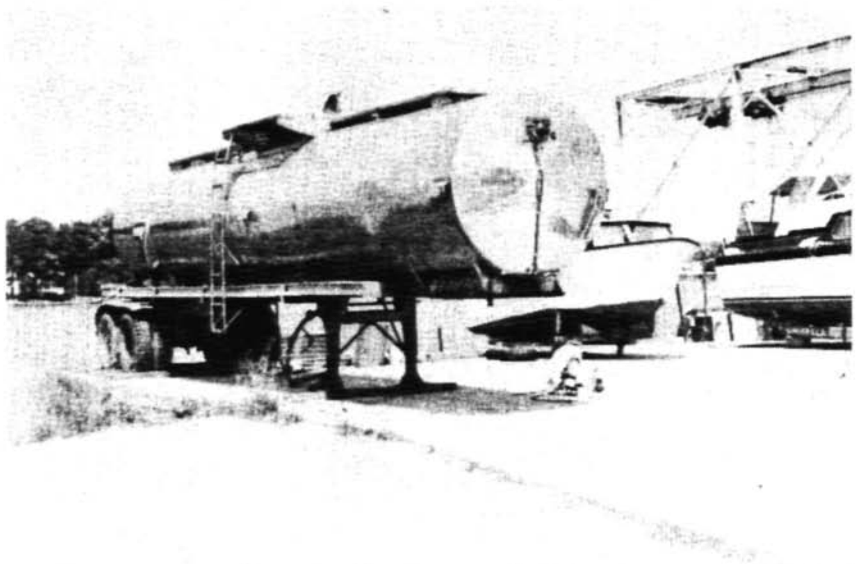

Figure 5. Bulk alum storage facility

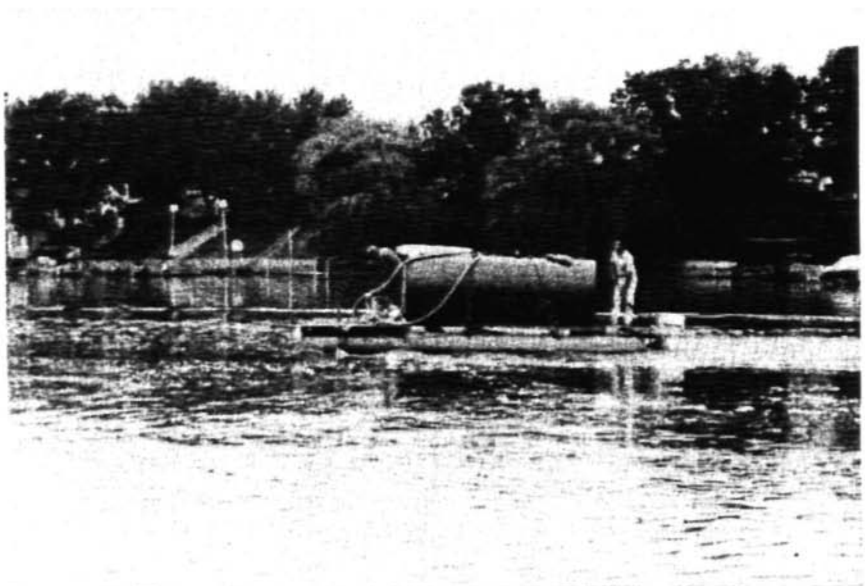

Figure 6. View of the pontoon tank fully loaded

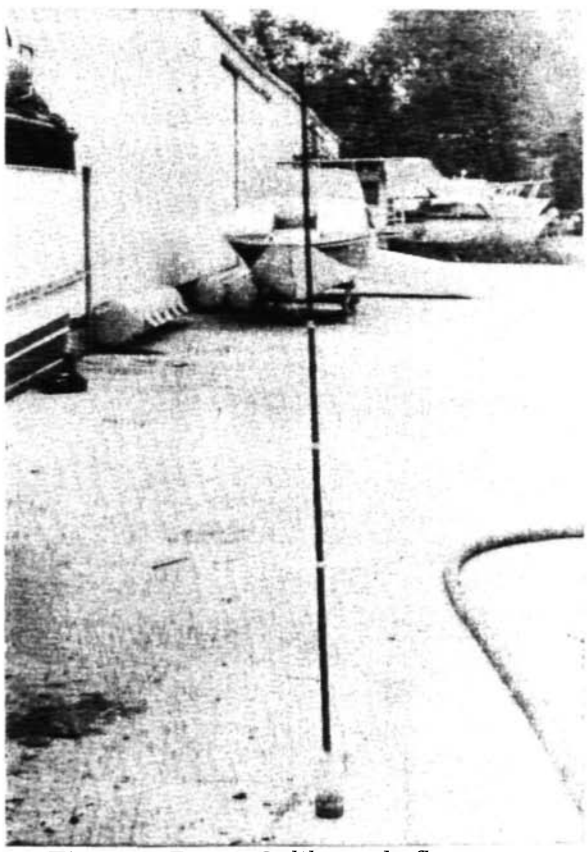

Figure 7. Calibrated float gage

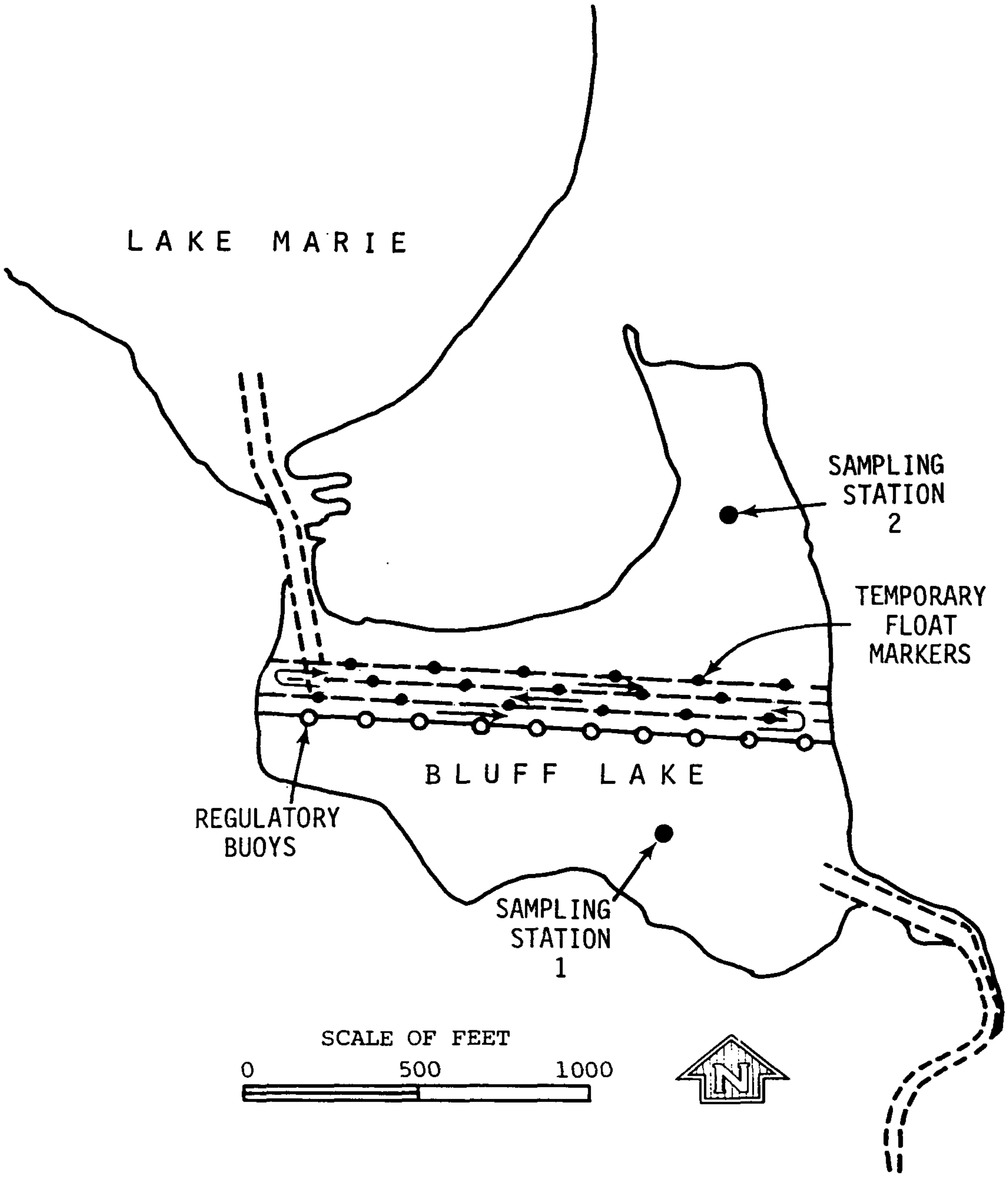

Figure 8. Setup for alum application, Bluff Lake

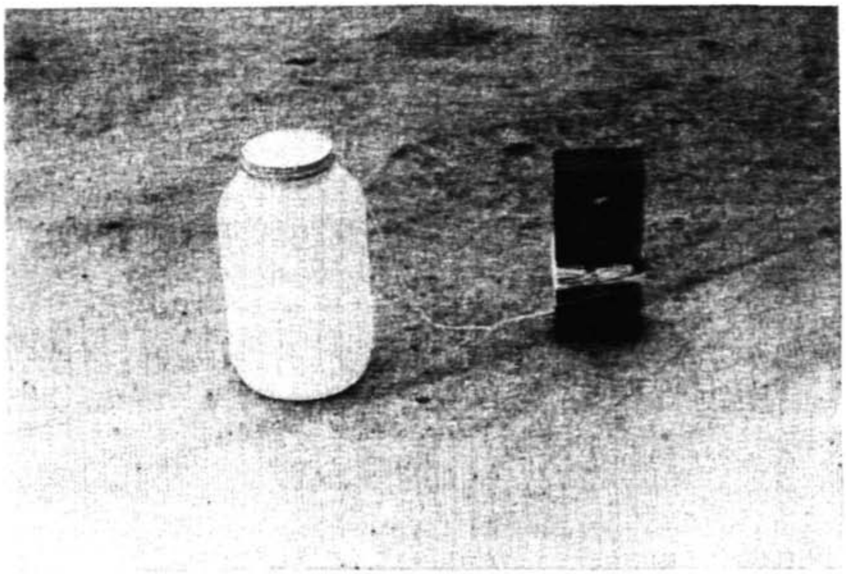

Figure 9. Float used to demarcate a treated strip of the lake surface

Figure 10. A row of floats in the lake (retrieving boat shown in foreground)

consecutive strips were treated, floats from the edge of the outer strip were retrieved and reused. Figure 10 shows a row of floats in the lake; the retrieving boat is shown in the foreground.

A total of 43.2 tons of liquid alum was applied to about 90 percent of the lake surface. Part of the lake surface was inaccessible because of boat docks.

Mounting of the underwater alum sprayer at the front end of the pontoons afforded quick mixing of the alum by the turbulence created by the pontoons and the outboard. A trail of aluminum hydroxide floc was visible' immediately behind the pontoon barge.

Sampling and Analytical Procedures

Pretreatment monitoring of Bluff Lake with regard to water quality characteristics started on May 31, 1977, on a weekly basis. Sampling station 1 was established at the deepest part of the lake, and station 2 was established for the shallow bay area in the northeast portion of the lake (see figure 8). In-situ observations of secchi disc transparency, temperature, and dissolved oxygen were made. At the deep station, temperature and dissolved oxygen measurements were made at 2-foot intervals. At station 2, these observations were made at 1-foot intervals. Water samples were collected at surface, mid-depth, and deep portions at station 1, while only surface samples were collected at station 2. Mud-water interface samples were initially collected at both stations on August 11, 1977, with an interface sampler developed by the Survey as described by Sullivan (1967).

The following determinations were made on water samples: turbidity, pH, alkalinity, hardness, nitrate, ammonia, sulfate, total and dissolved solids, total and dissolved phosphorus, aluminum, and algal identification and enumeration. The analytical procedures used are listed in table 2.

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 reappeared. Again the depth of immersion was noted. The average of these two observations was recorded at the secchi disc reading.

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 standardized in lake surface water in which dissolved oxygen content was determined by the modified Winkler method as outlined by the American Public Health Association et al. (1976).

For ammonia determinations, water samples were filtered through 0.45 micrometer (μm) millipore filters to prevent biomodification of the dissolved nitrogen form in the water samples.

Table 2. Analytical Procedures

PH	Glass electrode method using Beckman 4500 meter
Alkalinity	Potentiometric method
Aluminum	Atomic Absorption Spectrophotometric Method
Copper	Atomic Absorption Spectrophotometric Method
Hardness	EDTA titrimetric method
Sulfate	Turbidimetric method
Silica	Molybdosilicate method
Chlorine residual	Iodometric method I
Total phosphorus	Sample was digested with sulfuric-nitric acid mixtures and determined by ascorbic acid method
Dissolved phosphorus	Sample was first filtered through 0.45 μm filter paper, digested with sulfuric-nitric acid mixture and determined by ascorbic acid method
Ammonia-N	Phenate method
Nitrate-N	Chromotropic method
Total iron	Phenonthroline method
Total manganese	Periodate method
Total solids	Residue on evaporation at 103 to 105 C
Total dissolved solids	Residue on filtration and evaporation at 103-105 C
Turbidity	Nephelometric method, using Turner Fluorometer Model 110. Formazin was used as a standard

Water samples in volumes 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 examined.

At the time of examination, each sample was thoroughly mixed and a 1-ml aliquot was pipetted into a Sedgwick-Rafter cell. A differential interference contrast microscope equipped with 10X or 20X eyepiece, 20X or 100X objective, and a Whipple disc was used for identification and counting purposes. Five short strips were counted. Algae were identified to species level and were classified in five main groups: blue-greens, greens, diatoms, flagellates, and others. For enumeration, blue-green algae were counted by the number of 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 grouping or connections. For flagellates, a colony of Dinobryon or a single cell of Ceratium was recorded as a unit.

Results of Alum Application

Data regarding temperature, dissolved oxygen, and algal types and density at Bluff Lake are given in Appendix A. Water quality characteristics of Bluff Lake at stations 1 and 2 are given in tables 3 through 7. Figure 11 shows the temporal variations in surface dissolved oxygen concentrations, secchi disc transparency, algal counts, and total and dissolved phosphorus. The figure also includes the phosphorus concentrations in mid-depth and deep water samples.

The day after the completion of alum application in the lake, aluminum concentrations (Al^{3+}) in the surface, mid-depth, deep, and interface samples were 0.37, 0.26, 0.04, and 8.97 mg/l, respectively, indicating that the alum floc had settled to the bottom of the lake. Aluminum concentration in the bay area surface water sample (8/11/77) was 0.34 mg/l, and the bay interface sample showed a concentration of 2.26 mg/l. Aluminum concentrations in the water columns, in both the main lake and the bay area, decreased to about 0.04 mg/l in a week and remained at that level until this investigation ended in September 1977. The interface aluminum concentrations also showed a significant decrease.

As expected, the immediate effect of the alum treatment was a dramatic improvement in lake transparency and a decrease in algal counts resulting from precipitation and settling of algal cells. The transparency increased from an average value of about 23 inches prior to alum treatment to 45 inches. The algal counts decreased from an average value of 5240 to 920 counts/ml. Likewise, in the bay area transparency improved from a background level of 18 to 33 inches. Algal counts of 620/ml were observed.

As seen from figure 11 and table 3, these improvements did not last more than a few days, after which the conditions of lake clarity and algal density reverted to normal levels. This is mainly because of the interchanges in flows between Bluff Lake and adjacent lakes. The problem is compounded by the heavy usage of high speed boats and yachts in the lake system. Even though the algal counts in the lake indicated a declining trend after the alum application

Table 3. Water Quality Characteristics, Bluff Lake, Surface (Station 1)

Date	*Trans-parency (inches)*	*Tur-bidity (FTU)*	*pH*	*Alka-linity (mg/l)*	*Hard-ness (mg/l)*	*Ni-trate (mg/l)*	*Ammo-nia (mg/l)*
5/31/77	24	10	8.62	164	265	0.16	0.18
6/6/77	26	5	8.57	172	219	0.12	0.23
6/13/77	24	7	8.53	177	252	0.15	0.44
6/20/77	22	7	8.27	187	232	0.15	0.03
6/27/77	24	6	7.72	152	166	0.10	0.17
7/5/77	21	12	8.27	167	192	0.18	0.21
7/11/77	18	12	8.45	167	159	0.12	0.15
7/18/77	18	9	7.95	164	293	0.11	0.28
7/26/77	21	6	8.40	172	113	0.20	0.20
8/1/77	24	8	8.35	172	313	0.13	0.24
8/8/77	30	7	8.15	177	307	0.10	0.34
8/11/77	45						
8/17/77	27	15	8.25	177	287	0.10	0.31
8/22/77	30	11	8.30	187	287	0.12	0.14
8/30/77	24	11	8.60	177	293	0.15	0.12
9/6/77	21	14	8.65	192	307	0.05	0.18
9/27/77	18	30	8.30	187	300	0.18	0.94

Date	*Sul-fate (mg/l)*	*Solids (mg/l)*		*Pbospborus (mg/l)*		*Alu-minum (mg/l)*	*Algae (counts/ml)*
		Total	Diss.	*Total*	*Diss.*		
5/31/77	76.9	332	298	0.10	0.02		4350
6/6/77	74.2	518	484	0.13	0.03		2470
6/13/77	77.8	488	426	0.15	0.03		3430
6/20/77	80.9	358	348	0.34	0.11		4390
6/27/77	94.3	332	237	0.08	0.03		3610
7/5/77	71.8	408	356	0.14	0.02		2750
7/11/77	78.5	378	360	0.13	0.02		8170
7/18/77	77.2	384	352	0.11	0.03		9060
7/26/77	69.8	432	344	0.12	0.02		6920
8/1/77	68.8	426	278	0.15	0.02		6630
8/8/77	65.5	554	192	0.14	0.03		5840
8/11/77						0.37	920
8/17/77	66.5	414	390	0.18	0.10	0.05	3420
8/22/77	63.7	370	200	0.17	0.03	0.04	3811
8/30/77	59.2	408	386	0.17	0.03	0.01	2280
9/6/77	63.1	480	416	0.17	0.03	0.05	2740
9/27/77	59.4	504	360	0.21	0.07	0.03	750

Table 4. Water Quality Characteristics, Bluff Lake, Mid-depth (Station 1)

Date	*Turbidity (FTU)*	*pH*	*Alkalinity (mg/l)*	*Hardness (mg/l)*	*Nitrate (mg/l)*	*Ammonia (mg/l)*
5/31/77	6	8.54	167	278	0.16	0.24
6/6/77	3	8.54	175	185	0.09	0.21
6/13/77	7	8.37	174	232	0.15	0.36
6/20/77	5	8.04	159	265	0.15	0.39
6/27/77	5	7.92	184	166	0.15	0.61
7/5/77	5	.7.75	169	139	0.22	0.50
7/11/77	5	7.85	174	166	0.14	0.35
7/18/77	5	7.75	162	440	0.11	0.45
7/26/77	6	7.95	172	160	0.12	0.20
8/1/77	5	8.15	177	300	0.13	0.17
8/8/77	4	7.90	182	267	0.10	0.51
8/17/77	10	8.30	182	313	0.09	0.29
8/22/77	7	8.15	182	307	0.12	0.14
8/30/77	6	8.20	184	280	0.14	0.01
9/6/77	10	8.35	182	347	0.07	0.13
9/27/77	28	8.20	192	307	0.17	0.64

Date	*Sulfate (mg/l)*	*Solids (mg/l)*		*Phosphorus (mg/l)*		*Aluminum (mg/l)*	*Algae (counts/ml)*
		Total	*Diss.*	*Total*	*Diss.*		
5/31/77	78.6	322	316	0.13	0.02		2700
6/6/77	76.9	528	490	0.14	0.02		3350
6/13/77	76.9	490	426	0.18	0.04		2240
6/20/77	80.9	368	360	0.22	0.22		3210
6/27/77	80.7	326	233	0.14	0.08		3170
7/5/77	74.2	412	344	0.10	0.03		1850
7/11/77	78.5	338	296	0.13	0.06		5320
7/18/77	73.8	388	348	0.12	0.04		4110
7/26/77	71.4	426	334	0.12	0.03		4500
8/1/77	71.8	424	308	0.19	0.04		3510
8/8/77	69.0	472	200	0.13	0.08		2600
8/11/77						0.26	2970
8/17/77	70.3	390	374	0.19	0.05	0.04	950,
8/22/77	65.8	348	242	0.12	0.05	0.03	810
8/30/77	59.0	424	404	0.12	0.04	0.01	180
9/6/77	62.7	476	434	0.14	0.05	0.05	740
9/27/77	61.6	498	350	0.22	0.10	0.03	600

Table 5. Water Quality Characteristics, Bluff Lake, Deep (Station 1)

Date	*Turbidity (FTU)*	*pH*	*Unity (mg/l)*	*Hardness (mg/l)*	*Nitrate (mg/l)*	*Ammonia (mg/l)*
5/31/77	6	7.47	212	351	0.11	4.13
6/6/77	2	7.53	146	232	0.18	3.15
6/13/77	50	7.38	222	278	0.15	4.09
6/20/77	5	7.99	205	252	0.17	2.26
6/27/77	4	7.52	235	225	0.15	4.63
7/5/77	8	7.40	220	205	0.17	8.40
7/11/77	8	7.60	270	245	0.19	5.08
7/18/77	34	7.40	263	440	0.14	7.76
7/26/77	4	7.25	265	200	0.15	4.67
8/1/77	23	7.60	278	360	0.13	8.03
8/8/77	5	7.90	184	300	0.08	0.74
8/17/77	17	8.15	258	327	0.08	6.27
8/22/77	15	8.30	187	267	0.12	0.52
8/30/77	22	7.80	194	320	0.15	2.21
9/6/77	8	7.50	194	340	0.05	1.54
9/27/77	260	8.10	182	340	0.18	0.96

Date	*Sulfate (mg/l)*	*Solids (mg/l)*		*Phosphorus (mg/l)*		*Aluminum (mg/l)*	*Algae (counts/ml)*
		Total		*Total*	*Diss.*		
5/31/77	74.1	372	338	0.88	0.62		240
6/6/77	78.2	524	488	0.53	0.37		240
6/19/77	69.9	894	444	1.41	1.35		200
6/20/77	75.0	396	380	0.57	0.43		1970
6/27/77	75.5	358	340	0.80	0.71		
7/5/77	76.8	442	400	0.76	0.68		2130
7/11/77	65.5	404	400	1.43	1.21		3630
7/18/77	73.2	496	440	1.49	1.07		2670
7/26/77	56.2	460	370	1.31	1.17		2930
8/1/77	66.7	510	470	1.91	1.39		2660
8/8/77	68.4	410	288	0.22	0.10		180
8/11/77						0.04	200
8/17/77	57.9	474	442	1.06	0.83	0.06	750
8/22/77	66.0	400	320	0.28	0.18	0.03	660
8/30/77	63.5	466	422	0.47	0.25	0.03	140
9/6/77	66.1	462	422	0.27	0.20	0.03	100
9/27/77	64.1	910	368	0.86	0.11	0.21	100

Table 6. Water Quality Characteristics, Bluff Lake, Interface (Station 1)

Date	*Tur-bidity (FTU)*	*PH*	*Alka-linity (mg/l)*	*Hard-ness (mg/l)*	*Ni-trate (mg/l)*	*Ammo-nia (mg/l)*
8/11/77	308	8.40	308	400	0.12	9.47
8/17/77	137	7.55	323	347	0.26	13.29
8/22/77	875	7.50	220	287	0.22	1.87
8/30/77	47	7.30	237	327	0.29	6.77
9/6/77	20	7.85	232	427	0.28	6.76
9/27/77	2450	8.12	177	360	0.30	

Date	*Sul/-fate (mg/l)*	*Solids (mg/l)*		*Pbospborus (mg/l)*		*Alu-minum (mg/l)*
		Total	*Diss.*	*Total*	*Diss.*	
8/11/77	48.4	2206	440	1.93	0.08	8.97
8/17/77	24.2	3446	546	11.41	0.45	1.63
8/22/77	70.5	3446	452	9.04	0.41	1.05
8/30/77	62.5	5566	440	12.94	0.47	5.45
9/6/77	60.8	5762	462	9.68	0.57	0.82
9/27/77	10.8	38488	360	0.23	0.05	29.80

Table 7. Water Quality Characteristics, Bluff Lake, Bay Surface and Interface (Station 2)

Date	*Trans-parency (inches)*	*bidity (FTU)*	*pH*	*Alka-linity (mg/l)*	*Hard-ness (mg/l)*	*Ni-trate (mg/l)*	*Ammo-nia (mg/l)*
Bay surface							
8/11/77	33	68	7.80	174	307	0.11	0.72
8/17/77	30	10	8.30	182	327	0.11	1.47
8/22/77	18	16	8.35	182	273	0.10	0.04
8/30/77	18	19	8.70	162	307	0.18	0.02
9/6/77	24	10	8.70	187	360	0.04	0.12
9/27/77	9	25	8.37	187	313	0.12	0.68
Bay interface							
8/11/77		174	7.90	174	273	0.08	0.67
8/17/77		417	7.60	192	333	0.26	1.52
8/22/77		30	7.70	179	320	0.12	0.50
8/30/77		1092	8.60	197	300	0.14	0.04
9/6/66		2156	8.60	182	353	0.02	0.07
9/27/77		41	8.50	298	313	0.15	0.45

Date	Sul-*fate (mg/l)*	*Solids (mg/l)*		*Phosphorus (mg/l)*		*Alu-minum (mg/l)*	*Algae (counts/ml)*
		Total	*Diss.*	*Total*	*Diss.*		
Bay surface							
8/11/77	70.7	2176	304			0.34	620
8/17/77	67.2	386	286	0.15	0.04	0.06	2720
8/22/77	64.1	384	272	0.28	0.02	0.03	3610
8/30/77	61.4	484	390	0.04	0.03	0.02	3320
9/6/77	66.1	484	418	0.16	0.02	0.03	670
9/27/77	61.2	492	352	0.22	0.08	0.03	2050
Bay interface							
8/11/77	58.9	954	370	2.44	1.68	2.26	
8/17/77	44.2	1322	468	1.98	0.08	0.99	
8/22/77	69.5	616	488	0.52	0.03	0.14	
8/30/77	66.0	1122	384	0.91	0.03	0.38	
9/6/67	65.3	592	436	0.36	0.05	0.07	
9/27/77	64.1	530	350	47.51	1.86	0.08	

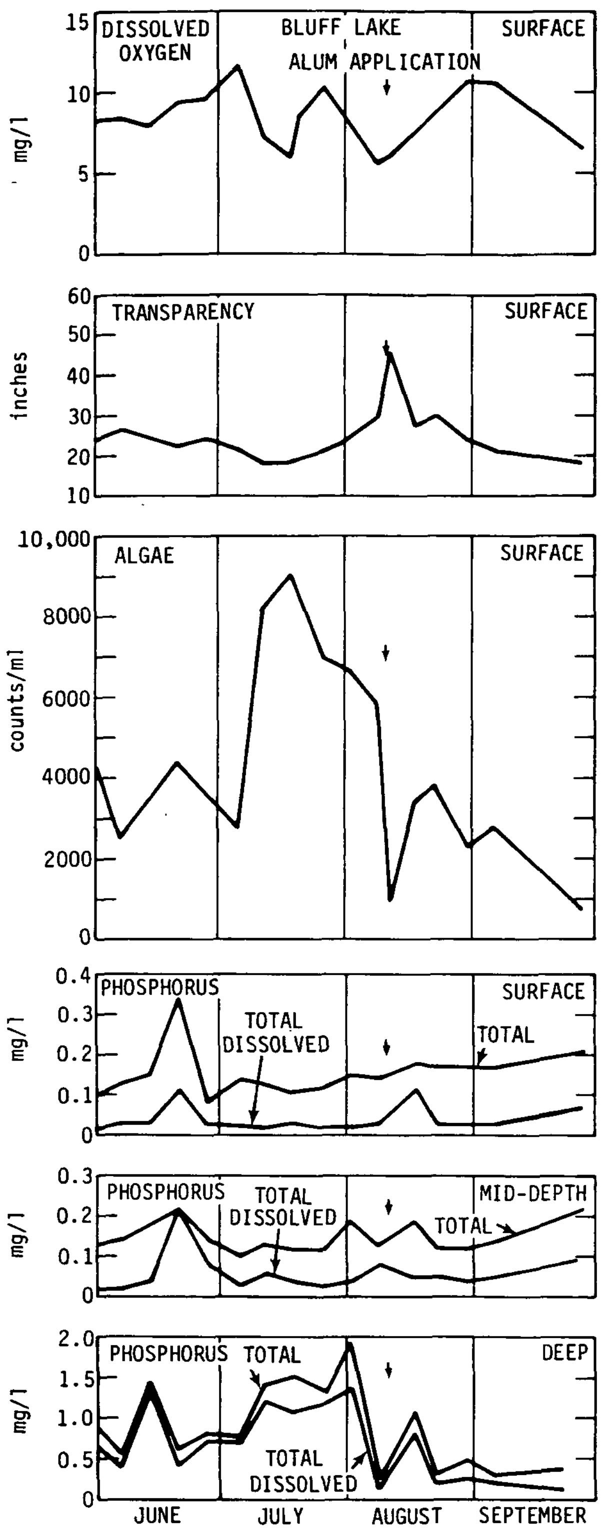

Figure 11. Bluff Lake water quality characteristies

(figure 11), aesthetic conditions in the lake did not improve except during a very short period after the alum application. However, a comparison of the algal densities with those observed in Bluff Lake for the year 1975 (Kothandaraman et al., 1977) indicates that an algal bloom of the magnitude that occurred in mid-September 1975 did not recur in September 1977.

The total and dissolved phosphorus levels in the surface and mid-depth samples did not change. However, a marked drop in total and dissolved phosphorus levels was observed in the deep water samples after alum treatment. The pretreatment average values for these parameters were 1.03 mg/l for total phosphorus and 0.83 mg/l for dissolved phosphorus. The posttreatment values for total and dissolved phosphorus were 0.58 and 0.31 mg/l, respectively.

No changes other than normal perturbances resulted from the alum treatment in the other water quality characteristics observed: turbidity, alkalinity, hardness, nitrate, ammonia, sulfate, and solids. Even the sulfate concentrations and pH values were unaffected by the treatment. The isothermal plots and the iso-dissolved oxygen concentration curves (figures 12 and 13) are similar to those for the corresponding period in 1975 (Kothandaraman et al., 1977).

The beneficial effects of alum treatment in Bluff Lake did not last for any appreciable length of time, in contrast to the experiences reported for other water bodies (Funk et al., 1977; Peterson et al., 1973; Shannon et al., 1974). Unlike the other water bodies that received alum treatment, Bluff Lake is part of a large system of lakes and is subjected to intensive recreational boating activities. On the basis of this investigation, it is concluded that nutrient inactivation as an interim means of lake restoration is not applicable to the lakes of the Fox Chain.

CHEMICAL TREATMENT IN MINEOLA BAY (FOX LAKE)

Materials and Methods

Copper sulfate was used as a chemical means of controlling algae in Mineola Bay of Fox Lake. The chemical was applied on a contractual basis by Midas Midwest, Inc., a company authorized by the State of Illinois to apply algicides, herbicides, pesticides, etc. The dry feed technique was employed for this purpose.

The application device, shown in figure 14, consists essentially of a 4-inch diameter polyvinyl chloride pipe with an enlarged bell-mouthed entry. Near the front end of this pipe, a vertical pipe is joined by a 4-inch "T" joint. Copper sulfate powder is hand-dispensed through this vertical pipe. The system is attached to two pipes with ends sealed, one on each side of the chemical feed pipe, to enable it to float in water. The whole system, which is portable, is mounted on one side of a work boat with the bell-mouthed end pointing in the direction of motion. The forward motion of the boat draws the lake water through the applicator, where it mixes with the chemical. The copper sulfate solution is discharged over the water surface from the rear end of the applicator.

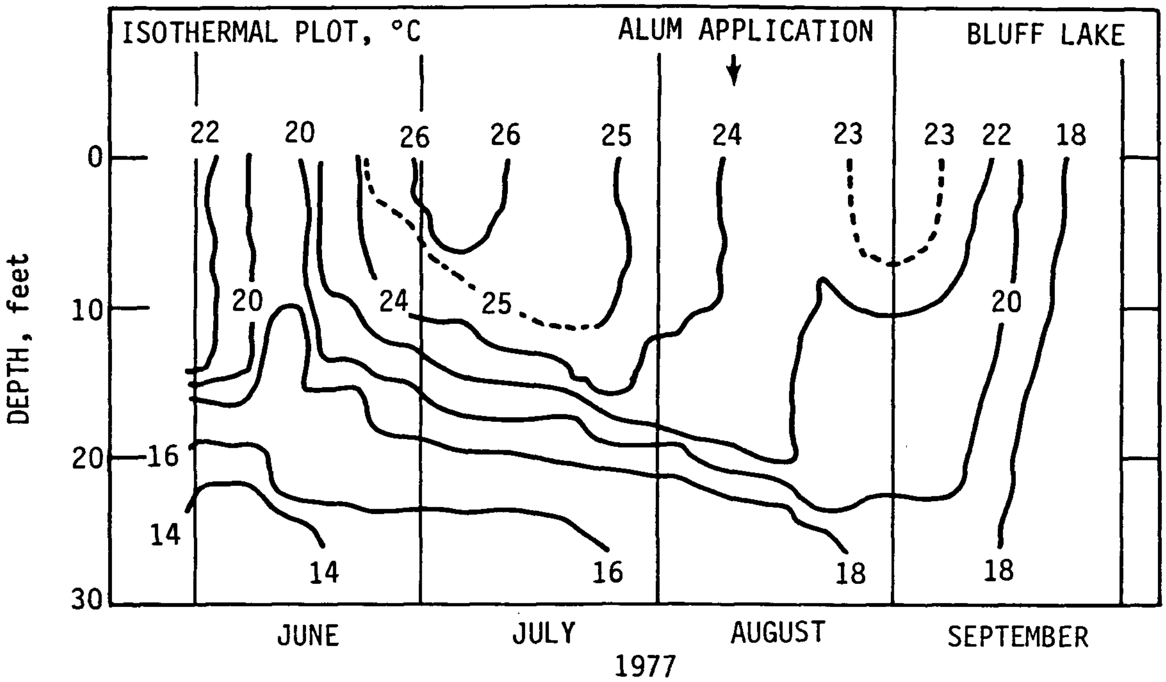

Figure 12. Isothermal plots for Bluff Lake

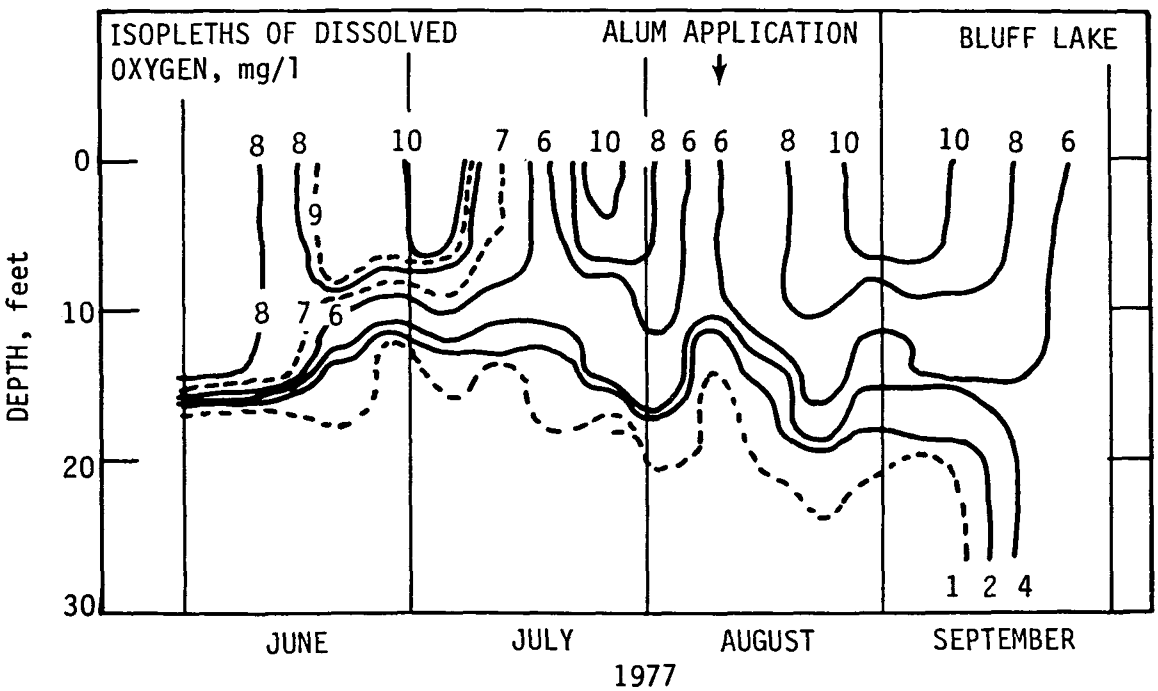

Figure 13. Iso-dissolved oxygen concentration curves for Bluff Lake

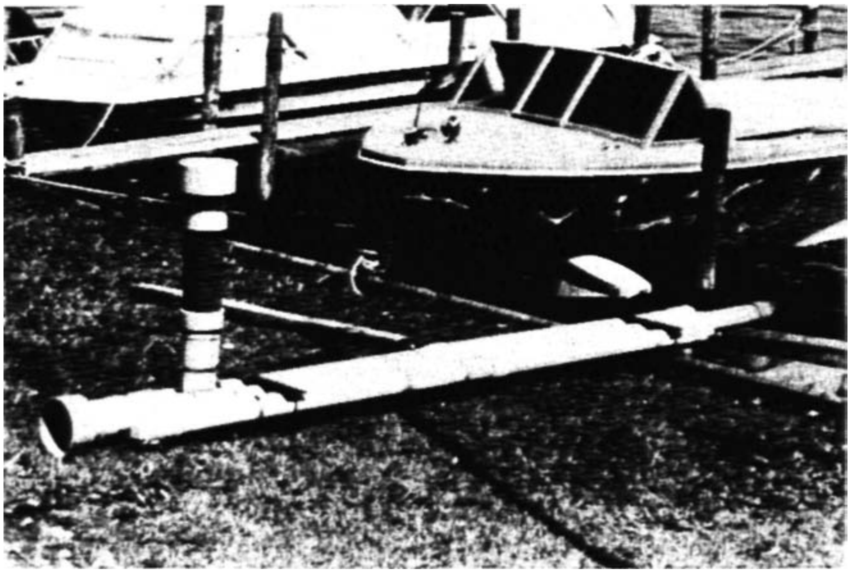

Figure 14. Copper sulfate application device

Copper sulfate was applied to the bay at the rate of 5.4 pounds per acre, which is equivalent to a dosage rate of 1 mg/l to the top 2 feet of the lake waters. The chemical was applied on three calm, sunny days - June 2, June 27, and July 19, 1977. Applications commenced at about 7 a.m. and lasted for about 3 hours.

A total of 1100 pounds of copper sulfate was applied on each occasion. The entire shoreline of the bay was treated, after which the copper sulfate was applied by criss-crossing the bay.

Soon after the completion of each chemical treatment, water samples for copper analysis were collected from the 8 locations shown in figure 15. Water samples were also collected from each of these locations on the following day. The results are shown in table 8. Except near the open waters of the bay, an average copper concentration of about 0.13 mg/l (as Cu^{++}) was observed on the days of chemical treatment. On days subsequent to chemical treatment, copper concentrations decreased to the limits of detectability. The mud-water interface samples obtained on three occasions did not show any significant increase of copper accumulation in the lake bottom. Change in color of the periphytic algal growth along the shoreline from green to whitish gray was observed after the chemical treatment.

Pretreatment and posttreatment water quality characteristics in Mineola Bay were monitored on a weekly basis starting May 16, 1977. Station 2 in figure 15 was used as the regular water sample collection site. In-situ observations, water sampling methods, and chemical analyses were the same as for Bluff Lake except that analysis for aluminum was replaced by copper analysis.

In addition to the Mineola Bay samples, water samples were collected and in-situ observations were made at an untreated part of Fox Lake adjacent to Mineola Bay. The depth of water at this location was about 5 feet, comparable to the regular sampling site in Mineola Bay. The results were treated as a control for comparison with the results of the copper sulfate treatment in Mineola Bay.

Results

Appendix B presents data on temperature, dissolved oxygen, and algal types and density for Mineola Bay and the Fox Lake control station. Water quality characteristics of these areas are shown in tables 9 and 10. Figures 16 and 17 depict the temporal variations in the parameters that were significantly impacted by the chemical treatment. From figure 16, it can be seen that copper concentrations varied from 0.06 to 0.20 mg/l on the days of copper sulfate application at the regular sampling station in Mineola Bay. On the following days it varied from 0.04 to 0.9 mg/l. On all other days the copper concentrations were either not detectable or at the threshold level of detectability.

The algal counts in Mineola Bay dipped significantly after each chemical treatment; however, they increased immediately thereafter. This is most likely because of the intermixing of the bay waters and the main lake caused by wind and wave action. The Mineola Bay algal counts were generally lower than those for the Fox Lake control station.

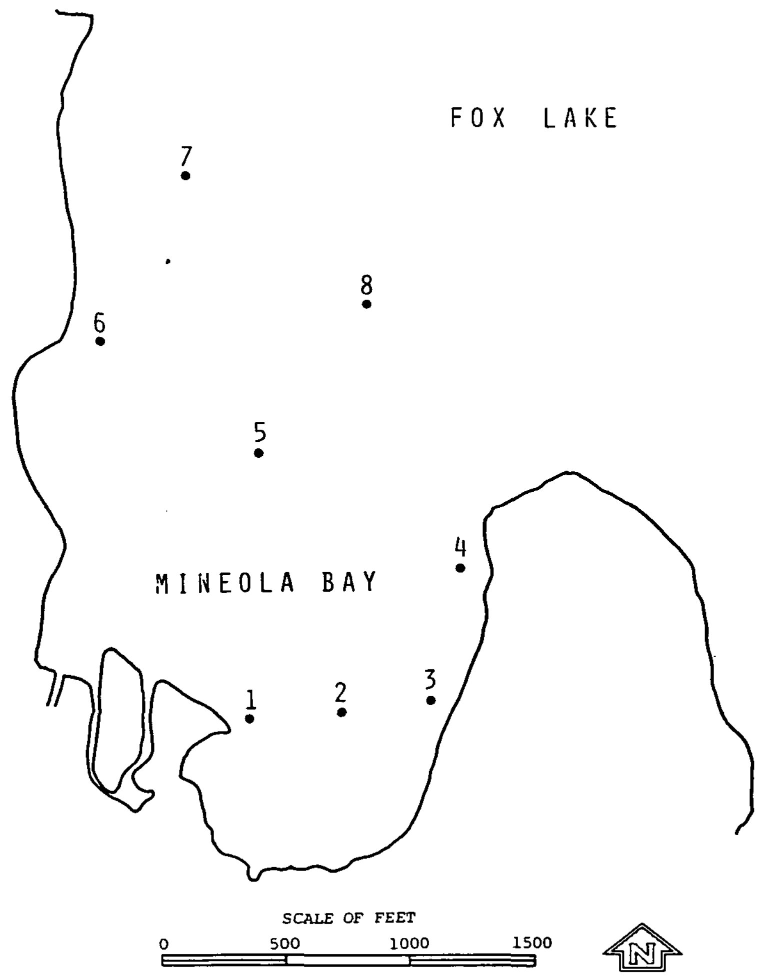

Figure 15. Sampling sites for copper analysis soon after copper sulfate application to Mineola Bay

Table 8. Copper Concentrations in Surface Samples, Fox Lake, Mineola Bay, after Copper Sulfate Application

Station	*Soon after appli-cation 6/2/77*	*Day after appli-cation 6/3/77*	*Soon after appli-cation 6/27/77*	*Day after appli-cation 6/28/77*	*Soon after appli-cation 7/19/77*	*Day after appli-cation 7/20/77*
1	0.12	0.06	0.12	<0.03	0.11	<0.04
2	0.12	0.09	0.20	0.04	0.06	<0.04
3	0.24	0.06	0.07	0.04	0.07	<0.04
4	0.16	0.06	0.09	0.03	0.13	0.29
5	0.04	<0.04	0.11	0.04	0.04	0.06
6	0.04	<0.04	0.06	0.04	0.18	<0.04
7	0.04	<0.04	0.04	<0.03	0.18	<0.04
8	0.04	<0.04	<0.03	<0.03	0.04	<0.03
2*		0.08		0.06		0.12

• *Mud-water interface samples at Station 2*

Table 9. Water Quality Characteristics, Fox Lake, Mineola Bay

Date	Transparency (inches)	Turbidity (FTU)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)
5/16/77	27	7	8.37	177	278	0.12	0.06
5/23/77	18	20	8.25	187	209	0.16	0.43
5/31/77	12	20	8.65	179	352	0.16	0.11
6/2/77	12						
6/3/77	12						
6/6/77	9	2	8.42	174	199	0.30	0.21
6/13/77	9	23	8.55	202	272	0.22	0.12
6/20/77	9	26	8.67	210	258	0.22	0.15
6/27/77	12	16	8.77	207	179	0.15	0.12
6/28/77	18	11	8.67	215	126	0.18	0.17
7/5/77	12	17	8.25	205	172	0.18	0.78
7/11/77	9	24	8.50	220	159	0.14	0.14
7/18/77	6	30	8.00	194	467	0.16	0.22
7/20/77	11						
7/26/77	10	24	8.70	194	113	0.13	0.09
8/1/77	6	24	8.70	202	307	0.16	0.28
8/8/77	6	29	8.40	217	320	0.14	0.28
8/17/77	9	34	8.40	197	373	0.14	0.63
8/22/77	9	26	8.20	197	273	0.16	0.03
8/30/77	9	9	8.20	197	293	0.13	0.09

Date	Sulfate (mg/l)	Solids (mg/l) Total	Solids (mg/l) Diss.	Phosphorus (mg/l) Total	Phosphorus (mg/l) Diss.	Copper (mg/l)	Algae (counts/ml)
5/16/77	83.0	405	375	0.13	0.07	ND	2160
5/23/77	79.0	408	387	0.21	0.08	ND	1960
5/31/77	81.8	368	238	0.25	0.03	ND	3770
6/3/77							2860
6/6/77	79.1	612	456	0.21	0.04	ND	4330
6/13/77	81.6	544	472	0.39	0.15	ND	3690
6/20/77	77.8	466	394	0.39	0.17	0.04	3860
6/27/77	78.1	344	246	0.23	0.09	ND	2880
6/28/77	74.0	360	240	0.29	0.12	ND	440
7/5/77	73.9	480	388	0.28	0.13		3530
7/11/77	73.6	392	380	0.31	0.13	0.04	6060
7/18/77	66.2	668	400	0.34	0.15	ND	5870
7/20/77							3570
7/26/77	66.4	508	364	0.47	0.17	ND	
8/1/77	69.5	490	376	0.49	0.17	ND	2020
8/8/77	71.3	500	360	0.34	0.16	0.04	2180
8/17/77	66.9	474	466	0.36	0.14	ND	870
8/22/77	59.8	404	374	0.28	0.11	0.05	3430
8/30/77	60.0	466	428	0.28	0.14	ND	140

Note: Copper sulfate was applied on 6/2, 6/27, and 7/19; ND = Not detectable, <0.03

Table 10. Water Quality Characteristics, Fox Lake, Control Station

Date	Trans-parency (inches)	Tar-bidity (FTU)	pH	Alka-linity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Ammo-nia (mg/l)
6/2/77	12						
6/3/77	6						
6/6/77	9	2	8.42	174	199	0.30	0.21
6/13/77	9	25	8.35	202	258	0.19	0.58
6/20/77	6	26	8.67	210	258	0.22	0.15
6/27/77	9	23	8.70	207	159	0.20	0.17
6/28/77	12	16	8.78	215	126	0.18	0.04
7/5/77	9	24	8.40	202	212	0.13	0.17
7/11/77	9	23	8.60	202	146	0.13	0.09
7/18/77	5	37	8.05	192	453	0.21	0.05
7/26/77	9	33	8.40	197	133	0.14	0.06
8/1/77	6	29	8.60	202	300	0.16	0.07
8/8/77	4	33	8.40	225	360	0.14	0.12
8/17/77	9	42	8.40	197	327	0.15	0.04
8/22/77	6	27	8.30	202	327	0.15	0.02
8/30/77	9	21	8.45	197	267	0.14	0.00

Date	Sul-fate (mg/l)	Solids (mg/l) Total	Solids (mg/l) Diss.	Phosphorus (mg/l) Total	Phosphorus (mg/l) Diss.	Copper (mg/l)	Algae (counts/ml)
6/2/77							3770
6/6/77	79.1	612	456	0.21	0.04	ND	4780
6/13/77	76.7	556	246	0.31	0.06	ND	3890
6/20/77	77.8	466	394	0.39	0.17	0.04	2230
6/27/77	79.2	472	248	0.40	0.16	ND	2780
6/28/77	78.0	390	251	0.25	0.08	ND	2290
7/5/77	72.6	434	394	0.26	0.07		4500
7/11/77	71.5	430	416	0.31	0.11	0.04	9140
7/18/77	70.4	512	406	0.45	0.18	ND	4110
7/26/77	37.0	538	406	0.66	0.13	ND	2000
8/1/77	76.2	464	400	0.52	0.17	ND	1740
8/8/77	76.0	522	364	0.36	0.11	0.04	3010
8/17/77	71.4	548	452	0.45	0.14	ND	680
8/22/77	66.8	430	302	0.38	0.18	0.05	3490
8/30/77	62.3	470	418	0.29	0.13	ND	220

Note: Interface copper concentration <0.03; ND = Not detectable, <0.03

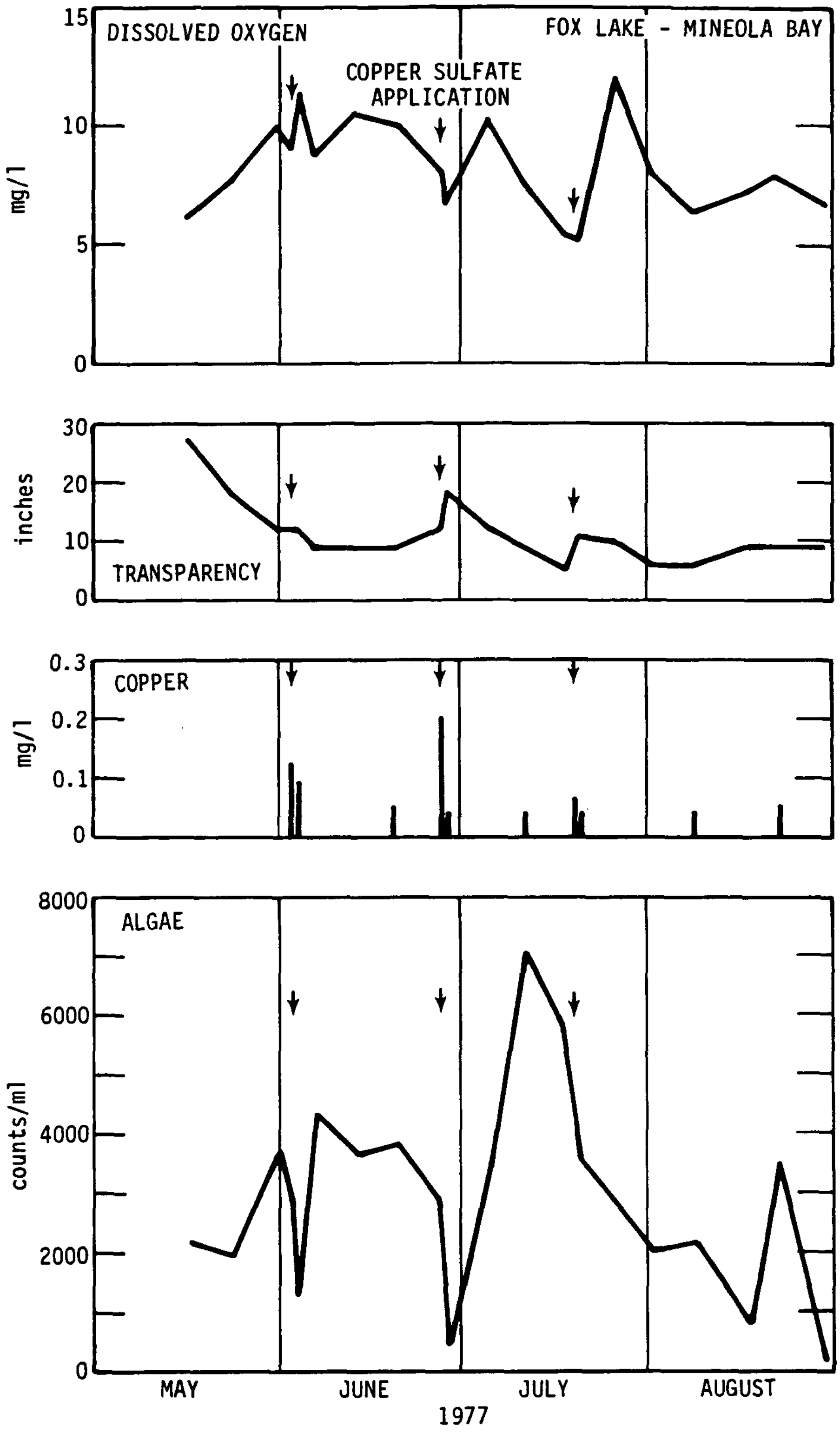

Figure 16. Water quality chavaoteristios, Fox Lake, Miveola Bay

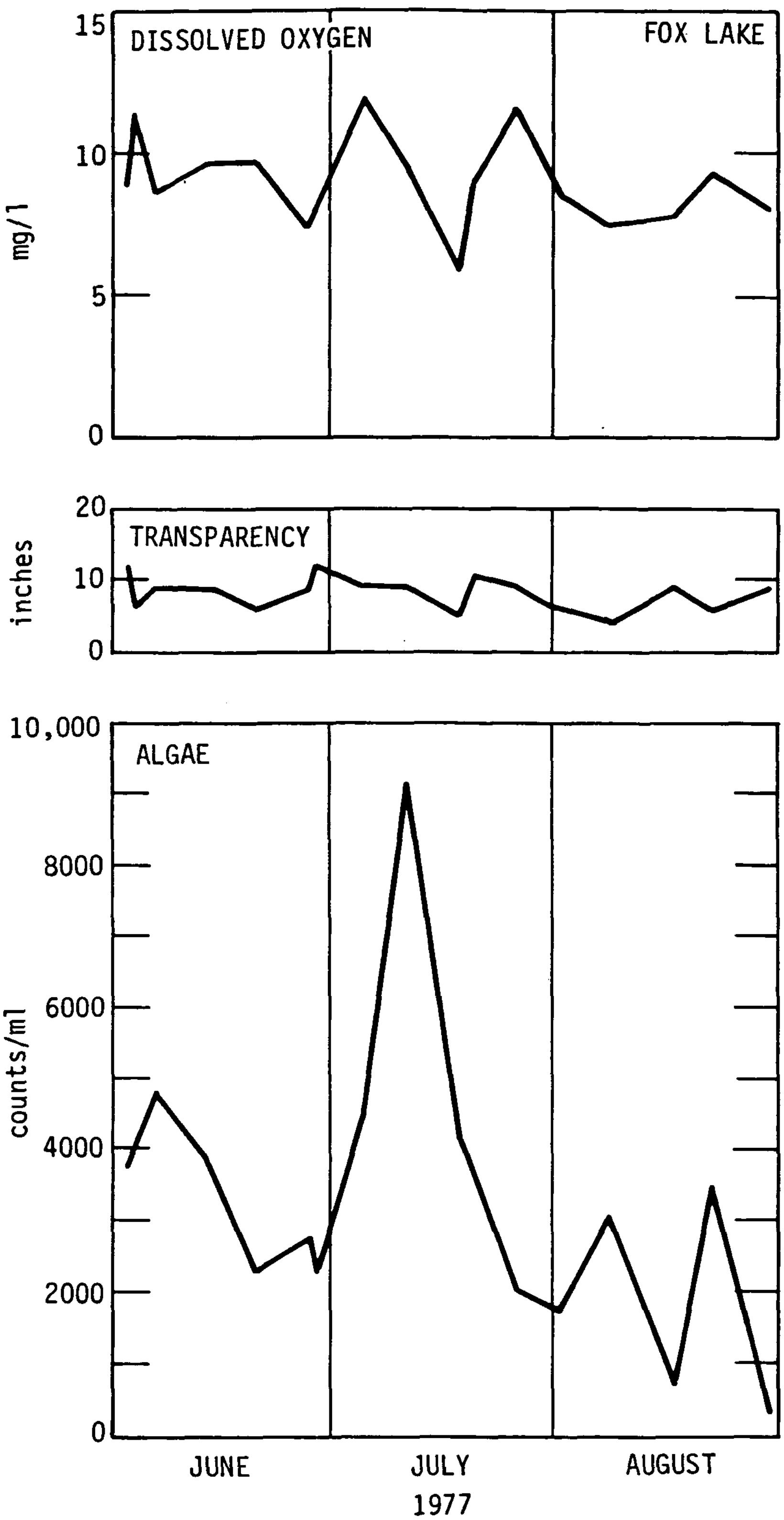

Figure 17. Water quality characteristics, Fox Lake, control station

Secchi disc transparency values did not show any differences between the treated and untreated portions of the lake. Temporal variations in surface dissolved oxygen concentrations were similar in magnitude and pattern (figures 16 and 17). Temperature and dissolved oxygen profiles shown in figure 18 for the two sampling sites indicate that the lake is isothermal and that during the summer months (June and July) the lake sediments exert a higher oxygen demand than is replenished from the atmosphere.

There were no perceptible differences in the other water quality parameters (pH, alkalinity, hardness, nitrate, ammonia, sulfate, solids, and phosphate) between the treated and untreated water bodies, other than the normal spatial and temporal deviations.

The chemical treatment in Mineola Bay did not prove to be an unqualified success. As with Bluff Lake, it was discovered that chemical control in a small portion of the lake system is ineffective because of the interconnection of the Chain's waters.

AERATION, DESTRATIFICATION, AND CHEMICAL TREATMENT IN LAKE CATHERINE

Background

Artificial destratification and hypolimnetic aeration are processes by which lake waters are oxygenated and circulated. This is generally accomplished either by mechanical pumping (Symons, 1969; Steichen, 1974) or by compressed air released at the lake bottom (Fast, 1971; Smith et al., 1975; Symons, 1969; New England Regional Commission, 1971, 1973a, 1973b). 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 lake waters down to the hypolimnetic zone to destratify and oyxgenate the anoxic zone.

In compressed air destratification, the rising air mass generates vertical water currents that 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, sinking 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 destratification, several types of aeration devices have been designed that oxygenate the hypolimnetic waters without disrupting thermal stratification. Typically such an 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.

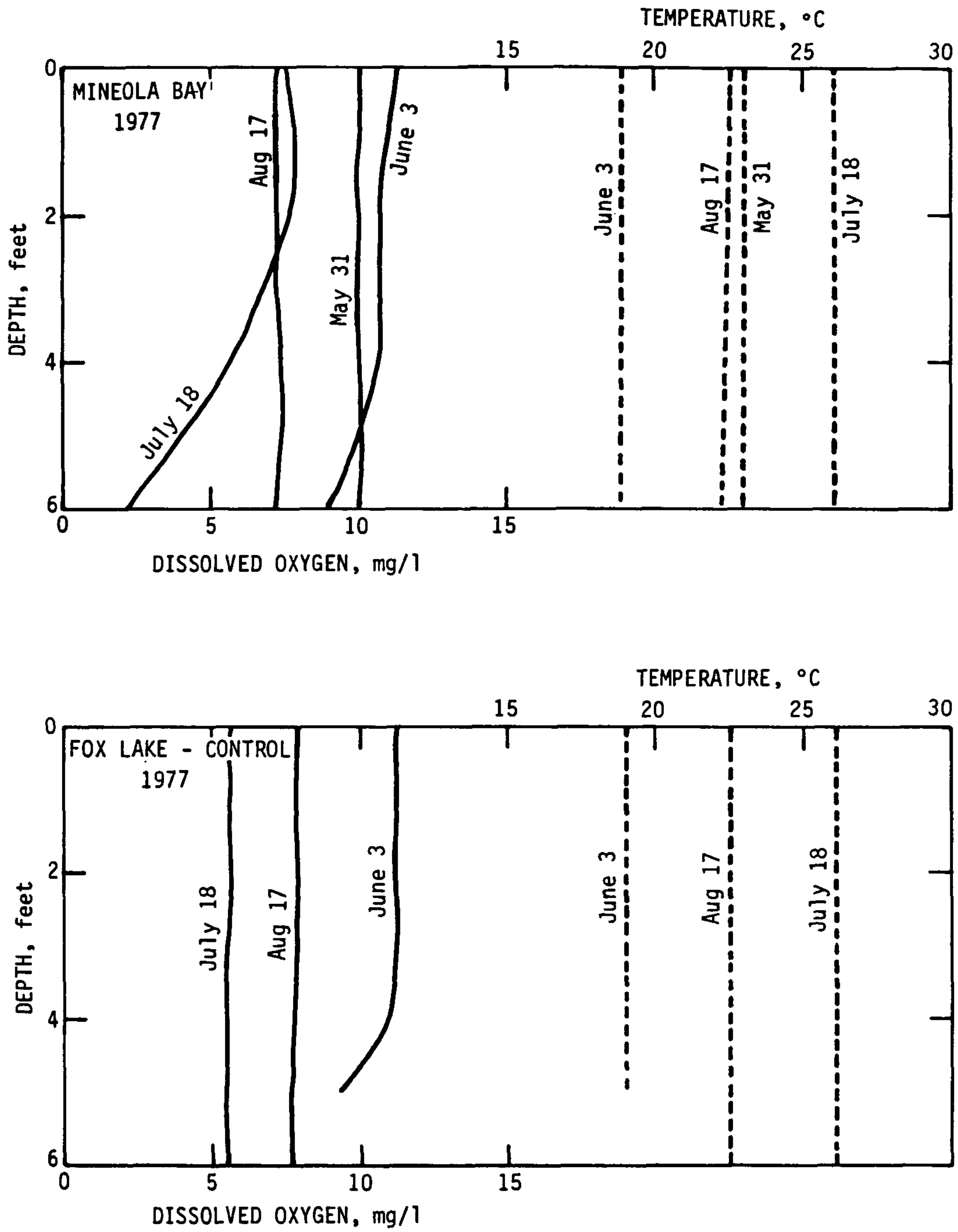

Figure 18. Temperature and DO profiles in Fox Lake

In addition to the oxygenation of the hypolimnetic waters of the deep lakes of the Fox Chain by total destratification, the control of algal blooms was a major consideration during this investigation. Control of nuisance blue-green algal blooms was deemed successful in Kezar Lake in Sutton, New Hampshire, with destratification by compressed air (New England Regional Commission 1971, 1973a, 1973b). Since cold water fisheries are insignificant in the Fox Chain, an increase in water temperature in the hypolimnetic zone due to total destratification is of minor consequence in this regard.

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, the anaerobic release of nutrients from the bottom sediments is reduced.
- Oxidation of reduced 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 the reduction in surface water temperatures.
- Water clarity increases.
- Winter fish kills may be prevented by the maintenance of sufficient oxygen levels under ice.

The disadvantages of artificial destratification include:

- The heat budget in the lake is increased.
- Water turbidity increases temporarily as a result of resuspension of bottom sediments.
- Artificial destratification may induce foaming.
- The oxygen demand of resuspended anaerobic mud may result in a decrease in oxygen concentrations, at least temporarily, that may kill fish.

Beginning in 1978, the efficacy of employing total destratification was investigated in Lake Catherine. Channel Lake, which is adjacent to and connected with Lake Catherine, was used as a control for comparative purposes. Both lakes stratify thermally during summer months, and water strata below the 15- to 18-foot level are devoid of dissolved oxygen. The morphometric details for the two lakes are shown in table 11.

Table 11. Morphometric Details, Lake Catherine and Channel Lake

Parameters	*Lake Catherine*	*Channel Lake*
Normal lake elevation, *msl*	736.5	736.5
Volume, *acre-feet*	2460	4370
Surface area, *acres*	147	320
Mean depth, *feet*	16.7	13.7
Maximum depth, *feet*	39	35
Normal lake length, *feet*	4200	7800
Normal lake width, *feet*	2200	2800
Length of shoreline, *miles*	1.84	3.37

Materials and Methods

Aeration and Destratification

After compiling cost data regarding lake aeration and destratification, the U.S. Environmental Protection Agency (1973) reported that 90 percent of the respondents they surveyed used compressed air devices for aeration and only 4 percent used mechanical pumps. Initially, a compressed air system was considered for Lake Catherine. Since the lake shore is completely developed for year-round residence, the noise associated with compressor operation was of major concern. For this reason a compressed air system was not selected. Because the base of operation for this investigation was located in Peoria, about 190 miles from the work site, a system with minimal maintenance requirements was necessary to carry out the investigation successfully. A raft-mounted pump system for destratification purposes was ruled out, as it would create a serious recreational hazard in the middle of the lake, which is extensively used for boating, waterskiing, and other water-based recreational activities.

A destratification system developed by the Aquatic Environmental Controls Company (AECC), based in Newberry Springs, California, was chosen for the Lake Catherine project. The system consists essentially of a submersible pump (a six-stage Berkley Pump with a rated capacity of 200 gpm at 100 psi driven by a 15-hp, 3-phase, 60-cycle motor) and the AECC destratification unit. The details of the unit are shown in figure 19. The device operates on the Venturi principle. The discharge from the submersible pump is directed through a constriction created by the primary cone shown in figures 19 and 20. The increased velocity created at the constriction causes a negative pressure to develop at the throat. Because of the negative pressure, air is drawn from the atmosphere through air hoses attached to the air induction nipples (figure 19) and extending above the water surface. A 3-inch PVC pipe nozzle is attached to the discharge end of the AECC unit. The assembly of the submersible pump and AECC unit with the nozzle is mounted on a skid with a variable pitch mounting system so the angle of inclination of the assembly can be varied within limits. Figure 21 shows the aerator completely assembled, with the free ends of the air hoses visible.

The aerator system selected and used in Lake Catherine is extremely quiet during operation. The reliability of submersible pump engineering has provided a trouble-free and maintenance-free operation. The system creates only one minor obstruction: the warning buoy, shown in figure 22, used to support the free ends of the two air hoses. The buoy carries a photosensitive warning light which turns on at night. Thus the chosen aeration device, which combines mechanical pumping and bubbling of air, has met all the criteria outlined for a destratification system for Lake Catherine.

Installation of the device involved placing the unit on the bottom of the lake in 28 feet of water, about 750 feet from the southern end of the lake. The first 300 feet of power cable extending from the shoreline were encased in galvanized pipe to protect the cable in the shallow portion of the lake from possible damage by boat traffic. Figure 23 shows the location of the aeration device in Lake Catherine. Figure 24 shows the relative positions of the aerator, buoy, power cable, power transformers, and control panel.

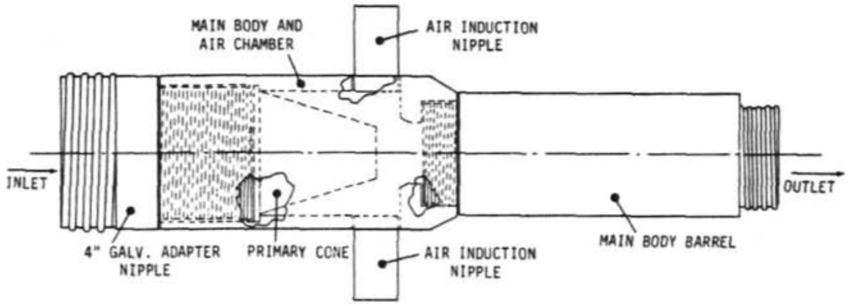

Figure 19. Details of Aquatic Environmental Controls Company aeration-aestratification unit

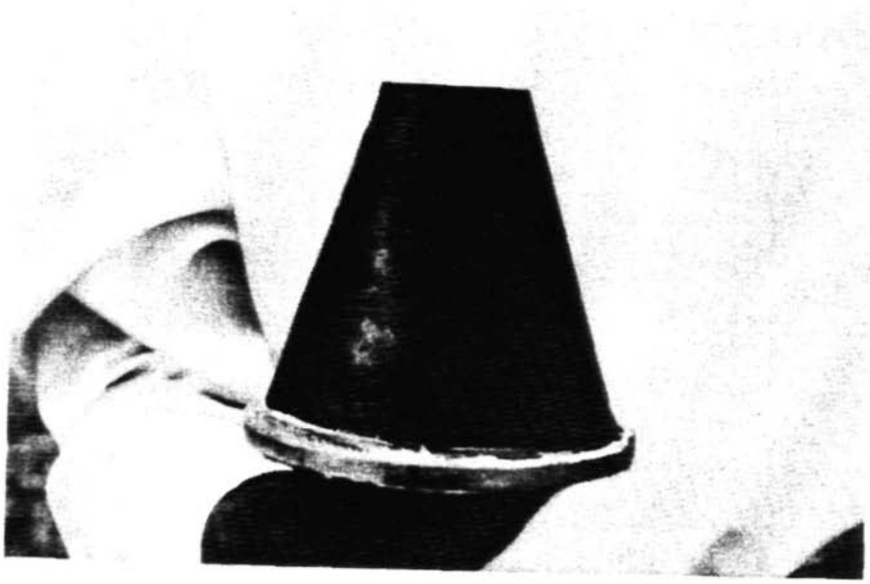

Figure 20. Primary cone of the AECC unit

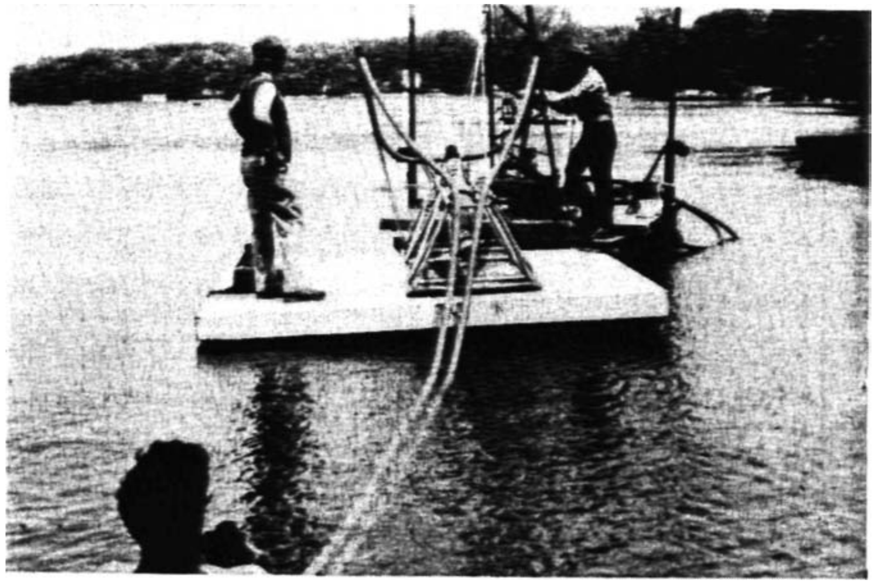

Figure 21. View of the aerator, with the free ends of the air hoses visible in the foreground

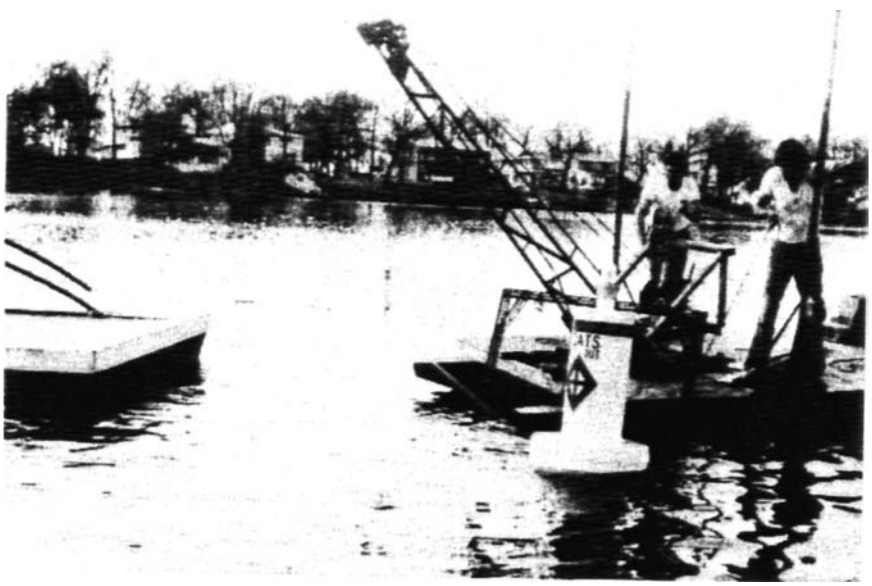

Figure 22. The aeration device and the buoy used to support the free ends of the air hoses

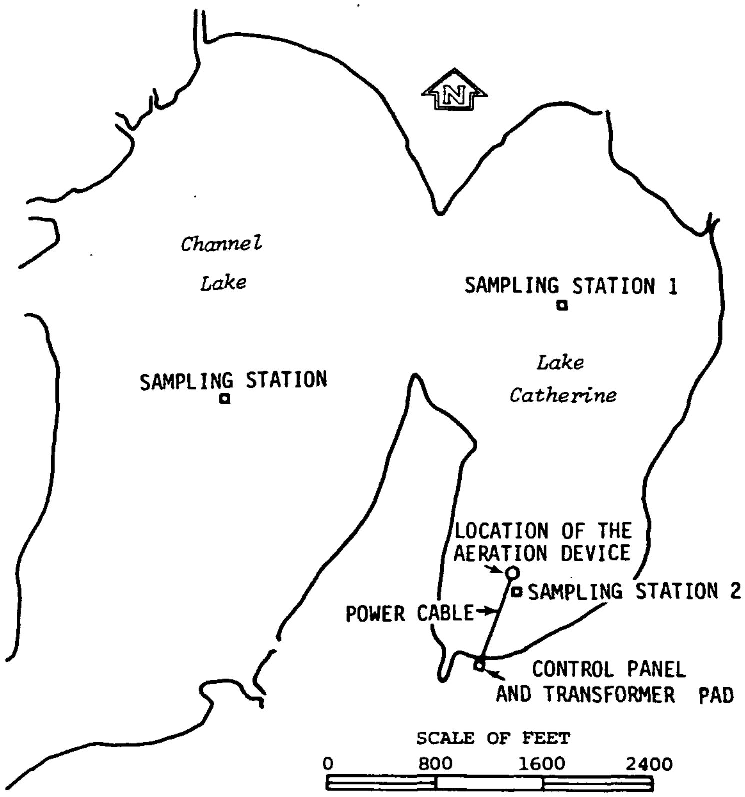

Figure 23. Location of the aeration device and sampling stations, Lake Catherine

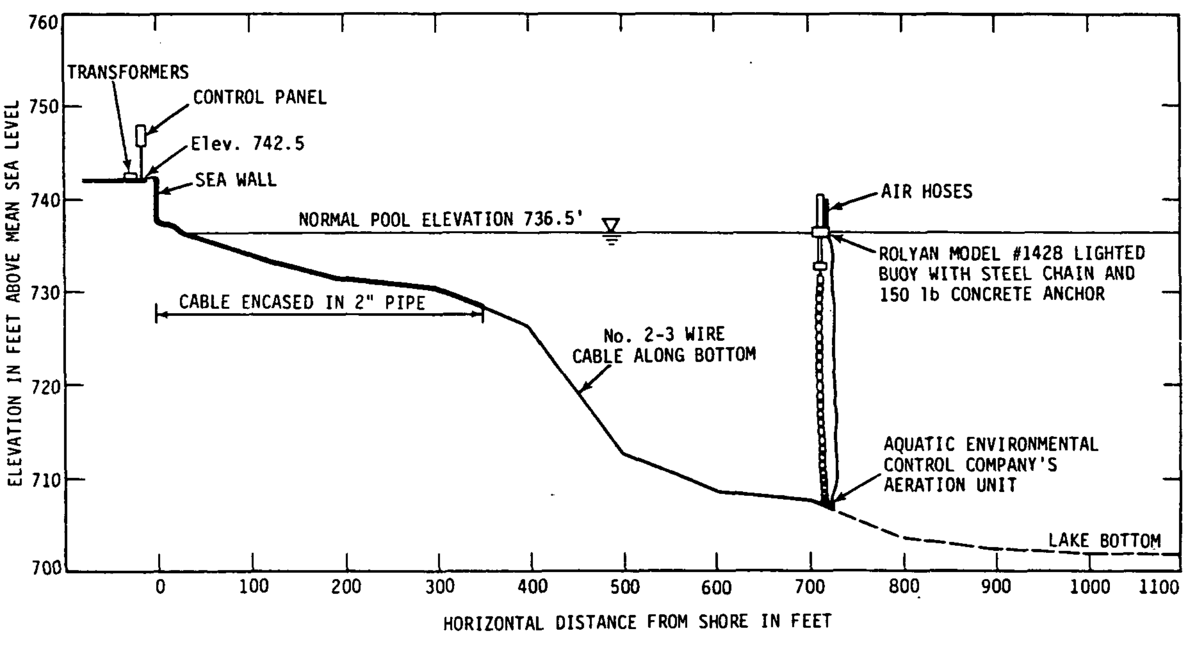

Figure 24. Sectional elevation along the power cable for the aeration unit in Lake Catherine

During the laying of the power cable on the lake bottom, the cable spool was supported by two cantilevered wooden beams anchored to a work barge, as shown in figures 25 and 26. About 325 feet of the cable were stretched out on the shore, and 2-inch galvanized pipes were slipped over the cable. Each pipe was supported on a tractor inner tube and secured temporarily with nylon cord. As each pipe was slipped over the cable, the previously completed pipe sections were floated out into the lake (figure 27). In all, 14 pipe sections were used, encasing about 300 feet of the cable. The pipe-encased cable was floated to its designated location and the inner tubes were cut loose, dropping the pipe-encased cable to the lake bottom. The remaining length of cable was then reeled out into the lake. After completion of the necessary power connections to the submersible pump, the aerator system was installed on the lake bottom by a crane mounted on a work barge (figure 28). The aerator was installed pointing in the northerly direction.

1978. The aerator began operating on May 18, 1978. Several inadequacies in the system soon became apparent. The unit did not develop adequate vacuum and consequently the air draw through the air hoses was less than satisfactory. Also, the polyethylene air hoses supplied with the equipment crimped, thus restricting, and at times completely shutting off, air flow when the buoy bobbed up and down. All of these inadequacies were rectified, and the system began satisfactory operation on July 6, 1978. The aerator was operated continuously thereafter until it was shut down on October 4, 1978. There were only four brief storm-related power failures resulting in brief interruptions in the operation of the aerator during this period,

1979. The aeration-destratification study in Lake Catherine was continued for the second year in 1979. Prior to the resumption of aerator operation in 1979, an attempt was made to relocate the aerator at greater depth than in 1978. The power cable was spliced to extend its length an additional 300 feet, and the aerator was relocated at a depth of 34 feet. Soon it was found that the lake bottom was too soft to sustain the weight of the aerator without causing it to settle unevenly. Subsequently, the bearing area of the mounting skid on which the aerator is carried was increased by inserting four 2-inch by 12-inch by 10-foot boards under the skid, nearly doubling the bearing area. The increase in bearing area distributed the weight of the aerator adequately over the soft lake bottom and prevented any undue sinking of the aerator.

The aerator resumed operating on May 10, 1979. The vacuum on the air suction hoses was 24.5 inches of mercury, as against 27.5 inches of mercury when the aerator was installed at the 28-foot depth in 1978. Since the amount of air aspirated through the aerator is related to the vacuum developed by the aerator, the amount of air drawn from the atmosphere through the aerator was less than when the aerator was operating at a depth of 28 feet. However, the fine bubble air plume had a longer rise through the water column in 1979 than in 1978. Attempts to measure the air flow through the suction hoses using a rotoflow meter proved futile because of the vigorous pulsating nature of the air flow-through system, which caused the flow meter indicator to oscillate at a very rapid rate between zero and maximum scale readings. As will be discussed later, the location at a 34-foot depth was found unsatisfactory, and the aerator was relocated at the 28-foot depth.

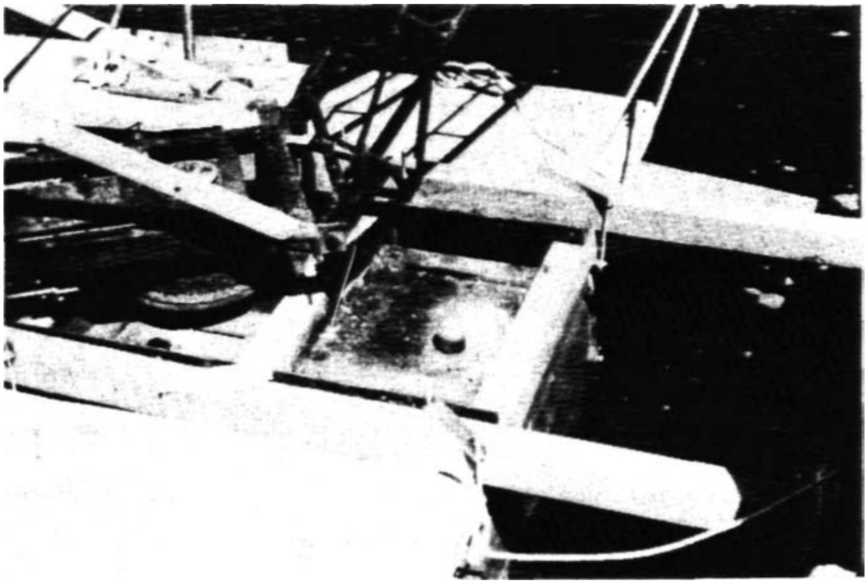

Figure 25. Cantilevered beams anchored to work barge for supporting power cable spool

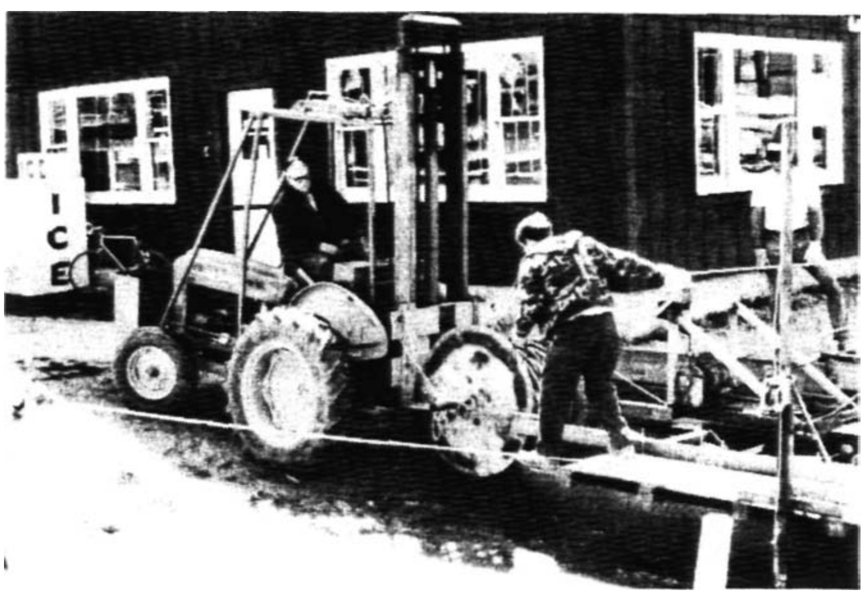

Figure 26. Power cable spool being transferred to the barge

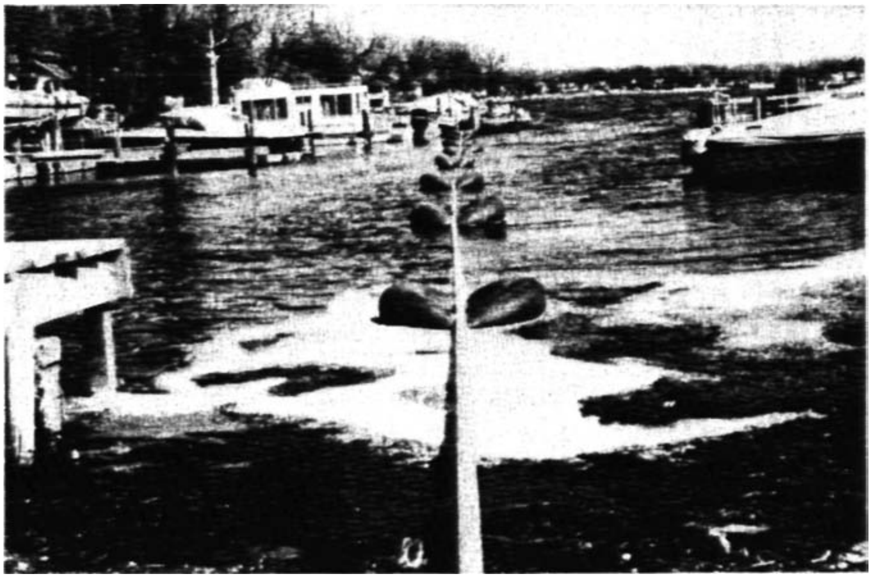

Figure 27. Encased cable supported by inner tubes being transported to cable location

Figure 28. Installation of the aerator in Lake Catherine

1980. The pilot aeration-destratification study was continued for the third year in 1980 with funding from the Illinois Institute of Natural Resources (now the Illinois Department of Energy and Natural Resources). During 1980, the Lake County Health Department, Division of Environmental Health, shouldered the responsibilities for the periodic field sampling, in-situ lake monitoring, in-lake chemical applications, laboratory analyses, and day-to-day operation and maintenance of the aeration system.

When the aerator was reinstalled on May 15, 1980, after winter storage, the system did not develop adequate vacuum. Upon inspection it was found that the air hoses had developed cracks at the places where they were fastened to the short air induction tubes of the aerator body. These cracks had developed because the anchor chain holding the buoy to the anchor block was longer than the air hoses. As a result, the air hoses were subjected to repeated and reversed stress when the buoy bobbed up and down because of the waves created by both wind and high-speed boating activities. The aerator was taken ashore, damaged portions of the air hoses were excised, and the air hoses were reconnected to the aerator. The anchor chain length was readjusted so it was shorter than the air hoses, ensuring that the anchor chain and not the air hoses would take the stress when the buoy bobbed. The aerator developed the normal vacuum of 26 inches of mercury after installation.

Chemical Treatment

The aerator installed in Lake Catherine is capable of dispersing chemicals throughout the lake from a single application point. Chemicals used in lake water quality management, such as copper sulfate and potassium permanganate, can be applied with the aerator by making use of the vacuum created in the AECC unit. With an installation having two air hoses, such as the one at Lake Catherine, one hose can be completely shut off with a gate valve and the other hose immersed in the package containing powdered chemicals (fine powder or granules). The powdery substance is sucked through the hose, mixed with lake water inside the AECC aeration unit, and dispersed into the lake via the upwelling column of air-water mixture. The chemical applied in this way is dispersed throughout the lake in a fairly uniform manner.

1978. A test application of 1000 pounds of copper sulfate was first made in Lake Catherine on August 16, 1978. The amount of chemical used was based on an application rate of 5.4 pounds per surface acre, with 25 percent excess dosage to allow for dilution. A strong southwesterly wind prevailed during the chemical application. The rate of chemical application was controlled by the depth of immersion of the open end of the air hose into the container. Although the application of 1000 pounds of copper sulfate could have been accomplished in 15 to 30 minutes, it was carried out gradually over a period of 3 hours.

1979. During the second year, 1000 pounds of copper sulfate was applied on each of four occasions (June 21, July 5, August 2, and August 23, 1979) with the aid of the aerator. On June 21, the copper sulfate was applied alone, but for the subsequent three copper sulfate applications, citric acid in the ratio of 1 part to every 2 parts of copper sulfate was used as a chelating agent. A slurry of copper sulfate and citric acid was prepared in 55-gallon drums using lake water, and this slurry was then applied with the aerator by immersing one of the air suction hoses in the slurry. Soon after the chemical applications were completed, water samples were collected from seven locations in Lake Catherine (figure 29) in order to examine the distribution of copper in the lake. Water samples were also collected the following day at these seven locations. Samples were collected from the surface and from 5-foot depths at all stations. The samples were immediately acidified with nitric acid for metal preservation. Copper concentrations were determined by atomic absorption procedures.

On July 11, six days after the July 5 copper sulfate-citric acid application, 220 pounds of potassium permanganate was applied. The same amount of potassium permanganate was applied again on August 7, five days after the August 2 copper sulfate-citric acid application. These applications were made primarily to oxidize the decaying algae after copper sulfate application and to avoid possible depression of dissolved oxygen concentration in the lake. Potassium permanganate also is known to have algicidal properties (Carr, 1975). Water samples for manganese analyses were collected soon after each application of potassium permanganate, and again the next day.

<u>1980</u>. During 1980, 1000 pounds of copper sulfate chelated with 500 pounds of citric acid was applied on two occasions (July 8 and August 8). A slurry of copper sulfate and citric acid was prepared in 55-gallon drums using lake water, and this slurry was applied to the lake with the aerator by immersing one of the air suction hoses in the slurry. These copper sulfate applications were followed by applications of potassium permanganate, 150 pounds each, on July 16 and August 12.

Water samples for copper and manganese determinations were collected from each of seven locations in Lake Catherine (figure 29) a few days after chemical applications. Determinations for copper and manganese were performed by atomic absorption procedures as outlined in <u>Standard Methods</u> (APHA, 1980).

Sampling and Analytical Procedures

<u>1978</u>. To evaluate the efficacy of the destratification of Lake Catherine from the standpoint of improvement in water quality, certain physical, chemical, and biological measurements were made on a weekly basis initially and at biweekly intervals during the first year, from July 12, 1978, until the shutdown of the aerator. Data collected in Lake Catherine and Channel Lake during 1977 (Kothandaraman et al., 1978) as a part of pre-aeration data collection efforts were also used in evaluating the performance of the aerator. <u>In-situ</u> observations of temperature, dissolved oxygen, and secchi disc readings were made during each field trip, and samples were collected for chemical and biological evaluations. Figure 23 shows the sampling stations established for Lake Catherine and Channel Lake. These sampling sites were selected at the deepest parts of the lakes. In addition, <u>in-situ</u> observations for DO, temperature, and secchi disc readings were made in the vicinity of the aerator, about 100 feet from the suction side of the unit.

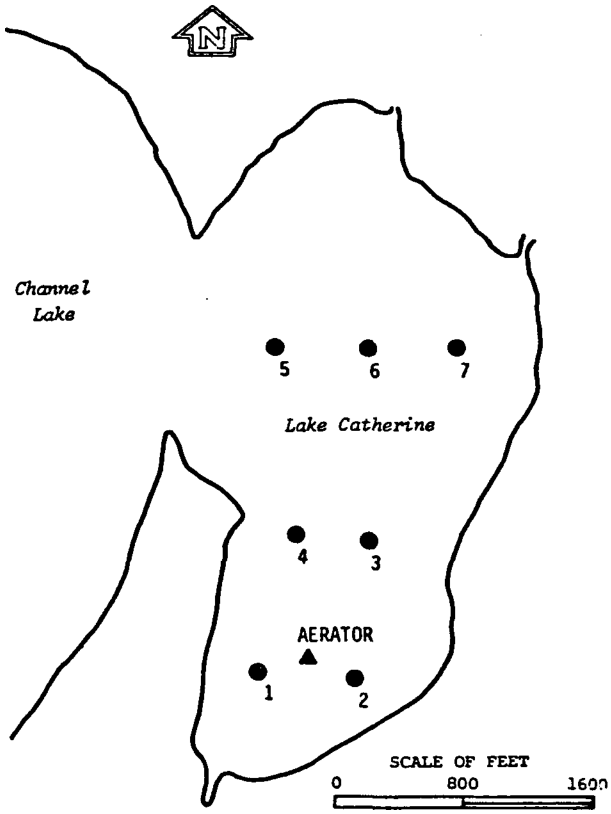

Figure 29. Sampling locations for copper and manganese analyses after copper sulfate and potassium permanganate applications

During the first year of aerator operation in Lake Catherine, the following physical and chemical determinations were made on water samples in the laboratory: turbidity, pH, alkalinity, hardness, nitrate, ammonia, total silica, total iron, total manganese, sulfate, total and dissolved solids, and total and dissolved phosphorus. The methods and procedures involved in these determinations were the same as those described previously in the discussion of the alum application in Bluff Lake (also see table 2). Procedures used in algal identification and enumeration were also the same as those previously described.

Benthic samples were obtained on three occasions (July 2, August 23, and September 20) from the two regular sampling stations of Lake Catherine and Channel Lake and from the vicinity of the aerator. Three grabs with an Ekman dredge (6 x 6 inches) were taken at each station, and the samples were washed in a 30-mesh sieve. The organisms were picked from the bottom detritus, identified and counted, and preserved in 70 percent ethyl alcohol.

Lake bottom sediment samples from the two regular lake sampling stations and from the vicinity of the aerator were collected in conjunction with benthic samples to determine water consistency of the sediments (percent water), and the percent fixed and volatile solids. Consistency was determined by first decanting the supernate from the stored sediment sample and thoroughly mixing the sample. Loss of weight from the wet sample at 103°C overnight, expressed as percent of original weight, was taken as a measure of the consistency of the mud sample. The fixed and volatile solids fractions were determined according to Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al., 1976).

1979. During the second year, the same chemical analyses were carried out as in 1978 except those for solids and manganese determinations. Also, chlorine demand determinations were initiated. Water quality characteristics were monitored at least at biweekly intervals starting May 9, 1979.

In addition, samples for zooplankton identification and enumeration were obtained from station 1 at Lake Catherine and from surface, mid-depth, and deep locations at Channel Lake. Samples were obtained on four occasions at 4-week intervals. A Juday sampler of 5-liter capacity, fabricated in ABS plastic pipe and fittings, was used to haul the required volume of sample from desired depths. The sampler was provided with a rubber stopper which could be released after the sampler reached the desired depth. A 20-liter water sample was filtered through Wisconsin plankton net, and the material retained in the net was washed into a plastic container with deionized water and preserved in 95 percent ethanol.

In the laboratory, the volume of the sample was made up to 200 ml, and a 1-ml aliquot was pipetted into a Sedgwick-Rafter cell. A differential interference contrast microscope was used to identify and enumerate the zooplankton. Five short strips were counted and the results extrapolated.

During 1979, benthic samples were obtained on five occasions at approximately 4-week intervals, beginning on May 22. The samples were obtained from the two regular sampling stations of Lake Catherine and Channel Lake and from the vicinity of the aerator. Also, two additional benthic sampling stations at depths of 18 to 20 feet and 12 to 15 feet were established in each of the two lakes. These two additional locations and the regular sampling location lie in an east-west transect passing through the regular stations.

Twenty liters of lake surface water samples from station 1 at Lake Catherine and from the Channel Lake station were obtained to determine the ash-free weight of lake surface plankton biomass. The procedures used are those outlined in Standard Methods (APHA et al., 1976) for the determination of standing crop biomass.

1980. During 1980 the lakes were monitored for physical, chemical, and biological characteristics at approximately biweekly intervals from May 13 to September 30. *In-situ* observations of temperature, dissolved oxygen, and secchi disc readings were made and samples were collected at the Channel Lake station and at station 1 of Lake Catherine. In addition, *in-situ* observations for DO, temperature, and secchi disc readings were made in the vicinity of the aerator at station 2 of Lake Catherine. The procedures for making *in-situ* observations were the same as reported by Kothandararaan et al. (1980).

Water samples for chemical analyses were collected at three different depths from both lakes: surface, mid-depth, and 1 foot from the bottom (designated the deep sample). Samples were collected in a clear plexiglass 3.2-liter Van Dorn type sampler and stored in acid-washed containers for analyses. Analyses for BOD, chlorine demand, pH, turbidity, alkalinity, hardness, nitrate, ammonia, sulfate, total iron, chloride, silica, total phosphorus, orthophosphate, and suspended solids were performed in accordance with Standard Methods procedures (APHA, 1980).

Water samples for algal identification and enumeration, and for chlorophyll and zooplankton analyses, were obtained with a Van Dorn style water sampler from three depths at the two regular sampling stations. Algal water samples were placed in 946-ml polyethylene bottles and stored in a cool, dark location until they were processed. In the laboratory they were mixed, and a 28-ml aliquot was pipetted into a 30-ml glass bottle and preserved with Lugol's solution. Prior to algal identification and enumeration, the sample was gently mixed and a 1-ml aliquot was pipetted into a Sedgwick-Rafter counting cell. A Nikon differential interference contrast microscope equipped with 10X eyepiece and 4X, 10X, and 20X objectives and Whipple disc was used to identify and enumerate the algae.

Two complete strips, the length of the cell, were used in counting. Algae were identified to genus level and grouped into four main groups: blue-greens, greens, diatoms, and flagellates. The unit count, which treats each colony or individual plankton as one unit as described by Weber (1973) and Welch (1948) was employed for counting. The number of algae per ml was calculated using the equation expressed by Weber (1973) and Standard Methods (APHA, 1980). Chlorophyll concentrations were determined by Standard Methods procedures (APHA, 1980).

Zooplankton water samples were collected once a month at three depths (surface, mid-depth, and deep) at the regular stations in Lake Catherine and Channel Lake. A 20-liter water sample was filtered through a Wisconsin type plankton net and the specimens were rinsed with deionized water into 936-ml polyethylene bottles. In the laboratory, the volume of the sample was made up to 28 ml and preserved with 5 ml of 95 percent ethanol, and a 1-ml aliquot was pipetted into a Sedgwick-Rafter cell. A Nikon differential interference contrast microscope equipped with a 10X eyepiece and 4X, 10X, and 20X objectives with a Whipple disc were used to identify and enumerate zooplankton. Two complete strips were used in identifying and counting the organisms. The number of zooplankton per liter was calculated using the equation outlined by Weber (1973) and Standard Methods (APHA, 1980).

Benthic samples for macroinvertebrates and sediment characteristics were collected once a month from the two regular stations in Lake Catherine and Channel Lake, station no. 2 in Lake Catherine, and the two additional benthic sampling stations.

Three grab samples with an Ekman dredge (6 x 6 inches) were obtained at each location. The contents were washed in a 20-mesh screen sieve with a pan, after which the organisms were picked and placed in a 50-ml glass container and preserved with 70 percent ethanol. In the laboratory, the organisms were boiled in a 7.5 percent potassium hydroxide solution, rinsed in distilled water, and beheaded, and the head capsule was mounted on a slide in accordance with the procedure given by Mason (1973). The organisms were then identified, counted, and expressed as number of organisms per square meter.

Lake bottom sediment samples were collected in conjunction with benthic samples. The procedures used and the determinations made were the same as those described for 1978.

Results of Aeration and Destratification

Physical Characteristics

Thermal Stratification. Thermal stratification of deep lakes, impoundments, and reservoirs in the temperate zone is a natural phenomenon. Most of the physical, chemical, and biological characteristics of impounded waters are functions of temperature. Closely related to temperature variation in lake waters 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. The deep lakes of the Fox Chain are no exception.

Figures 30 and 31 show the isothermal plots for Lake Catherine and Channel Lake for May-September 1977, prior to the commencement of aeration. Although the lakes exhibited comparable stratification features, the water strata of Lake Catherine, at depths of 10 to 15 feet below the water surface, were colder than those of Channel Lake. Maximum differences occurred at depths of 20 to 30 feet and ranged from 3.5 to 9°C. During 1977 the temperature at the water surface

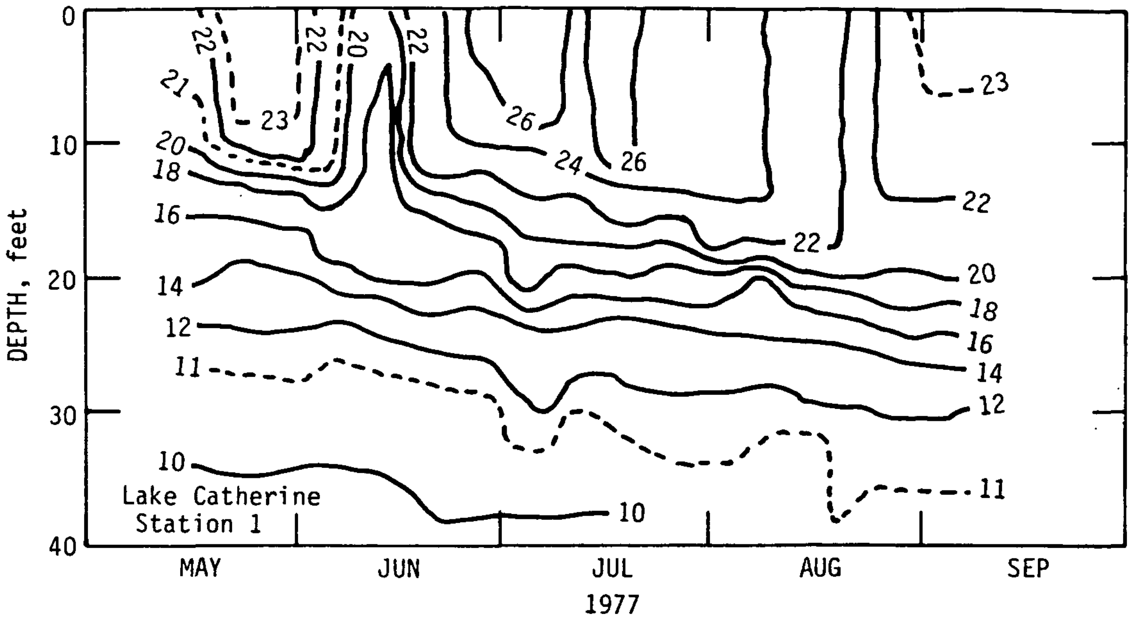

Figure 30. Isothermal plots, in °C, for Lake Catherine station 1, May-September 1977

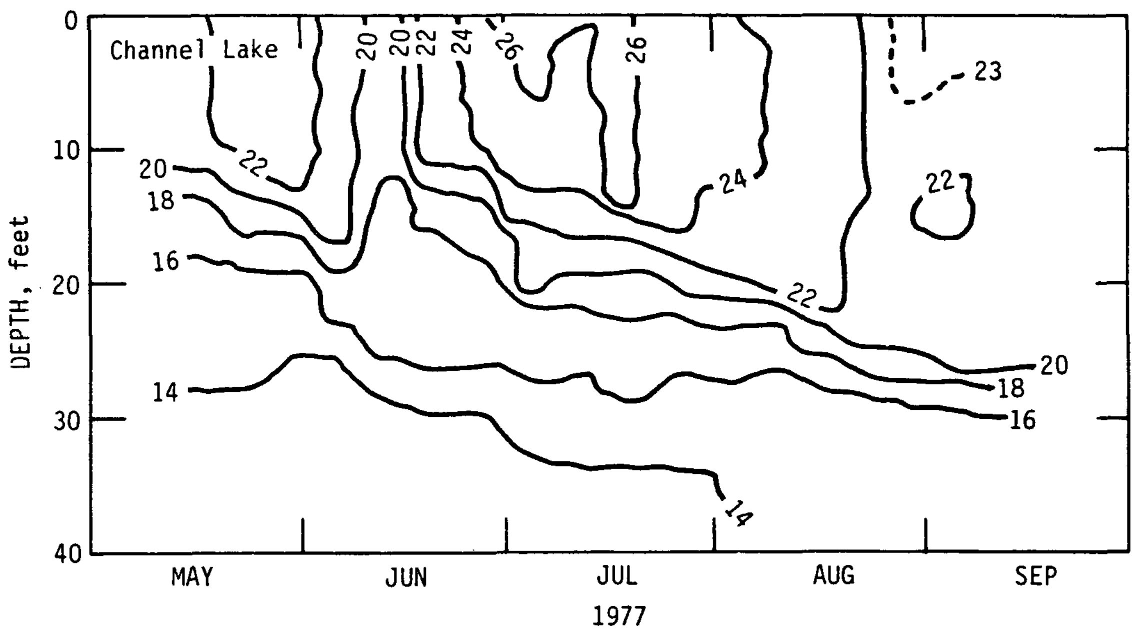

Figure 31. Isothermal plots, in °C, for Channel Lake, May-September 1977

attained a maximum of about 27°C. The peak period of stratification occurred during July and August, with the epilimnetic zones extended to 15 feet from the water surface in both lakes. Temperature gradients below the epilimnetic zone were comparable, with water temperature changes of about 10°C at a depth of 15 feet.

Data regarding temperatures in Lake Catherine and Channel Lake in 1977, 1978, 1979, and 1980 are included in Appendix C.

<u>1978</u>. Figures 32 and 33 show the May-October 1978 isothermal plots for Lake Catherine and Channel Lake, respectively. The surface water temperature in the lakes reached a maximum of 25°C. The thermal gradient in Channel Lake was more gradual than for the previous year. This is mainly because of the more moderate weather conditions experienced in the area and also because of the two entirely different hydraulic regimens to which the lakes were subjected in 1977 and 1978.

Flow hydrographs for the Fox River (the major tributary to the Fox Chain) at Wilmot, Wisconsin, are shown in figure 34 for the years 1977, 1978, and 1979. The river flow for the year 1977 was low and uniform, in contrast to the flow for 1978. The lakes of the Fox Chain were subjected to several periodic_ pulses of flood waters with consequent fluctuations in water levels in 1978. The monthly minimum, mean, and maximum flows for the Fox River at Wilmot are shown in table 12. The mean and maximum flows in the Fox River for 1978 are at least five orders of magnitude greater than the comparable values for 1977.

As shown in figure 1, Lake Catherine and Channel Lake are not located in the lake system where these orders of magnitude could be directly applied to them in flushing rates, etc. However, there is no doubt that because of higher flows in 1978, the Fox River had a greater modifying effect on the temperature regime of the two lakes during 1978 than it had in 1977.

Selected vertical temperature profiles for the lakes during 1978 are shown in figure 35. Prior to the destratification in Lake Catherine, both Channel Lake and Lake Catherine exhibited similar temperature variations with depth. As shown in figure 35a, temperatures varied from about 13°C at the surface to 10°C in the lower strata. After the start of the destratification operation in Lake Catherine on May 18, 1978, the surface water temperatures in the lake were lower than those in Channel Lake until July 12, 1978, when the temperatures in the epilimnetic zones of both lakes were similar. The lower surface water temperatures in Lake Catherine were caused by the upwelling of the colder hypolimnetic waters brought about by the aeration device. Figure 35 depicts the progress of artificial thermal destratification of Lake Catherine compared with the natural regime in Channel Lake. Lake Catherine destratified to a depth of about 26 feet, and the temperature became uniform within reasonable limits soon after the modifications to the aerator were completed on July 6, 1978. Surface water temperatures were comparable in both the lakes until mid-September, after which Lake Catherine exhibited higher temperatures. The increased heat budget in Lake Catherine is thus obvious and is even more dramatic when consideration is given to the fact that the water of Lake Catherine is usually 3.5 to 9°C colder than that of Channel Lake at depths of 20 feet and greater.

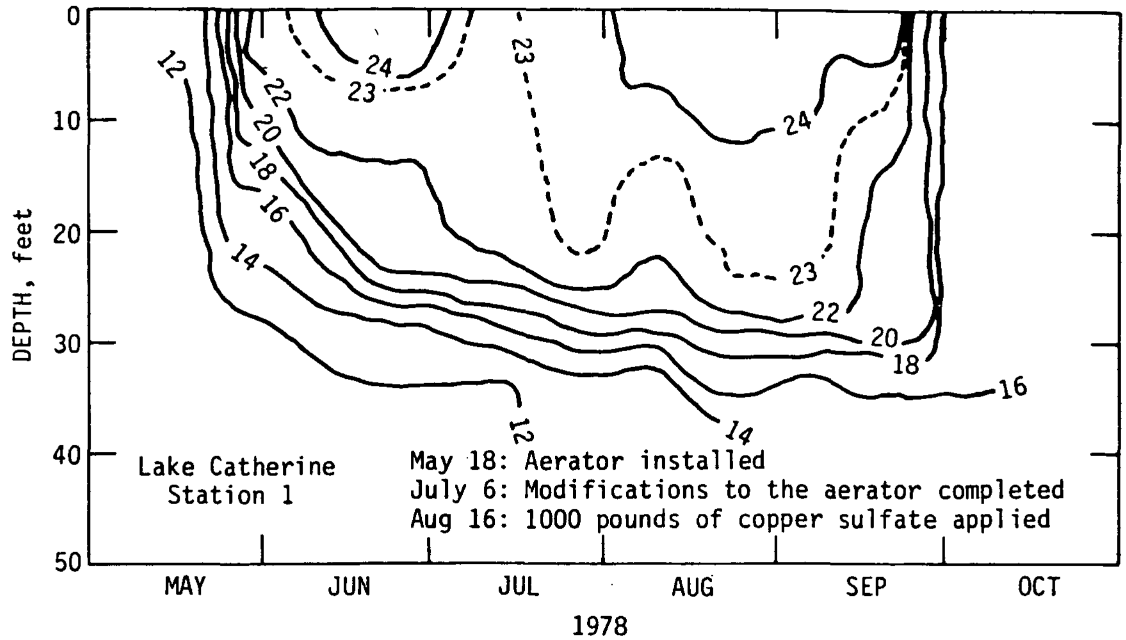

Figure 32. Isothermal plots, in °C, for Lake Catherine station 1, May-October 1978

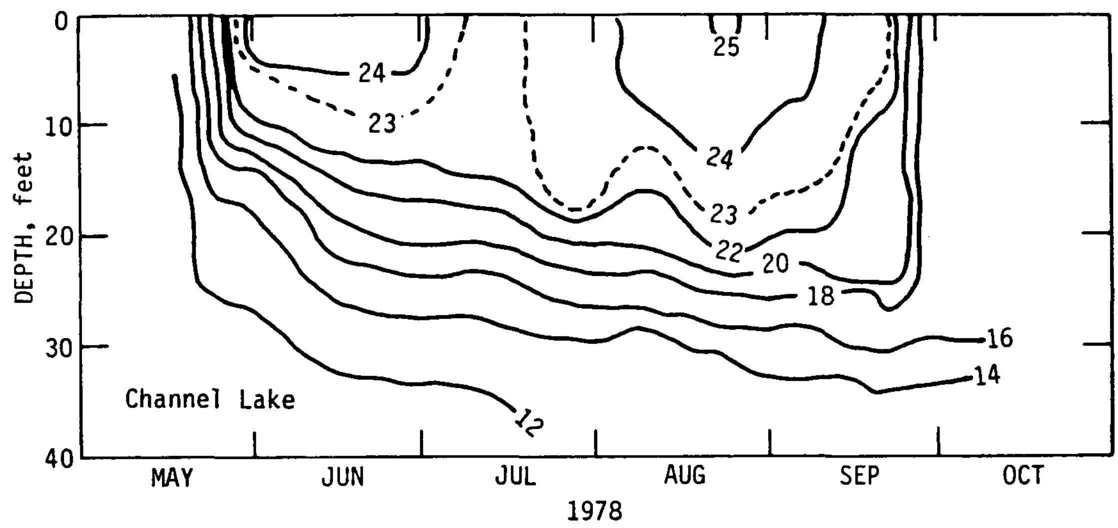

Figure 33. Isothermal plots, in °C, for Channel Lake, May-October 1978

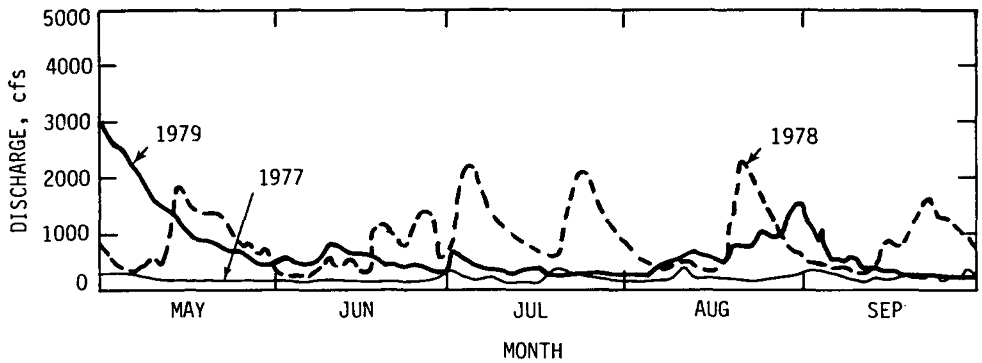

Figure 34. Flow hydrographs for Fox River at Wilmot, Wisconsin

Table 12. Monthly Flows, Fox River at Wilmot, Wisconsin
(Flow in cubic feet per second)

	1977			1978			1979		
	Minimum	*Mean*	*Maximum*	*Minimum*	*Mean*	*Maximum*	*Minimum*	*Mean*	*Maximum*
May	123	172	258	293	850	1810	402	1293	2910
June	108	136	170	209	637	1360	293	510	891
July	73	164	392	589	1257	2190	237	353	722
August	94	165	410	306	825	2270	284	719	1540
September	97	219	398	275	794	1640	229	427	1200

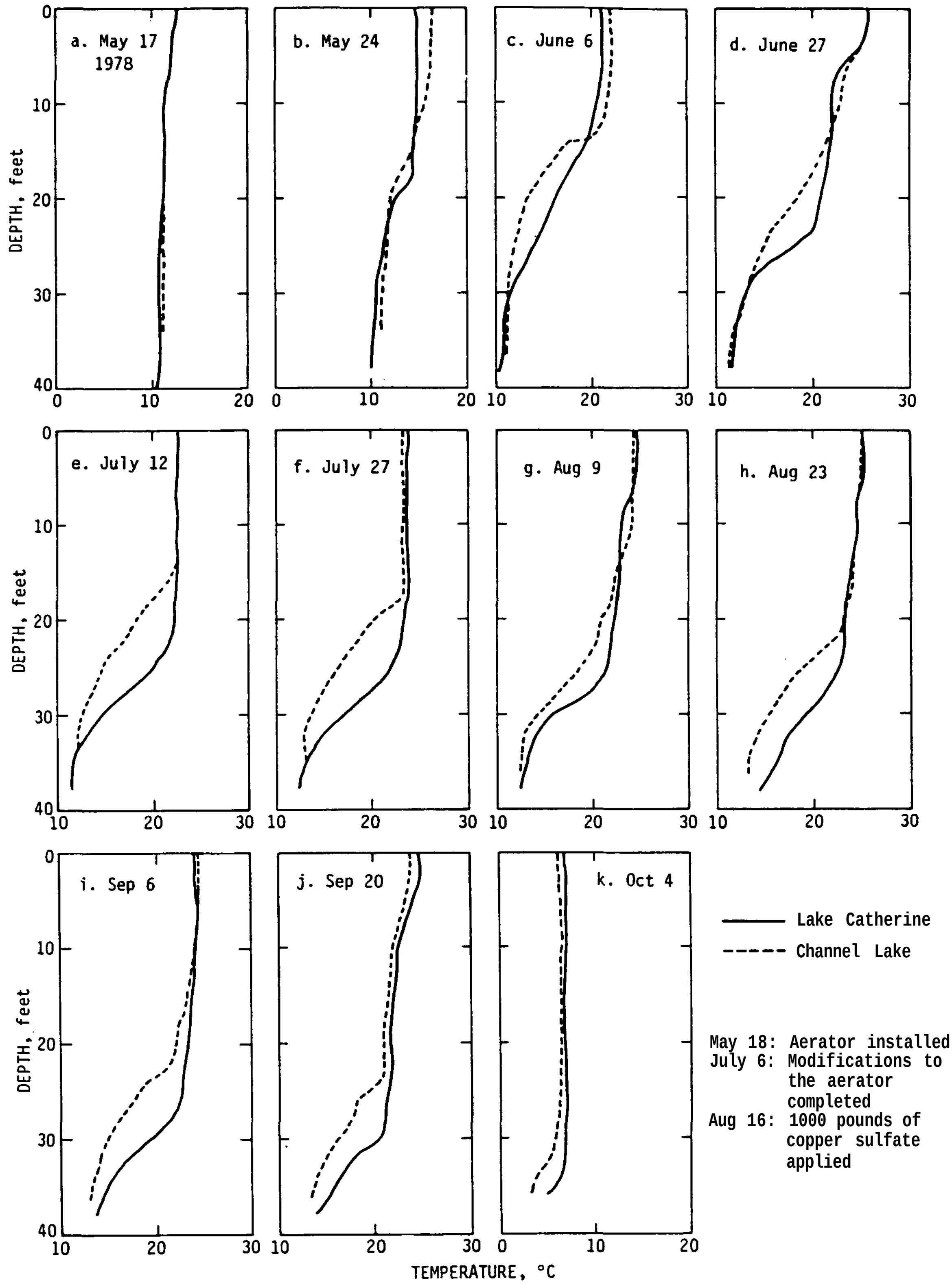

Figure 35. Temperature profiles for Lake Catherine and Channel Lake on selected dates, 1978

Isothermal plots for 1978 for Lake Catherine at station 2 in the vicinity of the aerator are shown in figure 36. The lake was completely destratified after mid-July, and the isothermal plots for the two stations in Lake Catherine are remarkably similar, indicating that the destratification of the lake had occurred uniformly to a depth of about 26 feet from the lake surface.

1979. The isothermal plots for 1979 for station 2 at Lake Catherine (near the aerator), for station 1, and for Channel Lake are shown in figures 37, 38, and 39, respectively. The periods of aerator shutdown that resulted from failure, control panel malfunctioning, or vandalism are noted in figures 37 and 38.

These results indicate that the aerator kept Lake Catherine destratified, whereas Channel Lake stratified, with the epilimnetic zone extending to only 15 feet from surface during July and August. During the extended period of shut-down of the aerator (July 14 to July 26, 1979), Lake Catherine exhibited a tendency to stratify again. However, when the aerator was restarted the lake soon destratified.

Selected vertical temperature profiles for the two lakes during 1979 are shown in figure 40. Prior to the start of aeration in Lake Catherine, water temperatures for the two lakes were similar to a depth of about 12 feet, below which the waters of Lake Catherine were colder than those of Channel Lake. Aeration started on May 10, 1979, and water temperatures in both the lakes became almost identical on May 22, 1979. Thereafter, the deeper waters of Lake Catherine became progressively warmer. The surface water temperatures in Lake Catherine were only slightly cooler than the water temperatures in Channel Lake because of the mixing of cooler hypolimnetic waters with the epilimnetic water in Lake Catherine. Both lakes were isothermal by October 4, 1979, when the aerator was shut off.

1980. The 1980 isothermal plots for Lake Catherine at station 1 and station 2 (near the aerator) and the plots for Channel Lake are shown respectively in figures 41, 42, and 43. It can be seen from figures 41 and 42 that the aerator kept the lake destratified up to a depth of 25 feet even at station 1 (about 2000 feet away from the aerator). Indeed, Lake Catherine station 2 was completely destratified. Lake Catherine, on the whole, was destratified to the depth of the location of the aerator. Channel Lake stratified at depths below 15 feet during summer months.

Selected vertical temperature profiles for the two lakes during 1980 are shown in figure 44. Because of the destratification in Lake Catherine, water temperatures in the lake at depths between 15 and 30 feet were higher than those for Channel Lake during summer months. The temperature profiles clearly bring out the fact that Lake Catherine was destratified up to about 25 feet from the surface.

Lake Stability. Lake stability is defined as the energy of resistance which a lake offers to oppose the upset of density stratification (Reid, 1961). It is a measure of the amount of work required to displace the center of gravity of the stratified mass of the lake waters to its original position

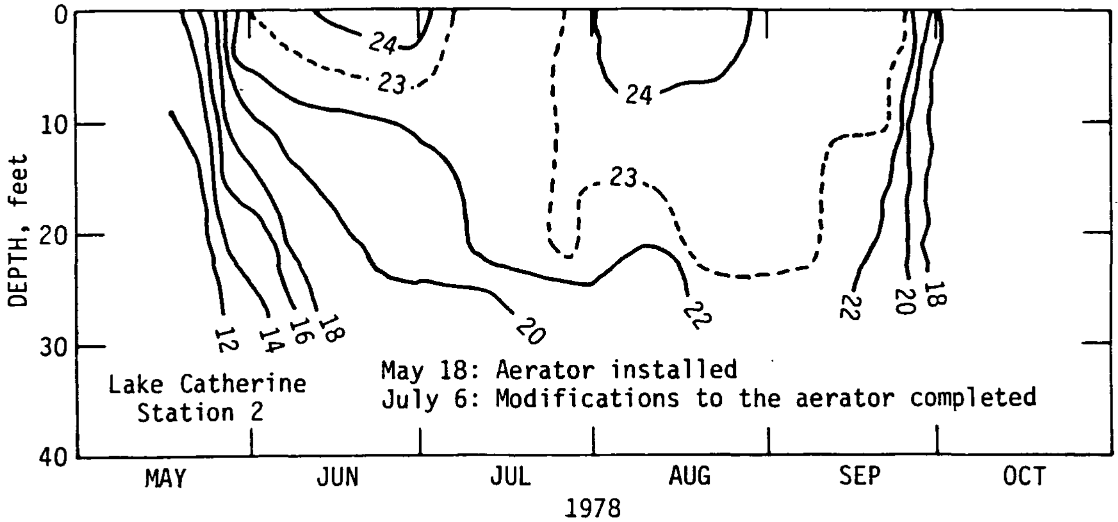

Figure 36. Isothermal plots, in °C, for Lake Catherine station 2, May-October 1978

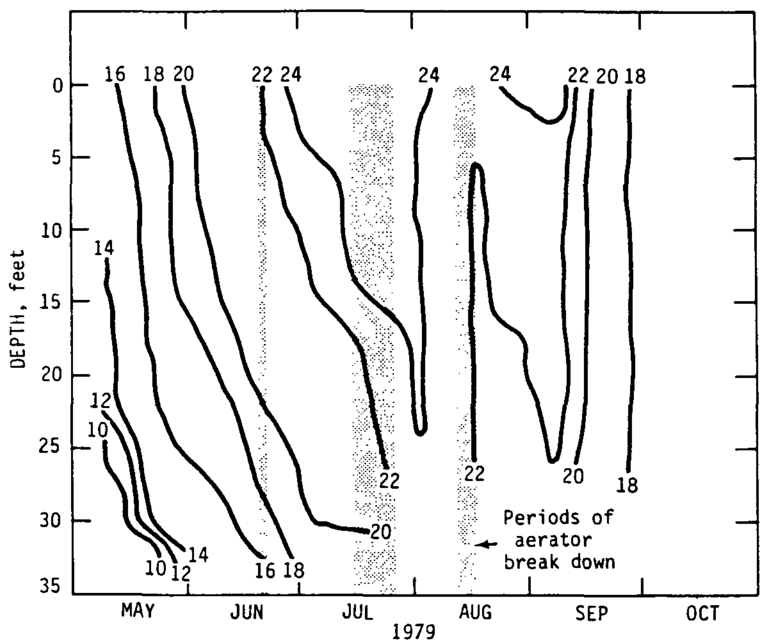

Figure 37. Isothermal plots, in °C, for Lake Catherine station 2, May-Ootober 1979

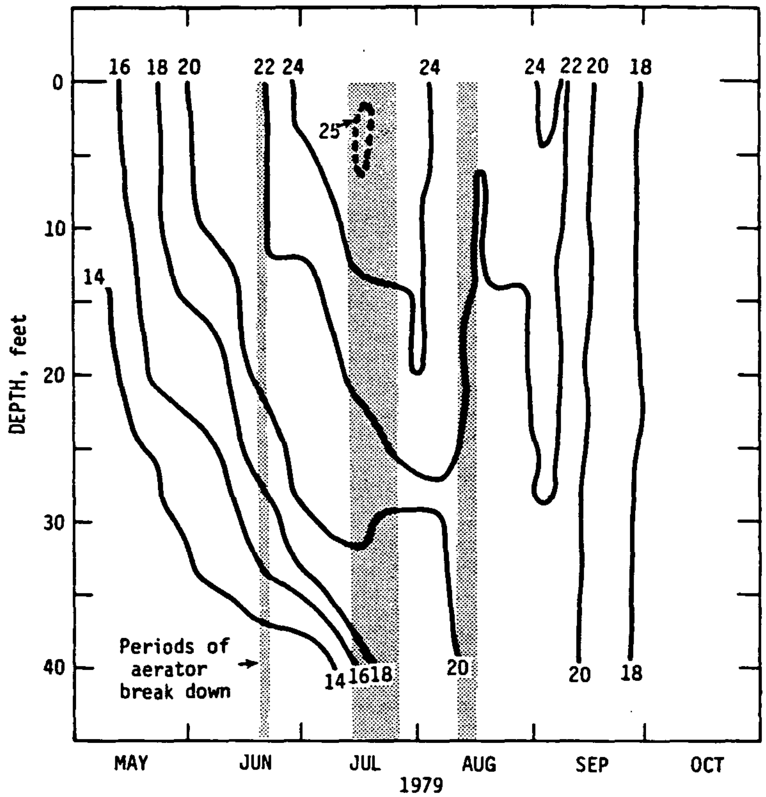

Figure 38. Isothermal plots, in °C, for Lake Catherine station 1, May-October 1979

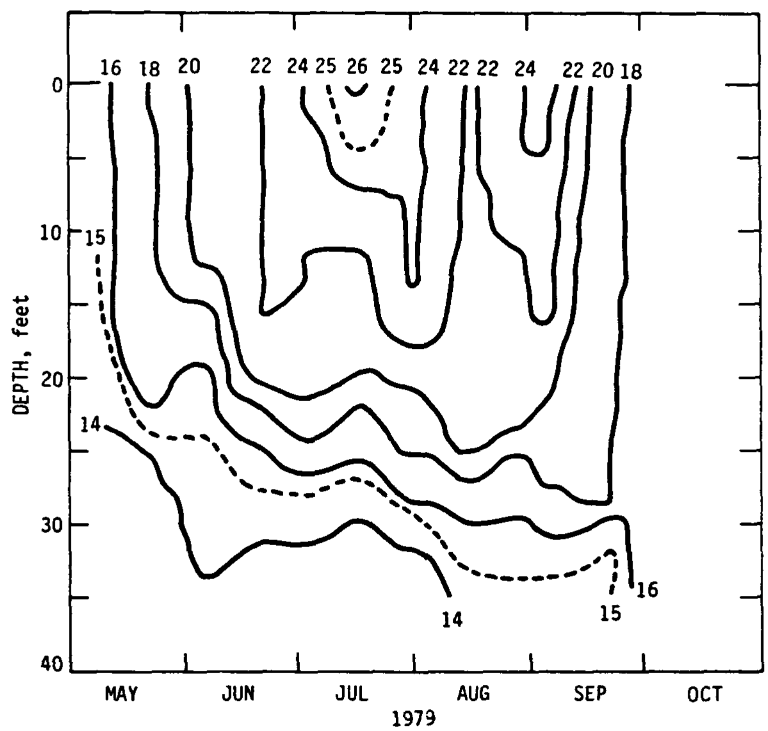

Figure 39. Isothermal plots, in °C, for Channel Lake, May-October 1979

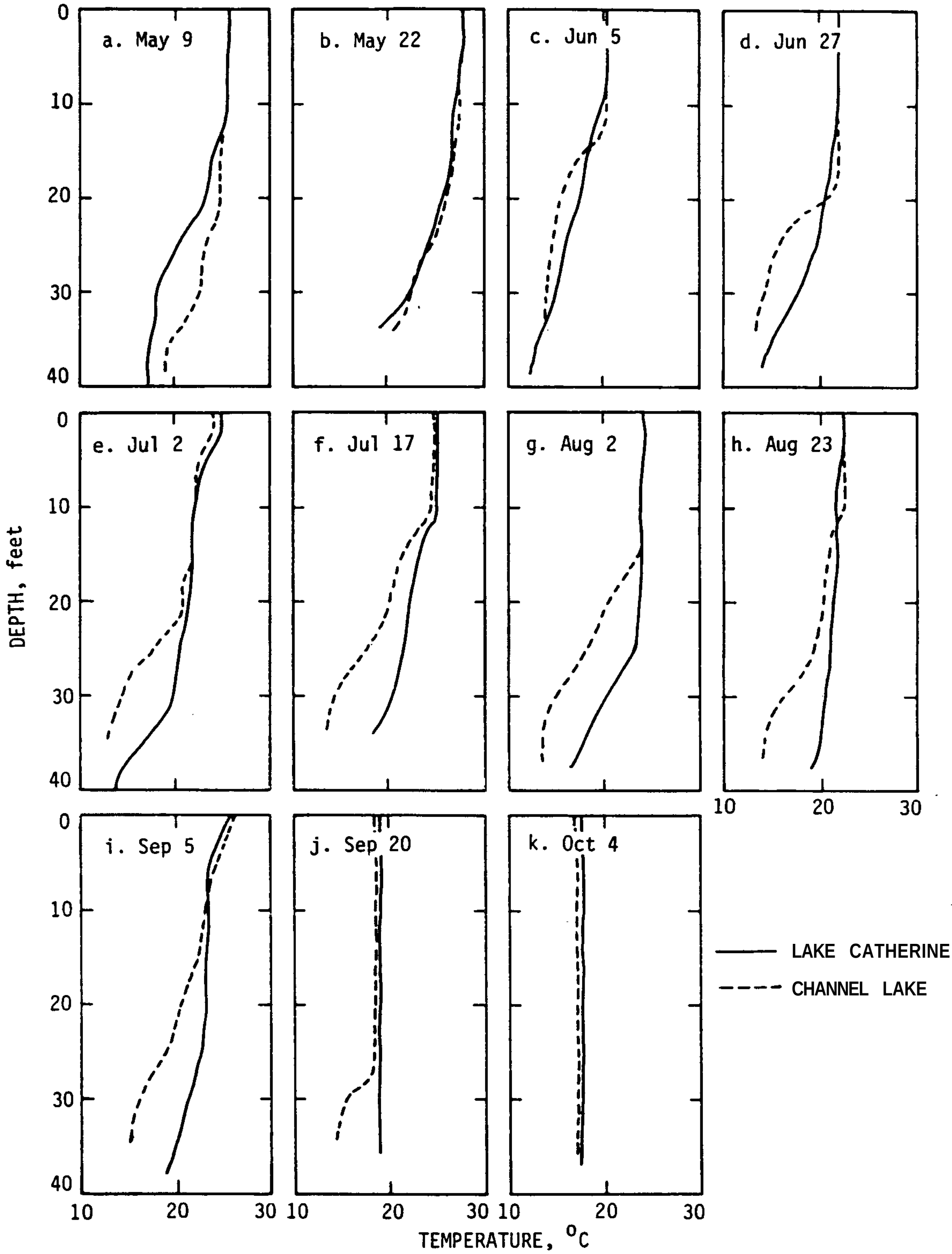

Figure 40. Temperature profiles for Lake Catherine station 1 and Channel Lake on selected dates, 1979

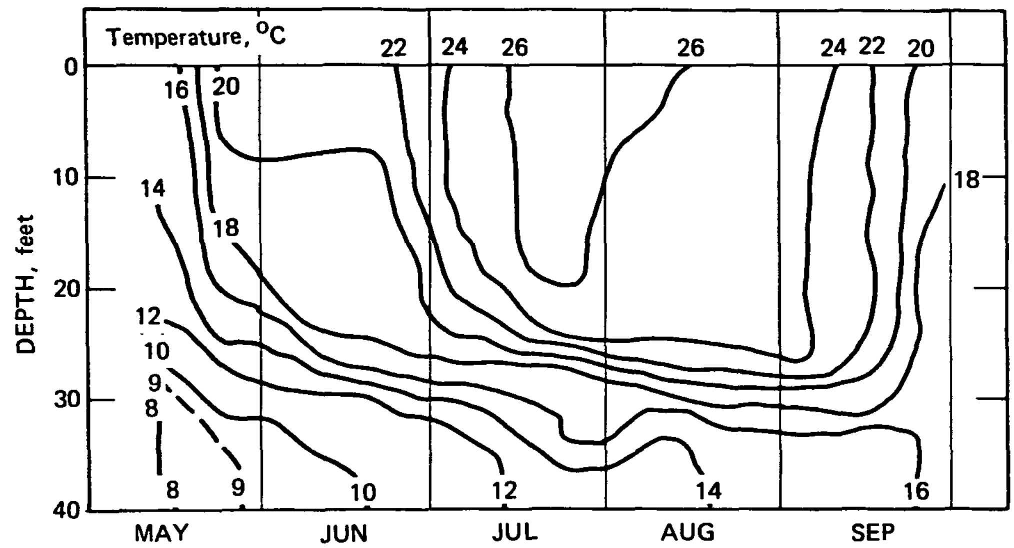

Figure 41. Isothermal plots, in °C, for Lake Catherine station 2, 1980

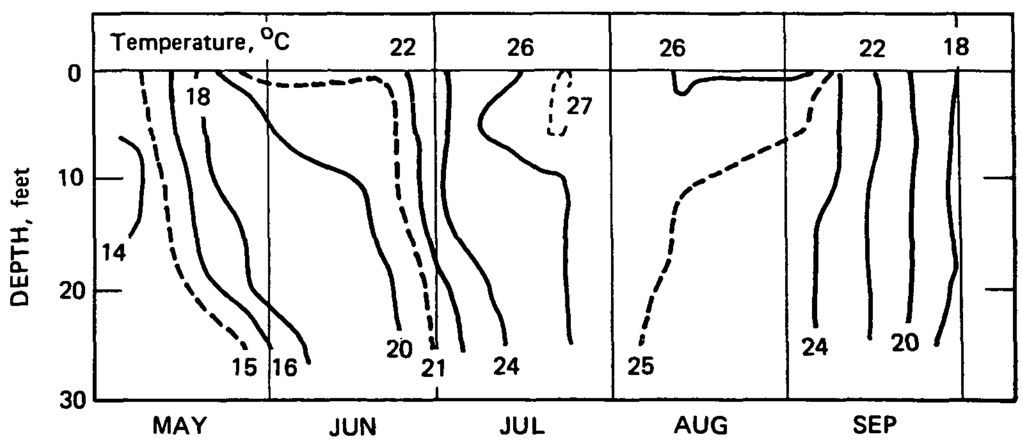

Figure 42. Isothermal plots, in °C, for Lake Catherine station 2, 1980

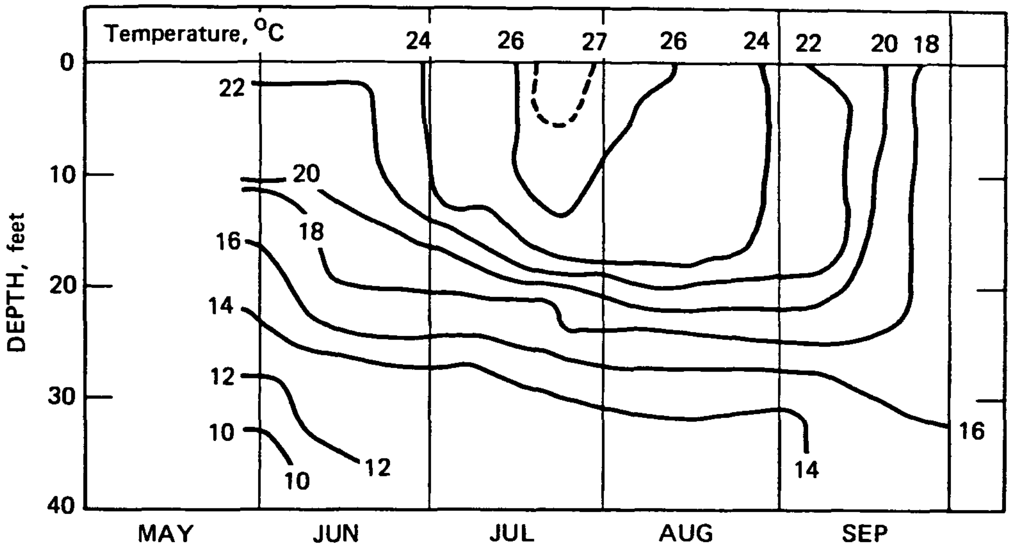

Figure 43. Isothermal plots, in °C, for Channel Lake, 1980

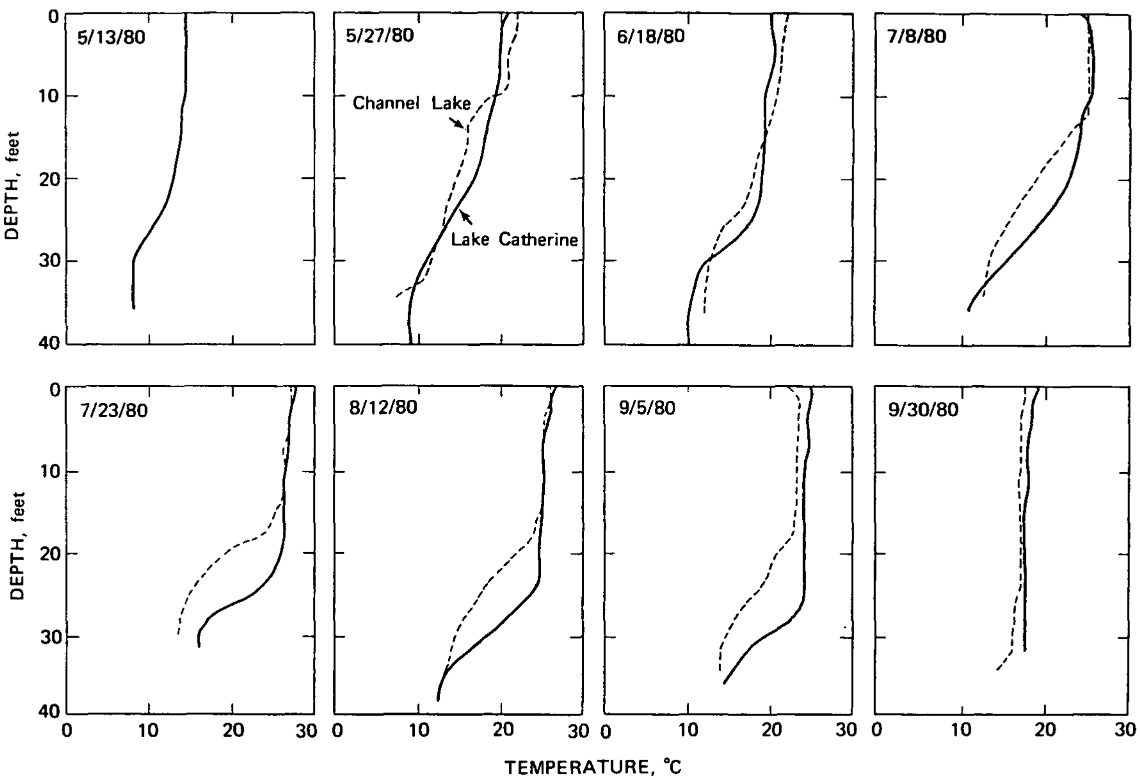

Figure 44. Temperature profiles for Lake Catherine station 1 and Channel Lake, 1980

prior to the onset of stratification, i.e., when the lake was holomictic with uniform temperature from the surface to the bottom. The greatest stability is generally reached just prior to maximum heat content in summer. Symons (1969) has discussed in detail the procedure for computing the stability factor for lakes, using periodic lake vertical temperature profiles.

The temporal variations in.the stability factor for Lake Catherine for 1977, 1978, and 1979 are shown in figure 45. On the basis of the temperature data, the stability factor for Lake Catherine was computed to the 26-foot depth of the lake, as this was the average depth at which the aerator was located and the lowest depth at which the aerator proved to be effective in the destratification process. The computed values for Lake Catherine were found to be comparable to published values (Symons, 1969; Steichen, 1974).

In 1977 the lake stability reached a peak at the end of June and then steadily decreased thereafter until the observations were terminated. In 1978 the stability value showed a significant increase in May, even after the aerator was installed. As mentioned previously, the performance of the aerator was unsatisfactory until the modifications were completed in early July 1978. The stability values decreased significantly thereafter and attained a zero value on October 4, 1978, indicating a complete fall overturn. The destratification efficiency (the ratio of the decrease in lake stability to the power input to the aerator in a given period of time) could not be assessed for the aerator used in Lake Catherine for various reasons. The sawtooth nature of the stability curve precluded choosing a suitable time interval for the destratification efficiency computations and for comparison with the values reported in the literature for comparably installed and operated aerators. In 1979 the lake stability was less than 5 kw-hr for the entire period, except during a 12-day period in July when the aerator was shut down.

Dissolved Oxygen. Where the depth of an impoundment or a lake is considerable, 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, as is the case with eutrophic lakes, the oxygen resources of the hypolimnetic zone are quickly exhausted. Anoxic conditions prevail during most of the warm summer months.

Observations of Lake Catherine and Channel Lake in 1975 (Kothandaraman et al., 1977) showed that the volume of the water column below the 15–foot depth was devoid of oxygen during summer stratification. As shown in figures 46 and 47, similar conditions prevailed during 1977 for Lake Catherine and Channel Lake, respectively. Waters at depths greater than 15 feet were practically devoid of dissolved oxygen during the month of July.

Appendix C presents data on dissolved oxygen in Lake Catherine and Channel Lake in 1977, 1978, 1979, and 1980.

1978. In 1978, as shown in figure 48, the peak anoxic zone in Channel Lake extended to a depth of 18 feet, in contrast to the 15 feet observed for two

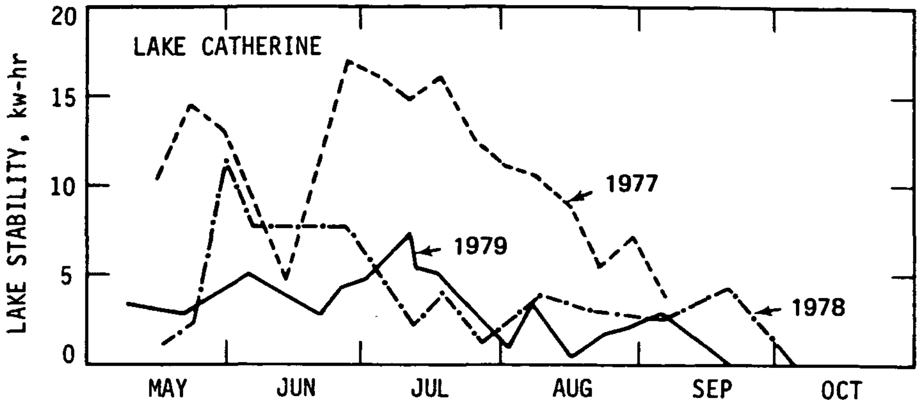

Figure 45. Comparison of lake stabilities in Lake Catherine, May-October 1977, 1978, and 1979

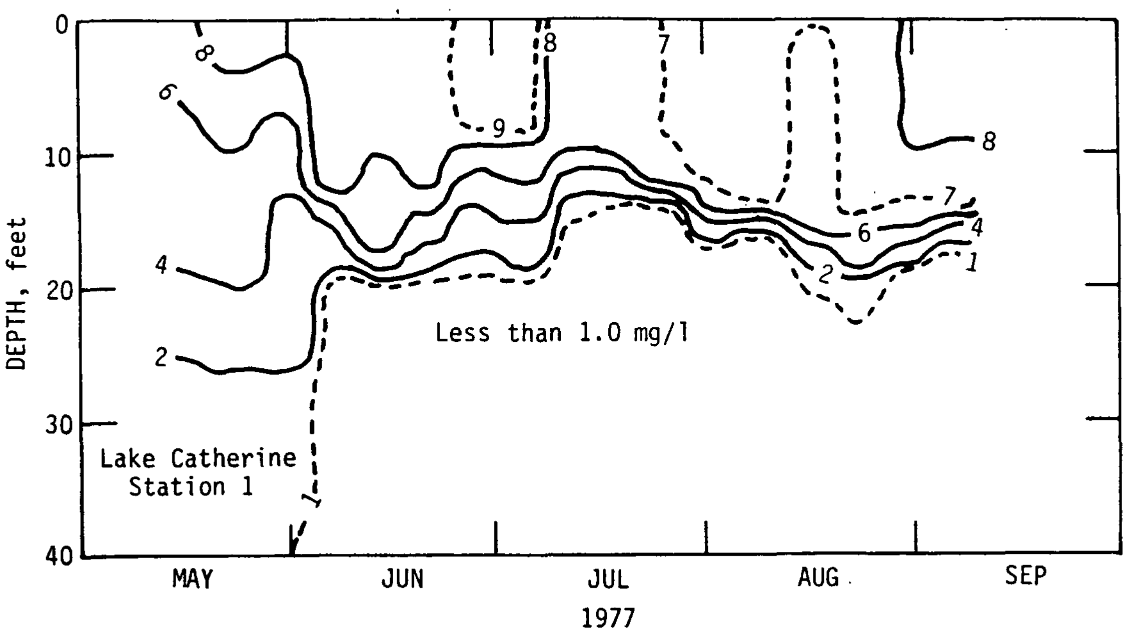

Figure 46. Isopleths of dissolved oxygen concentrations, in mg/l, for Lake Catherine station 1, May-September 1977

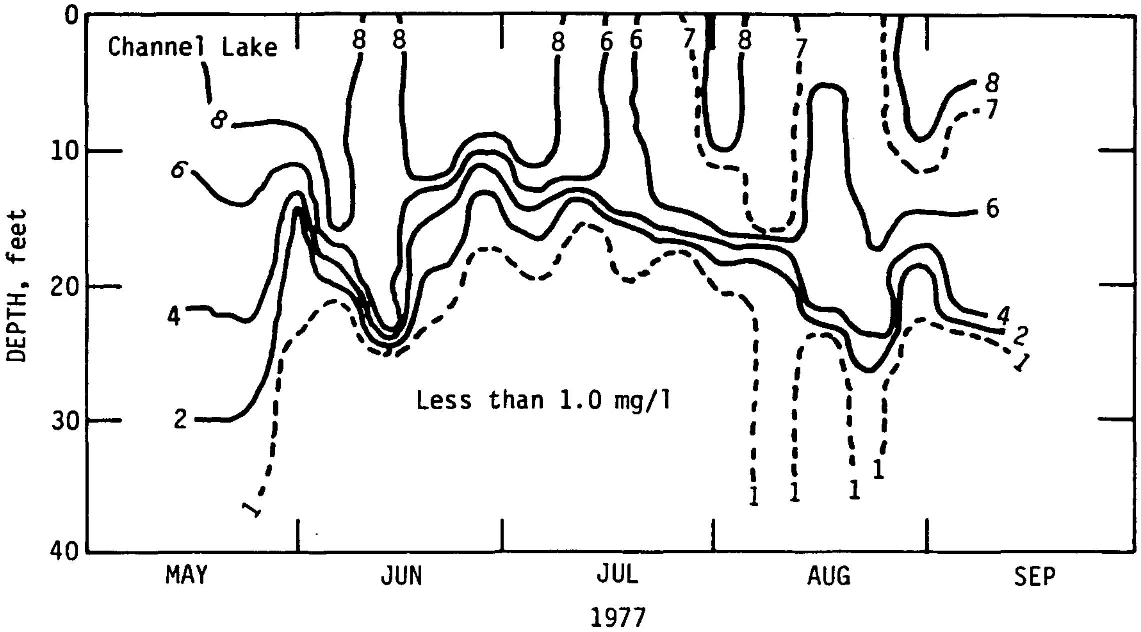

Figure 47. Isopleths of dissolved oxygen concentrations, in mg/l, for Channel Lake, May-September 1977

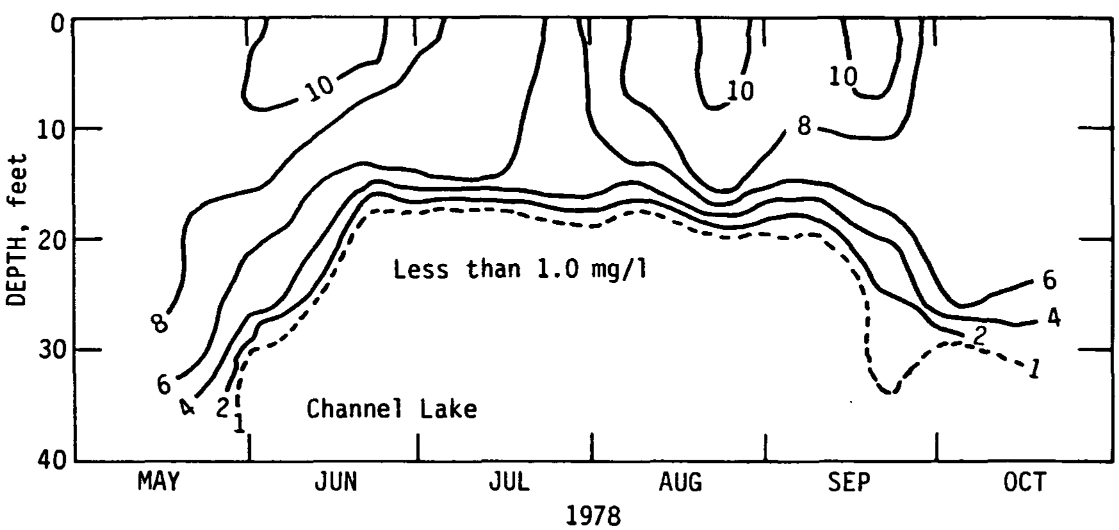

Figure 48. Isopleths of dissolved oxygen concentrations, in mg/l, for Channel Lake, May-October 1978

previous years. Presumably this improvement was caused by the substantial increases in flows of the Fox River during 1978 compared with the earlier years. Since the extent of dissolved oxygen depletion in the water column of the two lakes had been similar, it is reasonable to assume that the peak anoxic zone in Lake Catherine, without modification, also would have extended to a depth of 18 feet during 1978.

The effects of artificial destratification and aeration on the oxygen resources for Lake Catherine station 1 in 1978 are shown in figure 49. Although the aerator was started on May 18, 1978, it can be seen from this figure that there was a steady progression of the anoxic zone until the early part of July. After the modifications to the aerator were completed, the trend in anoxic zone progression was arrested and reversed. As discussed previously, the aerator was effective in augmenting oxygen to the lake waters at depths of 26 feet or less, but the lake still had an anoxic zone at depths greater than 26 feet. Figure 50 shows the isopleths of dissolved oxygen concentrations for Lake Catherine at station 2 in the vicinity of the aerator. This figure again confirms that the aerator was effective to a water depth of about 26 feet and that the depletion of dissolved oxygen normally occurring in the water column below the 15-foot level had been successfully modified.

Selected dissolved oxygen profiles for 1978 for Lake Catherine station 1 and Channel Lake are shown in figure 51. Figures 51a and 51b indicate comparable DO profiles in the two lakes. Figures 51c through 51i indicate clearly the zone and the extent of oxygen resources supplemented by the aerator. It may be seen from these figures that the maximum impact of the aerator was felt in the water volume between the depths of 15 and 26 feet. The marked reduction in DO in the upper lake strata shown in figure 51h is probably the result of the copper sulfate treatment on August 16. Figure 51k shows clearly the hastening of the fall turnover by the aerator in Lake Catherine.

Figure 52 shows the temporal variations in dissolved oxygen at different depths in Lake Catherine and Channel Lake in 1978. This again brings out the fact that the aerator was effective in the depth range of 15 to 26 feet. This aspect is amplified in figure 53, where the percent DO saturation values are plotted. In computing the percent saturation at different depths, the effect of increased hydrostatic pressures on oxygen saturation values was not considered.

The mass of oxygen present in Lake Catherine in the water layers between the 16- and 26-foot depths for the years 1977 and 1978 is shown in table 13. Column 2 of this table shows the oxygen mass computed from the observed oxygen concentrations on the 1978 dates shown in column 1. Column 3 is a measure of the oxygen mass in the same body of water if there had been no aeration. These values were computed from the Lake Catherine water mass and the observed oxygen concentrations in Channel Lake at corresponding depths. Similar computations were made for the 1977 oxygen data. The estimates of oxygen mass in Lake Catherine for 1978 without aeration seem reasonable when they are compared with the figures for 1977 during the summer months (columns 5 and 6). It can be seen that the aerator installed in Lake Catherine was able to maintain more than 5000 pounds of oxygen within the water volume between the 16- and 26-foot level during the critical summer months of 1978.

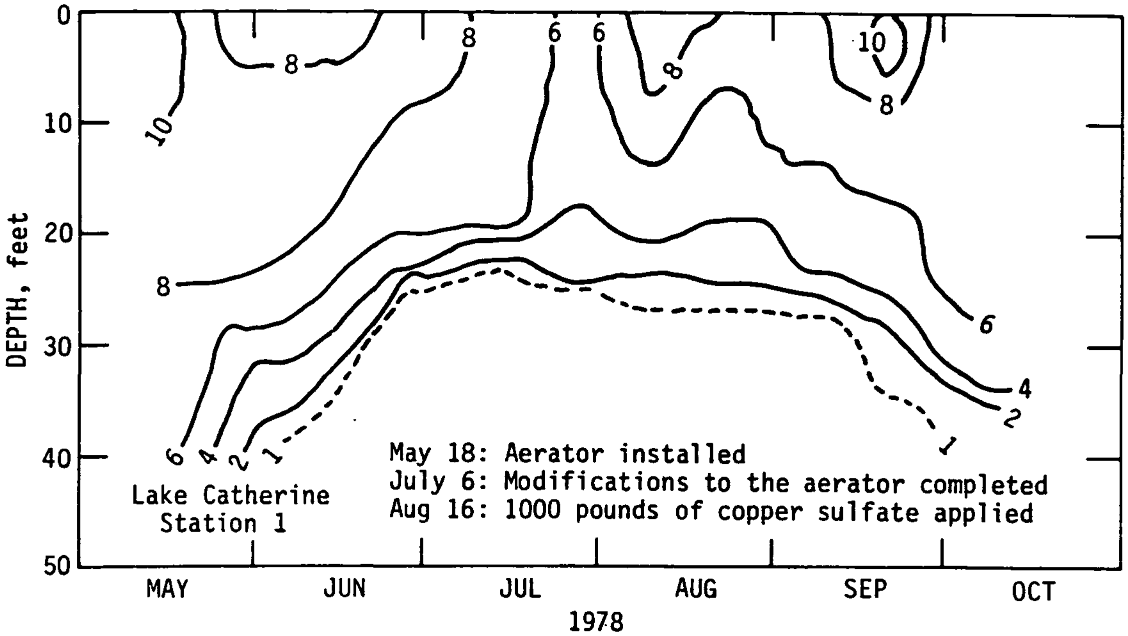

Figure 49. Isopleths of dissolved oxygen concentrations, in mg/l, for Lake Catherine station 1, May-October 1978

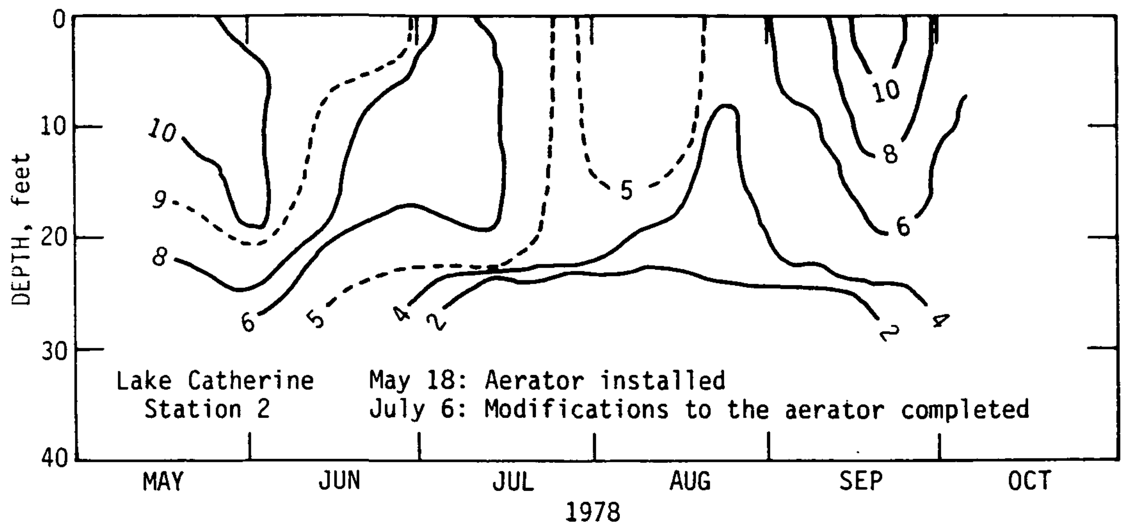

Figure 50. Isopleths of dissolved oxygen concentrations, in mg/l, for Lake Catherine station 2, May-October 1978

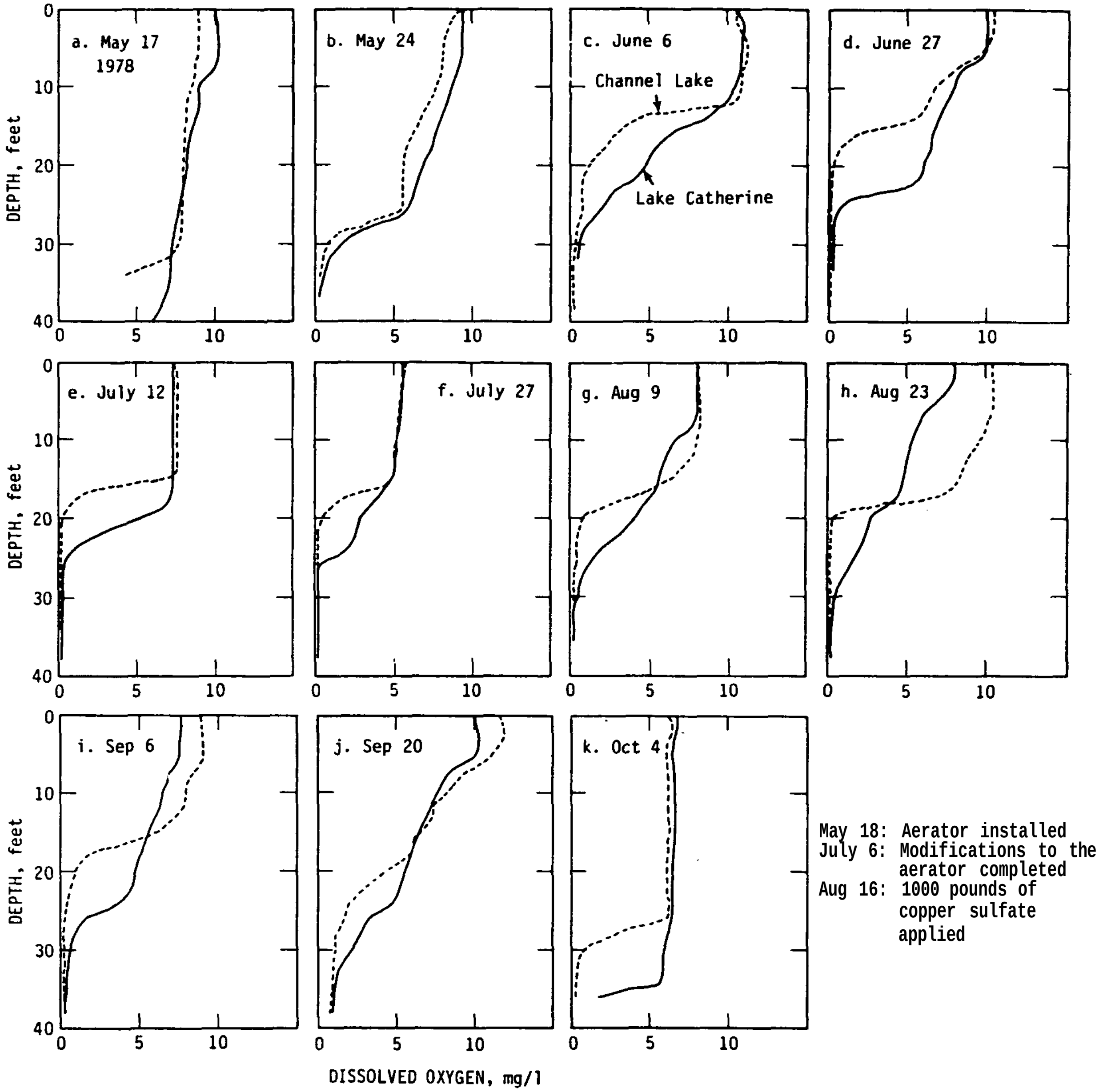

Figure 51. Dissolved oxygen concentration profiles for Lake Catherine station 1 and Channel Lake on selected dates, 1978

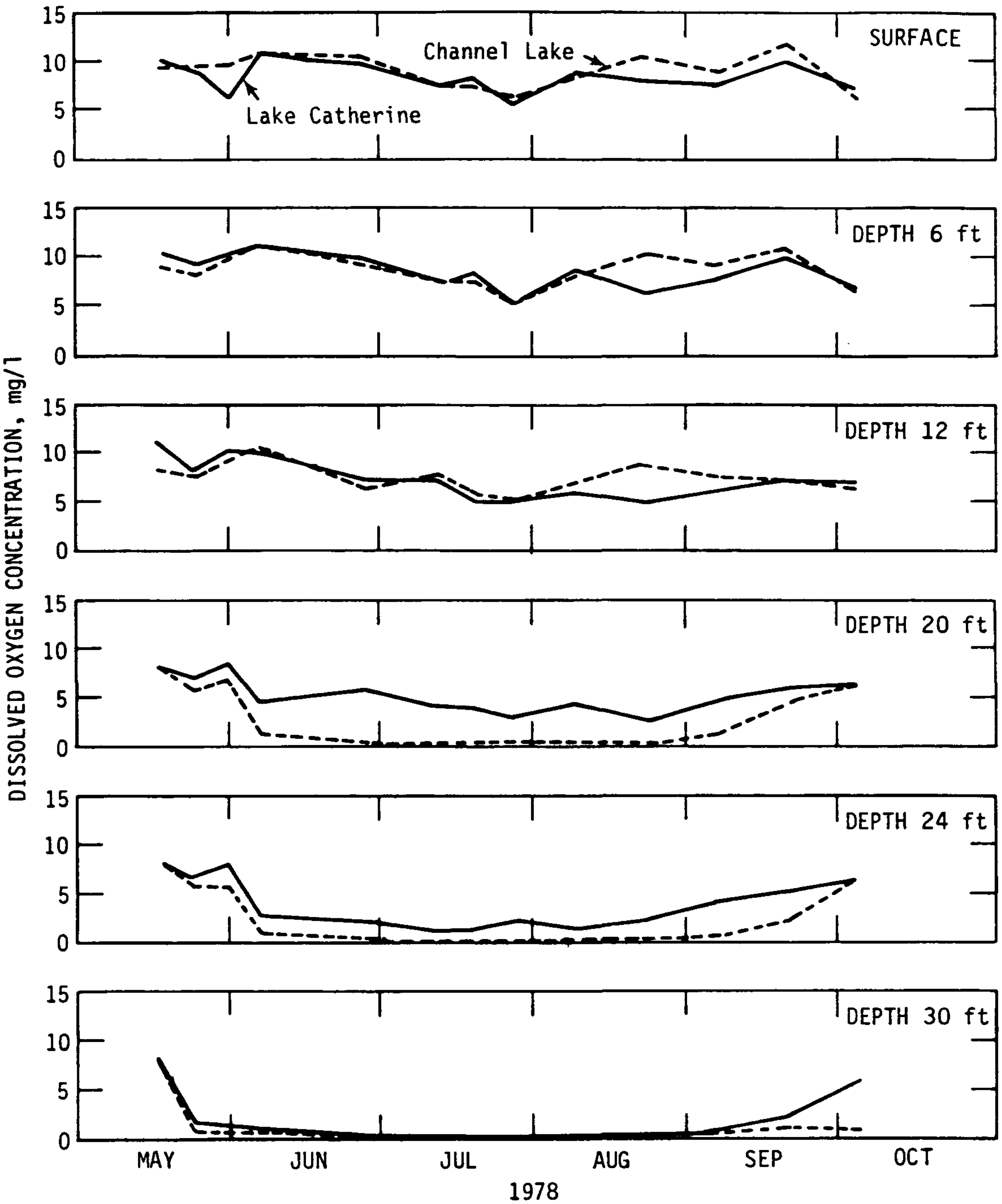

Figure 52. Temporal variations in dissolved oxygen concentrations in Lake Catherine and Channel Lake, 1978

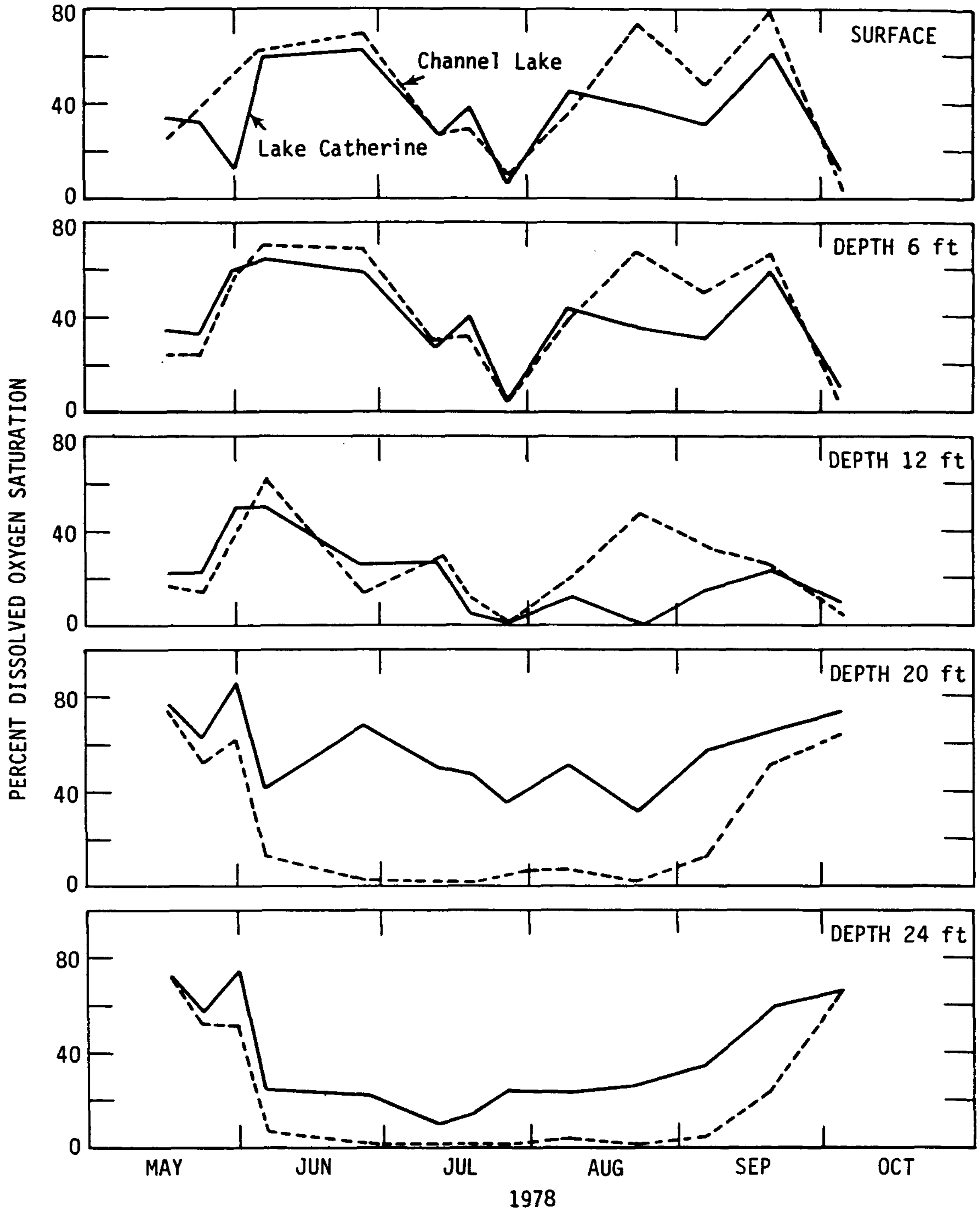

Figure 53. Percent dissolved oxygen saturation concentrations at different depths in Lake Catherine and Channel Lake, 1978

Table 13. Oxygen Mass in Water Layers between 16- and 26-Foot Depths, Lake Catherine, 1977 and 1978
(Values in pounds of oxygen)

Date 1978	*From 1978 observed values with aeration*	*Computed values without aeration **	*Date 1977*	*From 1977 observed values without aeration*	*1977 computed values without aeration •*
May 17	16,510	16,110	May 16	6,580	8,600
May 24	13,580	11,320	May 23	7,090	8,680
May 31	16,770	12,810	May 31	5,990	2,340
June 6	8,640	3,040	June 6	2,770	6,760
June 27	9,600	1,250	June 27	2,060	1,190
July 12	8,180	1,620	July 11	1,390	1,420
July 19	5,840	590	July 18	1,670	2,060
July 27	5,730	2,730	July 26	710	2,380
August 9	7,410	2,060	August 8	1,050	5,520
August 23	6,100	5,190	August 22	5,680	9,400
September 6	8,700	3,280	September 6	4,480	7,090
September 20	10,560	8,300			
October 4	12,620	12,270			

**Values computed with Lake Catherine volumes and the oxygen concentrations observed in Channel Lake at the corresponding depths*

From the 1975 observations of the lake, it was estimated that about 40 percent of the lake volume was anoxic (Kothandaraman et al., 1977). After installation of the aerator, the anoxic volume in the lake was reduced to about 14 percent. The total amount of energy used in operating the aerator from May 18 to October 4, 1978, was about 45,800 kilowatt hours at a total power cost of $1750.

As a consequence of the increased oxygen concentrations at greater depths, the habitat for fish and fish food organisms expanded. The marina operator and other local residents reported that sports fishing in the lake had improved, particularly in the proximity of the aerator.

Improvements in habitats for fish and other aquatic organisms have been reported in past attempts at artificial destratification and aeration (Gebhart and Summerfelt, 1976; Fast, 1971).

1979. The effects of artificial destratification and aeration on the oxygen resources of Lake Catherine in 1979 are shown in figures 54 and 55. Even though the aerator was started on May 10, 1979, and operated continuously for 2 months, with only a brief shutdown due to power failure, it is apparent that the oxygen demand exerted by lake sediments is much higher than the oxygen replenishment provided by aerator operation in the deeper layers. The anaerobic zone gradually extended upward. However, the rate of upward encroachment of the anoxic zone in Lake Catherine was very gradual and far less abrupt than that occurring in Channel Lake (figure 56).

Because of the extended period of shutdown of the aerator during the last half of July 1979, the anoxic zone extended to about 14 feet from the surface. It was during this period of shutdown that the aerator was brought ashore, checked, and reinstalled at a 28-foot depth as in 1978. With the resumption of aerator operation, oxygen levels increased in the deeper waters (below 14 feet). Again, the onset of anaerobic conditions was pronounced when the aerator broke down in August (August 11-16) as a result of vandalism. Figures 54, 55, and 56 clearly demonstrate that the month of July is the most critical month for oxygen resources.

The upward mobility of the anoxic zone in Channel Lake during 1979 was abrupt and occurred in May. In contrast, during 1978 it occurred in June and was more gradual (figure 48) because of the water movement through the lake system. The differences in the hydrologic regimes to which the lake system was subjected can be gauged by referring to figure 34, which shows the hydrographs for the Fox River at Wilmot, Wisconsin. The Fox River experienced periodic pulses of floods from May through September 1978. The Fox River flow from June to mid-August of 1979 was much less than in the previous year, and it was nearly uniform.

Selected dissolved oxygen profiles for 1979 for Lake Catherine station 1 and Channel Lake are shown in figure 57. The zone and the extent of oxygen resources supplemented by the aerator are indicated in figures 57b through 57j. Dissolved oxygen profiles in these lakes on July 17, 1979, were nearly identical. In Lake Catherine, oxygen levels at depths below 15 feet from the

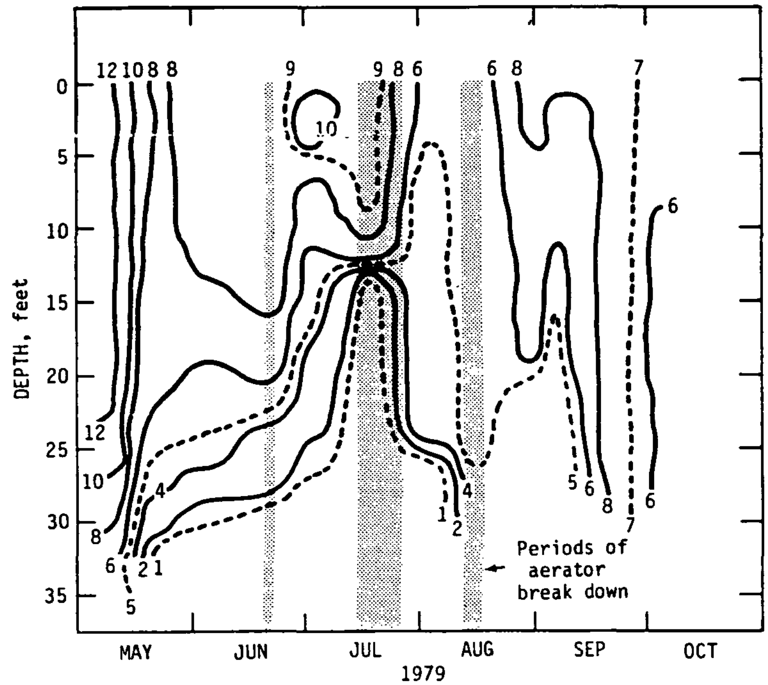

Figure 54. Isopleths of dissolved oxygen, in mg/l, for Lake Catherine station 2, 1979

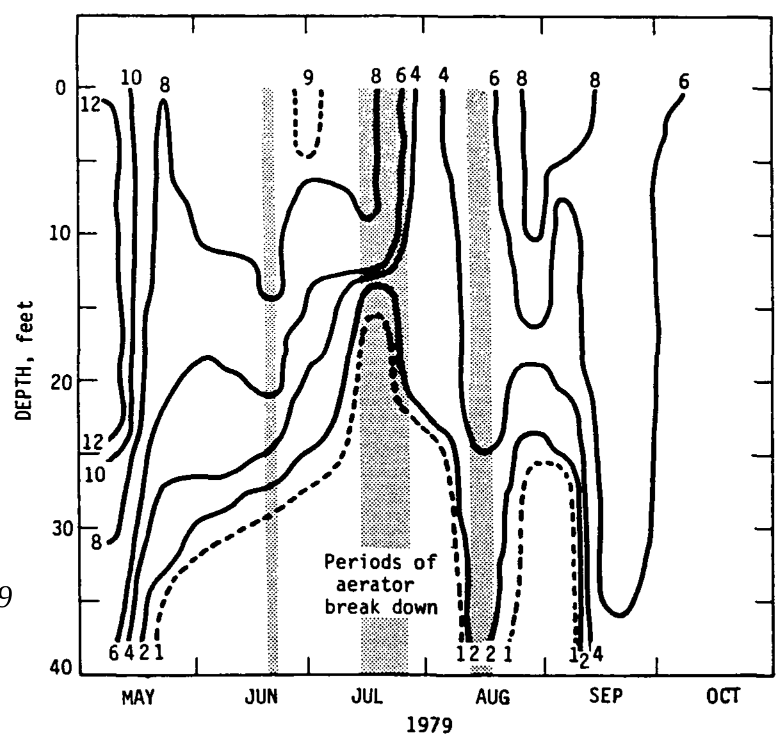

Figure 55. Isopleths of dissolved oxygen, in mg/l, for Lake Catherine station 1, 1979

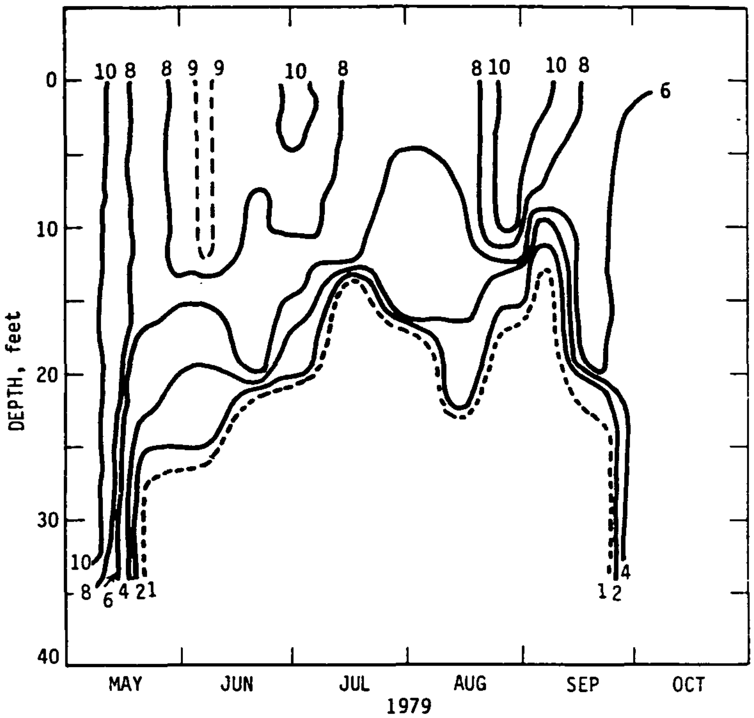

Figure 56. Isopleths of dissolved oxygen, in mg/l, for Channel Lake, 1979

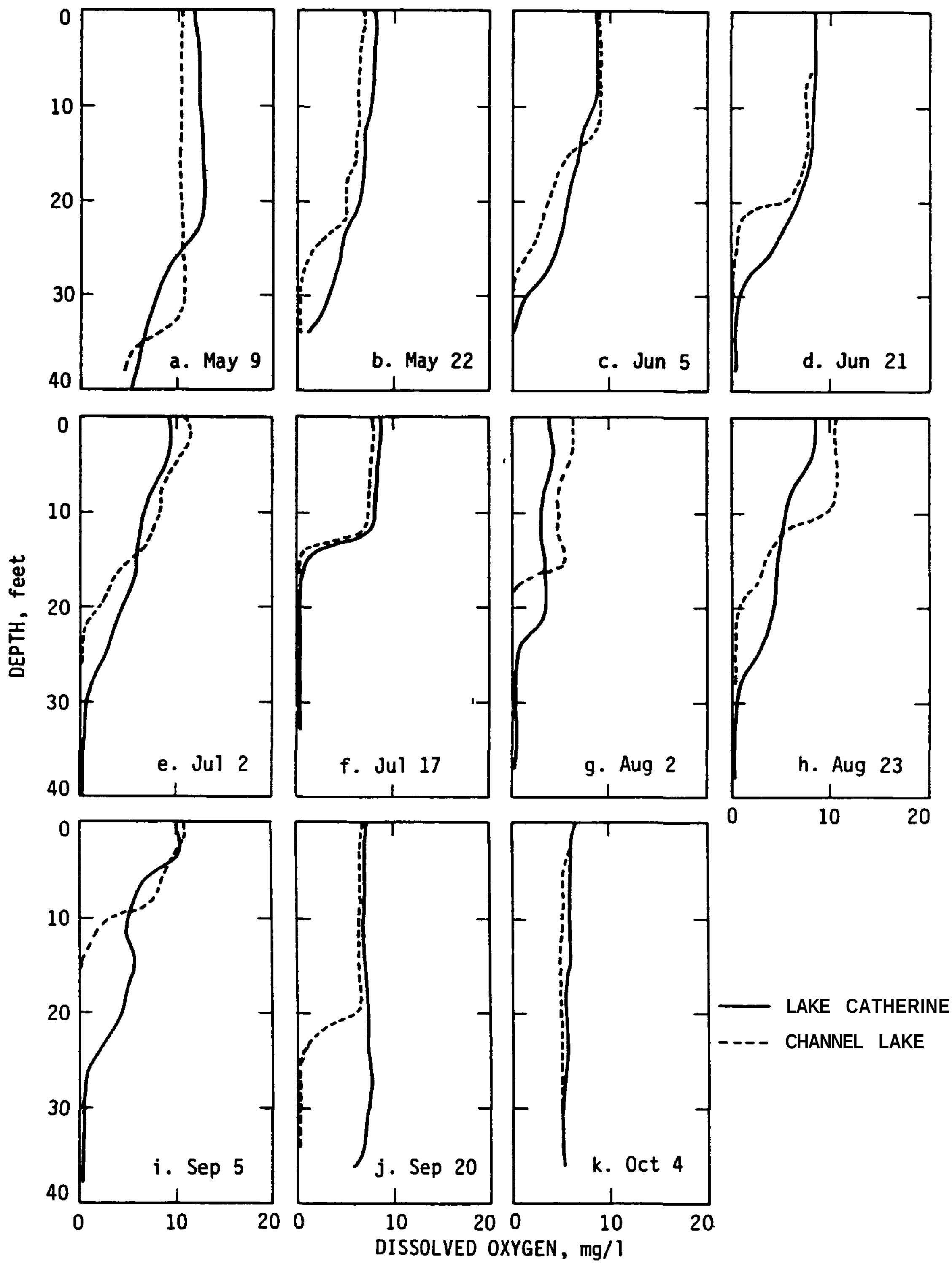

Figure 57. Dissolved oxygen concentration profiles for Lake Catherine station 1 and Channel Lake on selected dates, 1979

surface were reduced to zero just two days after the aerator system broke down on July 14, 1979. Up to that time at least 1 mg/l of dissolved oxygen was being maintained at the 25-30 foot depth.

Figure 58 shows the temporal variations in dissolved oxygen at different depths in Lake Catherine and Channel Lake in 1979. Although there was a perceptible improvement in oxygen concentrations at depths between 15 and 25 feet from the surface, it was not as pronounced as during the first year of operation of the aerator (Kothandaraman et al., 1979), probably because of the breakdown in the aerator system during the critical period of operation, July 14 to July 26, 1979. Figure 59 shows the variations in percent DO saturation at different depths in Lake Catherine and Channel Lake. Again, these were not as significant as for the earlier year.

1980. The effects of artificial destratification/aeration on the oxygen resources of Lake Catherine in 1980 are shown in figures 60 and 61. Figure 62 shows the isopleth plots of dissolved oxygen for Channel Lake. There was practically no oxygen at depths below 15 feet during summer months in Channel Lake. However, Lake Catherine was found to be well oxygenated throughout the water column at station 2 (figure 61).The oxygen levels in Lake Catherine at station 1 improved significantly to a depth of 25 feet from the surface compared to the preaeration results (figure 60).

Dissolved oxygen profiles for Lake Catherine station 1 and Channel Lake for 1980 are shown in figure 63. The zone and extent of oxygen resources supplemented by the aerator in Lake Catherine are clearly brought out in this figure. It should be noted that during summer months dissolved oxygen levels were near zero in Channel Lake at depths below 15 feet, whereas the aerator was able to maintain sufficient dissolved oxygen levels throughout Lake Catherine in the zone between 15 and 25 feet from the surface.

Figure 64 shows temporal variations in dissolved oxygen at different depths in Lake Catherine and Channel Lake in 1980. There was no significant difference in dissolved oxygen content in the lakes at the surface or at 6-foot, 12-foot, or 30-foot depths. However, a perceptible improvement in oxygen concentrations at 18- and 24-foot depths was observed.

Secchi Disc Transparency. Secchi disc transparency is a measure of lake water transparency or its ability to allow light transmission. Among the lakes of the Fox Chain, Lake Catherine has exhibited the highest secchi disc readings. During the 1975 survey of the lakes (Kothandaraman et al., 1977), Lake Catherine had minimum, mean, and maximum values of 27, 58, and 180 inches, respectively. The corresponding 1975 figures for Channel Lake were 24, 43, and 104 inches. The observations for these two lakes were much higher than for any other lake in the Fox Chain. A comparison of the secchi disc values in these two lakes for the years 1975, 1977, 1978, and 1979 is shown in table 14. The secchi disc readings observed in Lake Catherine and Channel Lake in 1978 were no better than the observations for 1975, and were comparable in the years 1977, 1978, and 1979.

1977 and 1978. The temporal variations in secchi disc values for Lake Catherine and Channel Lake in 1977 and 1978 are shown in figure 65. In 1977,

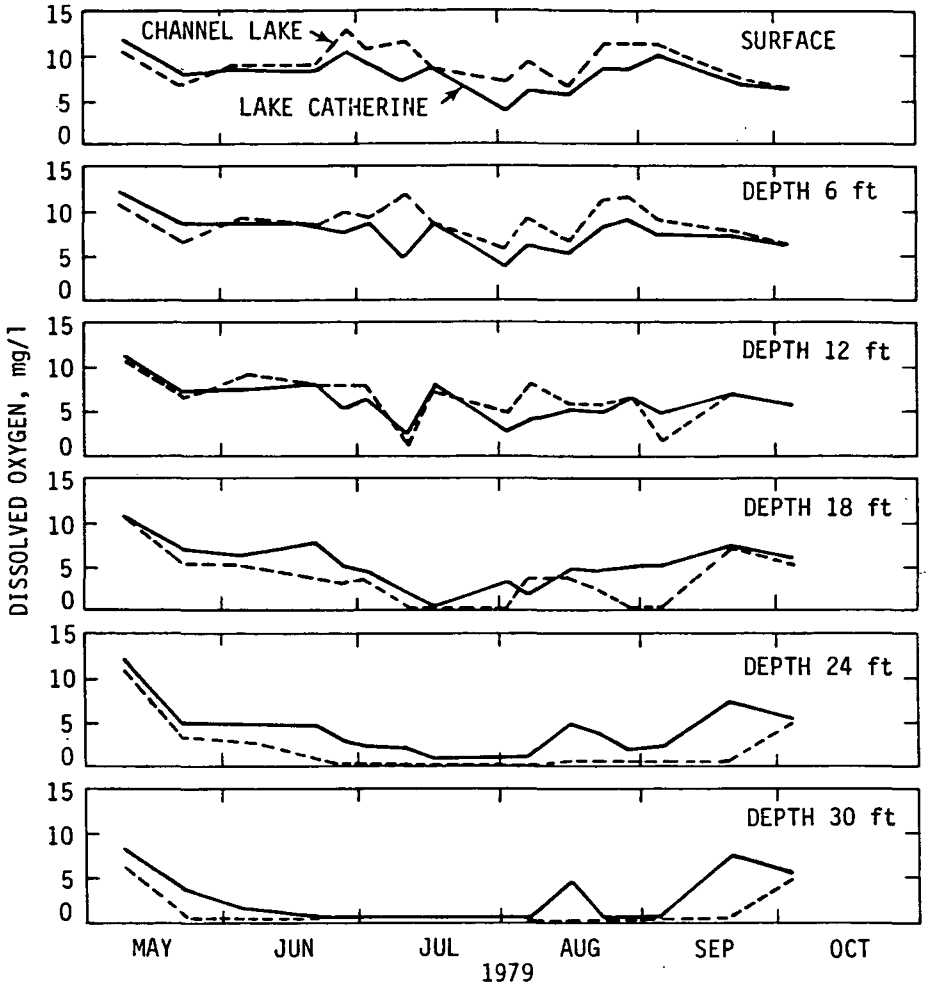

Figure 58. Temporal variations in dissolved oxygen concentrations in Lake Catherine station 1 and Channel Lake, 1979

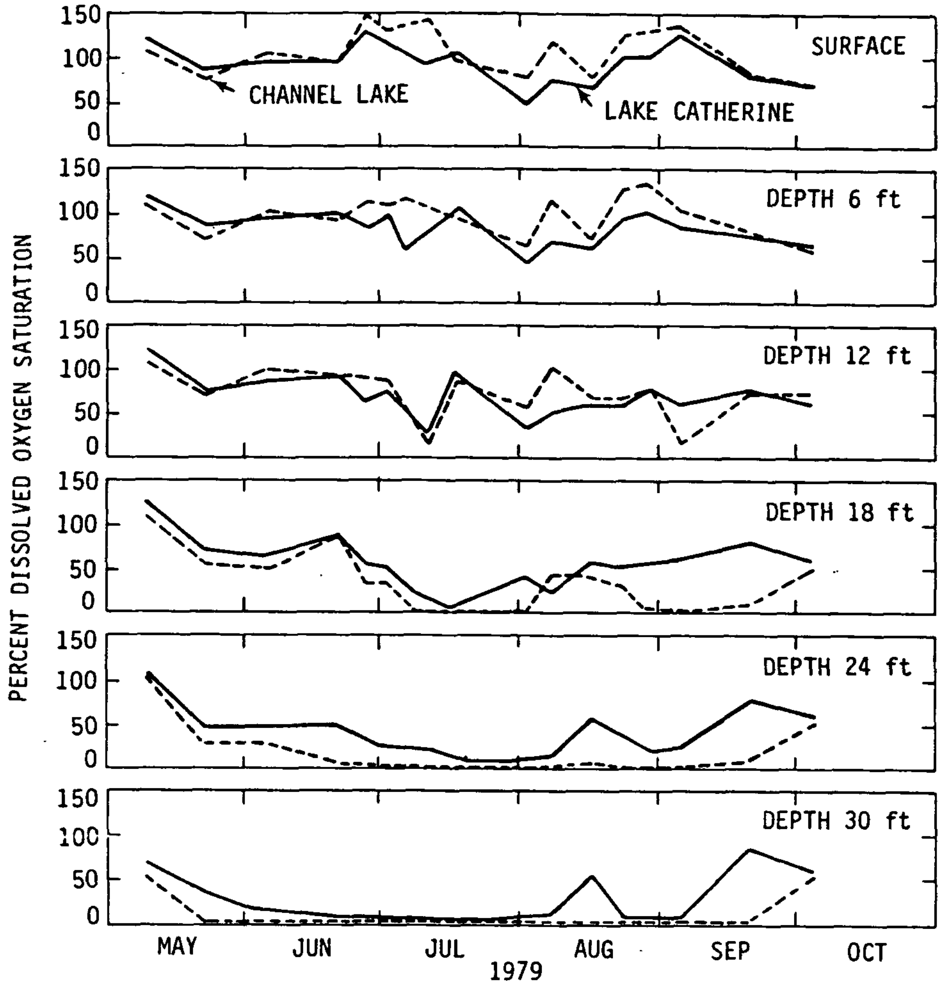

Figure 59. Percent oxygen saturation concentrations at different depths in Lake Catherine station 1 and Channel Lake, 1979

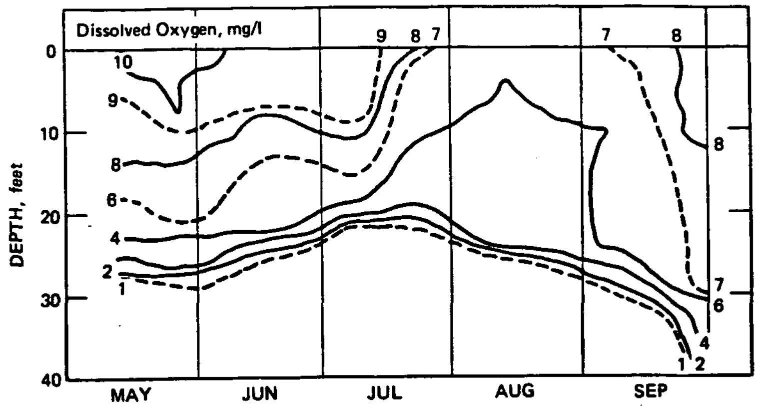

Figure 60. Isopleths of dissolved oxygen, in mg/l, for Lake Catherine station 1, 1980

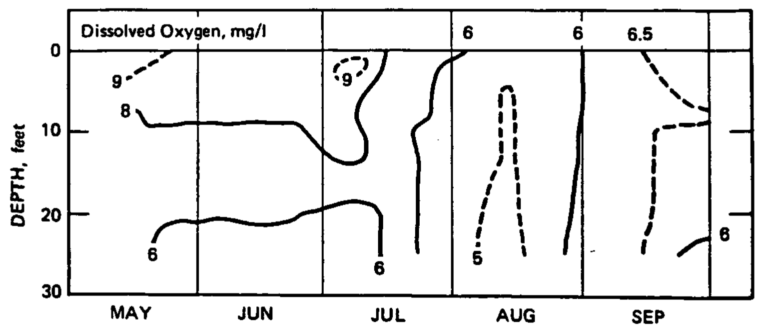

Figure 61. Isopleths of dissolved oxygen, in mg/l, for Lake Catherine station 2, 1980

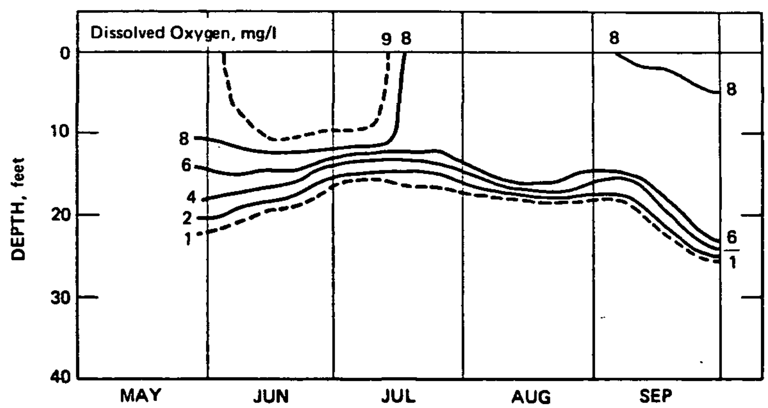

Figure 62. Isopleths of dissolved oxygen, in mg/l, for Channel Lake, 1980

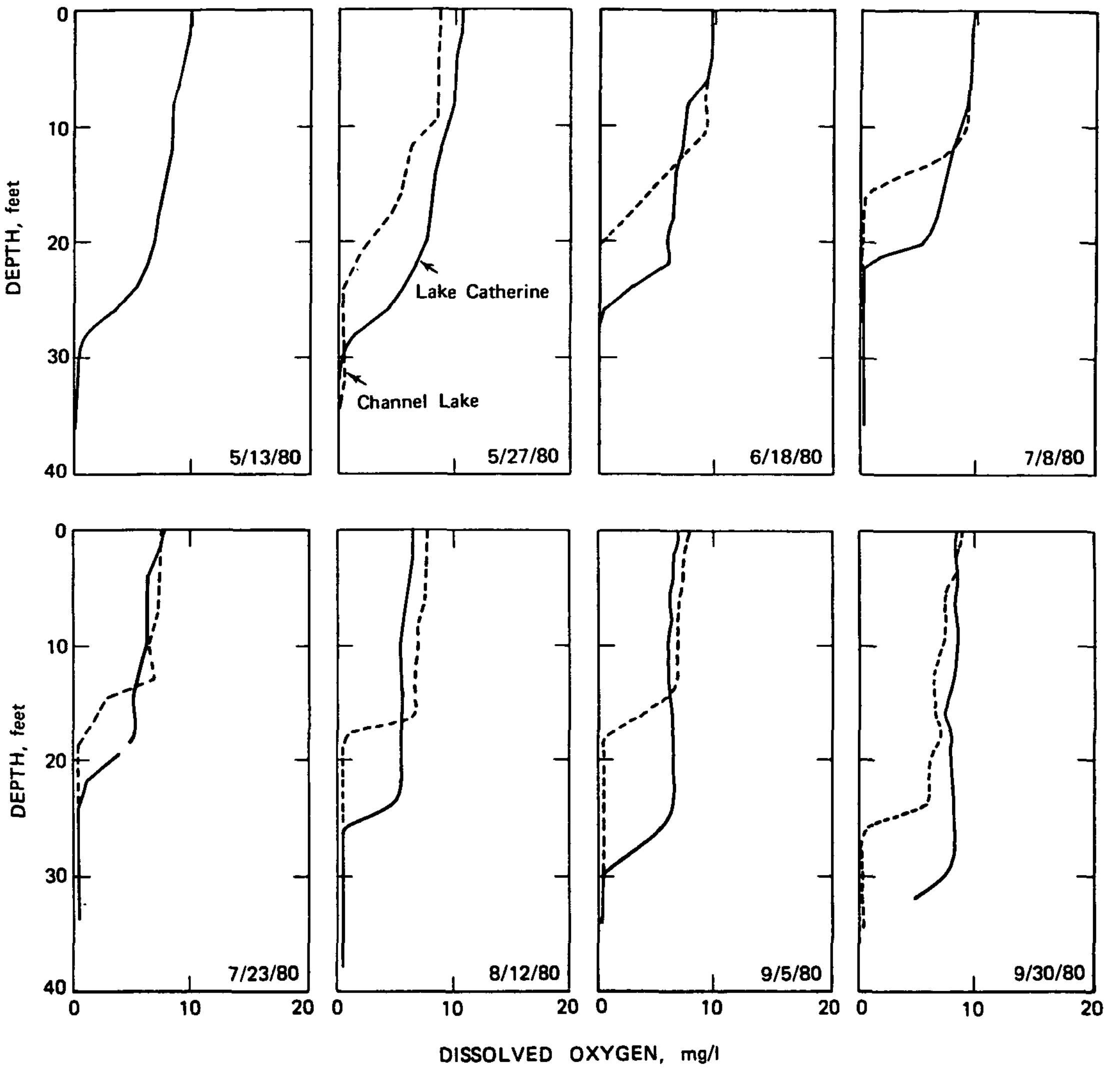

Figure 63. Dissolved oxygen concentration profiles for Lake Catherine station 1 and Channel Lake, 1980

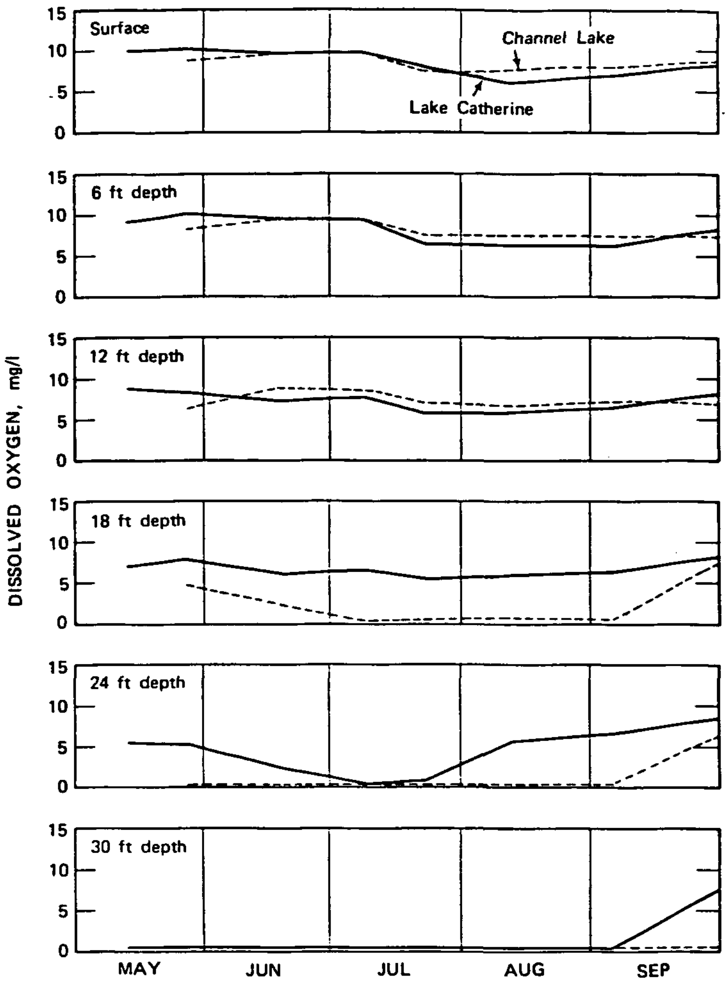

Figure 64. Temporal variations in dissolved oxygen concentrations in Lake Catherine station 1 and Channel Lake, 1980

Table 14. Comparison of Secchi Disc Values in Lake Catherine and Channel Lake (Transparency values in inches)

	Lake Catherine			*Channel Lake*		
	Minimum	*Mean*	*Maximum*	*Minimum*	*Mean*	*Maximum*
1975	27	58	180	24	43	104
1977	33	45	69	27	36	60
1978	30	48	99	27	40	75
1979	27	44	84	24	36	81

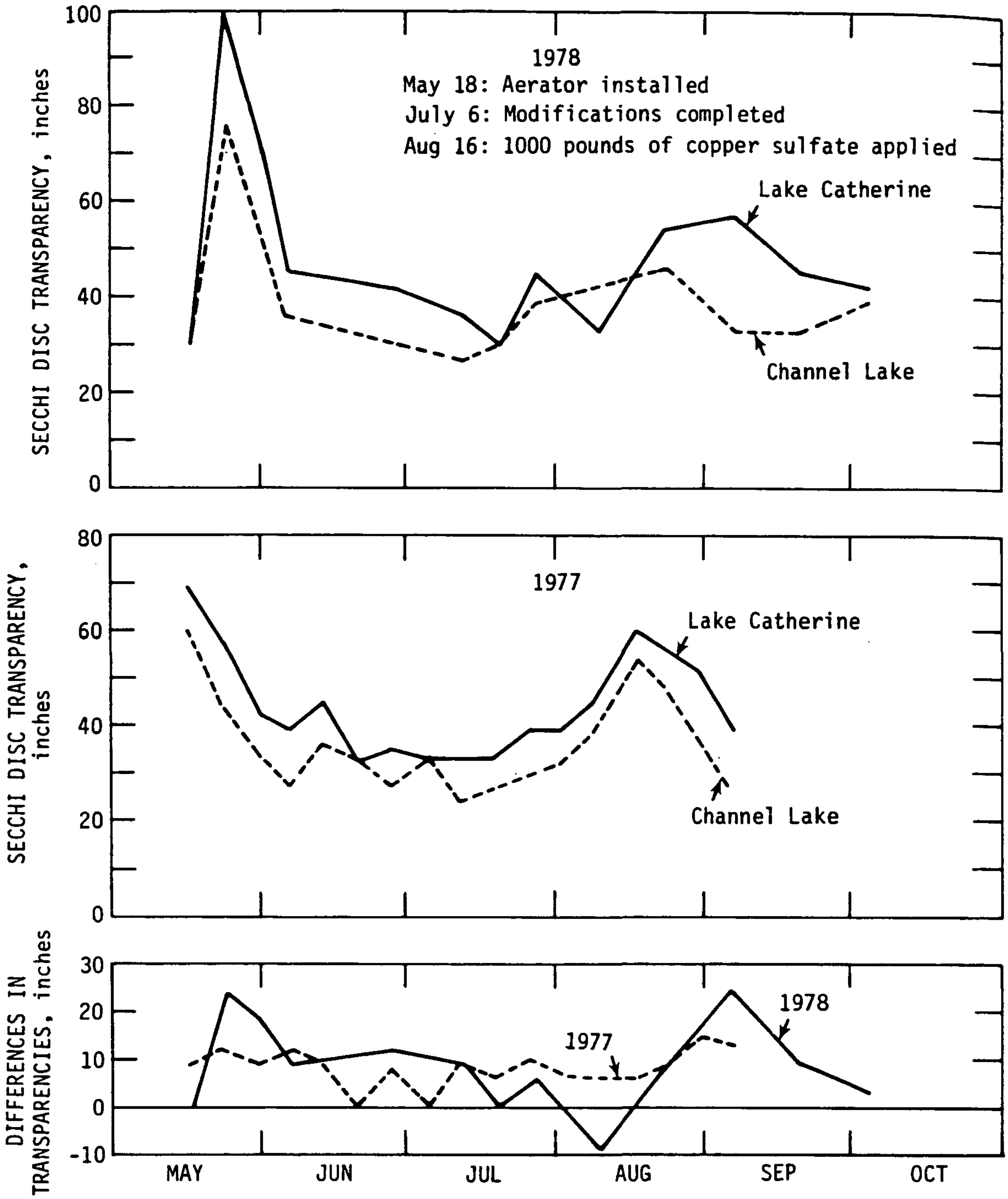

Figure 65. Transparencies in Lake Catherine and Channel Lake, 1977 and 1978

all of the values for Lake Catherine were above those for Channel Lake except on two occasions when they were equal. In 1978, only one Lake Catherine observation showed a smaller secchi disc reading than Channel Lake. Figure 65 also shows a plot of the variations in differences in the secchi disc readings for these two lakes. A statistical analysis was performed to test whether these differences for 1978 were significantly different from those for 1977. No significant differences could be discerned.

1979. The temporal variations in secchi disc observations for Lake Catherine and Channel Lake for 1979 are shown in figure 66. The days on which chemical treatment was used in Lake Catherine to control algae are also noted on the figure. Secchi disc observations in Lake Catherine appeared to increase after each copper sulfate application, but these improvements in clarity could not be sustained for long, probably because of an ingress of wind-swept algae from Channel Lake. Occurrences of this nature have masked the beneficial effects of controlling blue-green algae by copper sulfate in combination with aeration. Generally, the transparencies of these two lakes observed during 1979 were not significantly different from those observed in the past.

In 1979 the aerator did not cause an improvement in the clarity of the lake. This is contrary to the experience in Kezar Lake in Sutton, New Hampshire (New England Regional Commission, 1971, 1973a, 1973b), where compressed air was found to improve the clarity of the lake significantly. On the other hand, start-up operations of the aerator did not cause any increase in lake water turbidity as was initially anticipated.

1980. The minimum, mean, and maximum secchi disc readings observed in Lake Catherine during 1980 were, respectively, 32, 71, and 137 inches. The corresponding values for Channel Lake were 32, 40, and 53. The temporal variations in secchi disc observations in these two lakes are shown in figure 67. The days of chemical treatment to control algae are also noted in the figure. Secchi disc observations in Lake Catherine appear to have increased after chemical treatment. Transparency in Lake Catherine during July, August, and September was significantly higher than in Channel Lake.

Biological Characteristics

Algae. One of the major objectives of the water quality management of the Fox Chain of Lakes is to control the proliferation of the problem-causing blue-green algae. The total productivity of the lakes cannot be reduced until the nutrient input to them, both from external and internal sources, is controlled and reduced drastically. However, there are cases reported in the literature which suggest that a beneficial effect of aeration is the shifting of the dominant algal species from problem-causing blue-greens to greens and diatoms. The notable examples are the experiences in Kezar Lake in Sutton, New Hampshire (New England Regional Commission, 1971, 1973a, 1973b), and in Boltz Lake in northern Kentucky (Symons, 1969). In the latter case, a reduction in the total algal counts was also reported.

1977 and 1978. The total algal counts and the species distribution of algae found at three different depths in Lake Catherine (station 1) and Channel

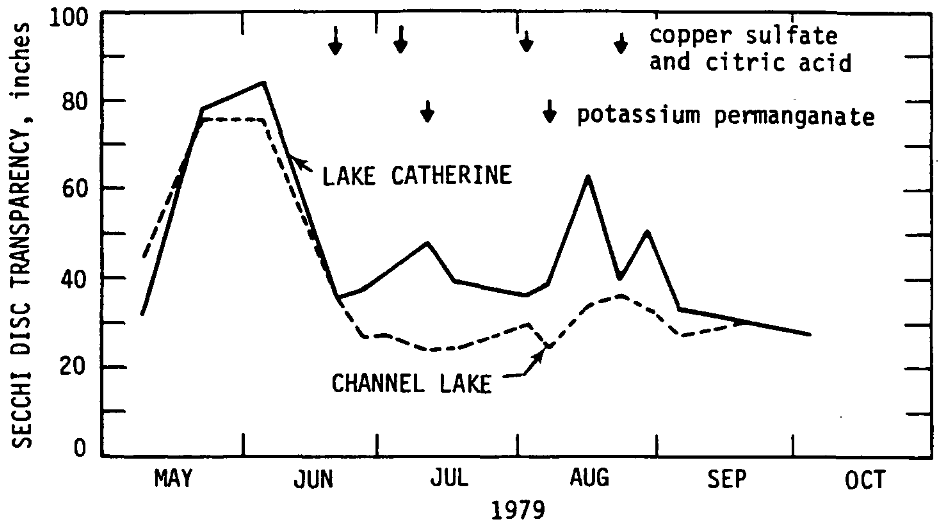

Figure 66. Transparencies in Lake Catherine and Channel Lake, 1979

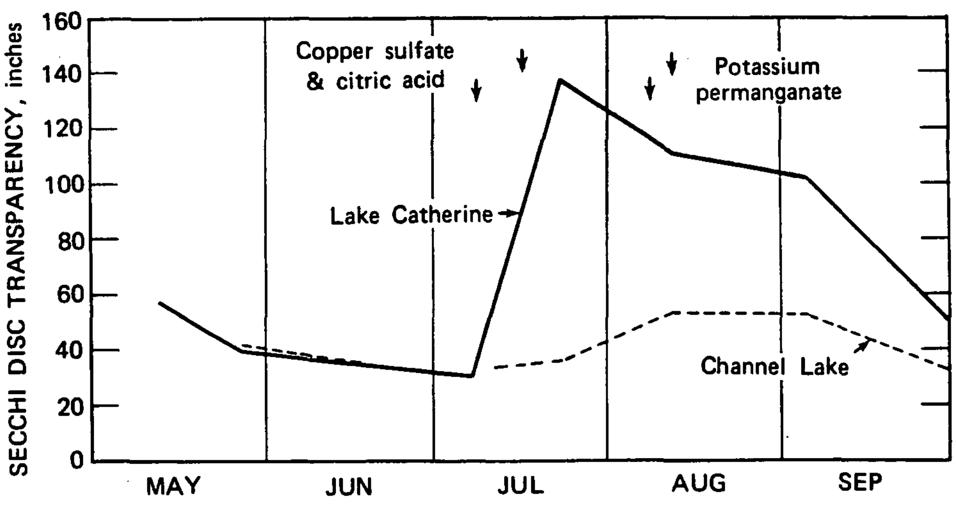

Figure 67. Transparencies in Lake Catherine and Channel Lake, 1980

Lake during 1977 and 1978 are shown in table 15 and table 16, respectively. The temporal variations in the total algal densities in these two lakes for 1977 and 1978 are plotted in figure 68.

Figure 68 clearly indicates that the surface algal densities in Lake Catherine in 1978 were much lower than in 1977. For Channel Lake, they were lower in 1978 than in 1977 until mid-July, when they became comparable. Similar trends are discernible for mid-depth and deep sampling points in both lakes. Contrary to past experiences, algal scums were absent during 1978 in Lake Catherine and in Channel Lake. The algal densities in the two lakes were generally less than in the previous two monitoring periods. This could be the result of the increased flushing rate experienced by the lake system during 1978 as indicated by the hydrograph for the Fox River at Wilmot, Wisconsin (figure 34).

The surface algal densities in Lake Catherine generally were found to be lower than those in Channel Lake. However, the densities at the deep sampling point in Lake Catherine were higher than in Channel Lake. This is clearly a result of the mixing of the hypolimnetic waters of Lake Catherine with its surface waters.

The dominance of algal species observed in the two lakes was examined by computing the ratio of the blue-green densities for each water sample to the total algal densities. These ratios were computed for the observations made in 1977 and 1978, and the results are plotted in figure 69. The dominance of the blue-green algae increased in 1978 in both lakes; thus the anticipation that aeration in Lake Catherine would cause a shift in dominance from blue–green to other desirable species did not materialize in 1978. However, no aesthetic problems from blue-greens were experienced because lower algal densities prevailed in 1978 than in the immediate past few years.

<u>1979</u>. The results for 1979 in Lake Catherine were different from those for 1978, probably because of the periodic chemical treatment instituted in Lake Catherine and the continued aeration for the second year. The total algal counts and the species distributions of algae found at three different depths in Lake Catherine (station 1) and Channel Lake in 1979 are shown in table 17. The temporal variations in the total algal densities in these two lakes are shown in figure 70. Algal densities at the surface and mid-depth in Lake Catherine were generally less than in Channel Lake. Observations made in these lakes during 1977 (Kothandaraman et al., 1978) as presented in table 18 indicate that the algal densities were generally comparable prior to aeration in Lake Catherine. The data presented for 1979 clearly indicate a reduction in total algal counts in Lake Catherine. This is not just because of the redistribution of algae throughout the water column. If that were the case, there would have been an increase in algal densities in the deeper water samples of Lake Catherine compared with those of Channel Lake.

The increasing or decreasing trends in the algal densities in Lake Catherine very closely followed the trends in Channel Lake (figure 70). These trends in Lake Catherine sometimes went counter to the anticipated effects of copper sulfate application. Thus it can be concluded that the algal blooms in

Table 15. Algal Types and Densities for Lake Catherine Station 1 and Channel Lake, 1977
(Density in counts per milliliter)

	Surface						Mid-depth						Deep					
	B-G	G	*D*	*F*	O	*T*	*B-G*	G	*D*	*F*	O	*T*	*B-G*	G	*D*	*F*	O	*T*
Lake Catherine Station 1																		
5/16	400	1530	400	240	0	2570	0	710	0	670	0	1380	0	140	70	50	0	260
5/23	230	2470	390	0	0	3090	320	180	660	0	0	1160	30	110	0	0	0	140
5/31	530	1760	0	0	0	2290	250	850	190	0	0	1290	40	150	40	0	0	230
6/6	190	380	0	0	0	570	150	330	70	0	0	550	60	110	20	0	0	190
6/13	2840	640	1701	480	0	5661	1250	410	350	250	0	2260	110	50	10	10	0	180
6/20	2750	1460	1900	0	0	6110	2380	250	4760	0	0	7390	2060	430	1920	0	0	4410
6/27	1350	1160	630	0	0	3140	1530	1250	130	0	0	2910	1080	690	580	180	0	2530
7/5	860	1430	740	0	0	3030	50	50	50	0	0	150	10	40	30	0	0	80
7/11	1740	680	370	0	0	2790	240	310	140	0	0	690	120	470	130	0	0	720
7/18	1470	460	200	50	0	2180	870	1350	390	340	0	2950	1110	330	290	70	0	1800
7/26													610	160	40	0	0	810
8/1	2990	820	370	0	0	4180	650	110	90	0	0	850	70	70	20	0	0	160
8/8	1700	460	210	220	0	2590	500	40	80	0	0	620	90	10	10	0	0	110
8/17	2160	580	670	0	0	3410	1910	200	410	0	0	2520	80	20	110	0	0	210
8/22	1950	2090	840	0	0	4880	1161	650	710	0	0	2521	240	100	470	0	0	810
8/30	250	240	130	0	0	620	80	30	70	30	0	210	40	60	50	0	0	150
9/6	440	230	30	0	0	700	60	50	30	0	0	140	30	90	50	0	0	170
Channel Lake																		
5/16	330	600	0	50	0	980	0	620	0	0	100	720	0	110	0	0	30	140
5/23	440	2080	270	0	10	2800	0	470	70	0	10	550	0	260	0	0	30	290
5/31	1070	2290	140	10	0	3510	230	740	0	0	0	970	10	150	160	0	0	320
6/6	390	370	20	0	0	780	360	80	220	0	0	660	590	170	120	0	0	880
6/13	2490	450	200	200	0	3340	1840	600	160	250	0	2850	450	130	140	0	0	720
6/20	2080	550	1060	0	0	3690	1310	560	900	0	0	2770	1630	140	600	0	0	2370
6/27	1980	1410	200	0	0	3590	890	1140	0	0	0	2030	100	70	20	0	0	190
7/5	320	280	140	0	0	740	40	60	40	0	0	140	30	30	70	0	0	130
7/11	1380	350	890	70	0	2690	330	320	250	0	0	900	1380	860	750	130	0	3120
7/18	1620	140	140	0	0	1900	1700	370	230	150	0	2450	580	230	60	20	0	890
7/26	2470	170	300	0	0	2940	1480	220	710	260	0	2670	90	60	10	0	0	160
8/1	2860	220	590.	0	0	3670	1190	320	440	0	0	1950	170	40	20	0	0	230
8/8	1920	230	90	170	0	2410							90	40	10	0	0	140
8/17	320	260	200	20	0	800	330	50	250	0	0	630	20	20	90	0	0	130
8/22	3290	1410	490	0	0	5190	1460	1350	370	0	0	3180	150	190	140	0	0	480
8/30	360	350	110	0	0	820	110	40	30	0	0	180	80	90	30	0	0	200
9/6	80	90	30	0	0	200	90	50	40	0	0	180	30	70	30	0	0	130

Note: B-G = Blue-Greens; G = Greens; D = Diatoms; F = Flagellates; O = Other; and T = Total

Table 16. Algal Types and Densities for Lake Catherine Station 1 and Channel Lake, 1978
(Density in counts per milliliter)

	Surface						Mid-depth						Deep					
	B-G	*G*	*D*	*F*	*O*	*T*	*B-G*	*G*	*D*	*F*	*O*	*T*	*B-G*	*G*	*D*	*F*	*O*	*T*
Lake Catherine Station 1																		
5/10	220	130	200	0	0	550	200	290	210	0	0	700	150	150	40	0	0	340
5/17	250	90	310	0	0	650	240	200	50	0	0	490	110	10	10	0	0	130
5/24	260	10	50	0	0	320	130	20	30	0	0	180	70	30	10	0	0	110
5/31	300	120	0	0	0	420	150	0	50	0	0	200	140	50	0	0	0	190
6/6	380	340	10	0	10	730	200	110	0	0	0	310	150	90	30	0	0	270
6/27	480	30	10	0	0	520	320	20	0	0	0	340	90	0	0	0	0	90
7/12	350	70	30	0	0	450	250	40	30	0	0	320	140	30	10	0	0	180
7/19	2330	0	0	0	0	2330	1400	0	0	0	0	1400	960	0	0	0	0	960
7/27	1780	0	0	0	0	1780	1040	20	0	0	0	1060	270	0	0	0	0	270
8/9	560	0	100	10	0	770	350	20	10	0	0	380	80	50	0	0	0	130
8/23	900	0	90	0	60	1050	340	40	10	60	0	450	320	10	0	10	0	340
9/6	450	0	0	50	0	500	390	50	0	0	0	440	260	10	30	0	0	300
9/20	260	0	0	10	0	270	190	0	0	0	0	190	170	0	0	0	0	170
10/4	50	0	50	10	0	110	0	20	0	0	0	20	0	20	0	0	0	20
Channel Lake																		
5/10	260	250	360	0	0	870	60	140	80	0	0	280	10	10	10	0	0	30
5/17	270	140	200	0	0	610	110	100	20	0	0	230	70	20	50	0	0	140
5/24	90	120	0	0	10	220	40	30	0	0	70	140	60	30	0	0	0	90
5/31	300	180	310	0	0	790	170	200	0	20	0	390	110	40	0	0	0	150
6/6	530	0	120	20	0	670	220	90	100	0	0	410	70	30	30	0	0	130
6/27	750	0	0	40	0	790	350	20	0	0	0	370	130	0	0	0	0	130
7/12	710	300	200	10	0	1220	470	210	170	30	0	880	170	140	20	10	0	340
7/19	3260	0	0	0	30	3290	2420	10	0	0	0	2430	450	10	0	0	0	460
7/27	3480	20	0	0	160	3660	1370	50	0	0	300	1720	460	10	0	0	0	470
8/9	2090	70	0	0	150	2310	1160	10	120	0	260	1550	460	0	0	0	40	500
8/23	1660	30	0	0	0	1690	920	40	40	0	0	1000	430	0	0	0	0	430
9/6	820	0	0	60	0	880	430	10	20	10	0	470	120	30	0	0	0	150
9/20	620	90	0	0	0	710	190	0	0	70	0	260	80	0	0	0	0	80
10/4	120	10	30	20	0	180	40		20	10	0	70	0	0	10	10	0	20

Note: B-G = Blue-Greens; G = Greens; D = Diatoms; F = Flagellates; O = Other; and T = Total

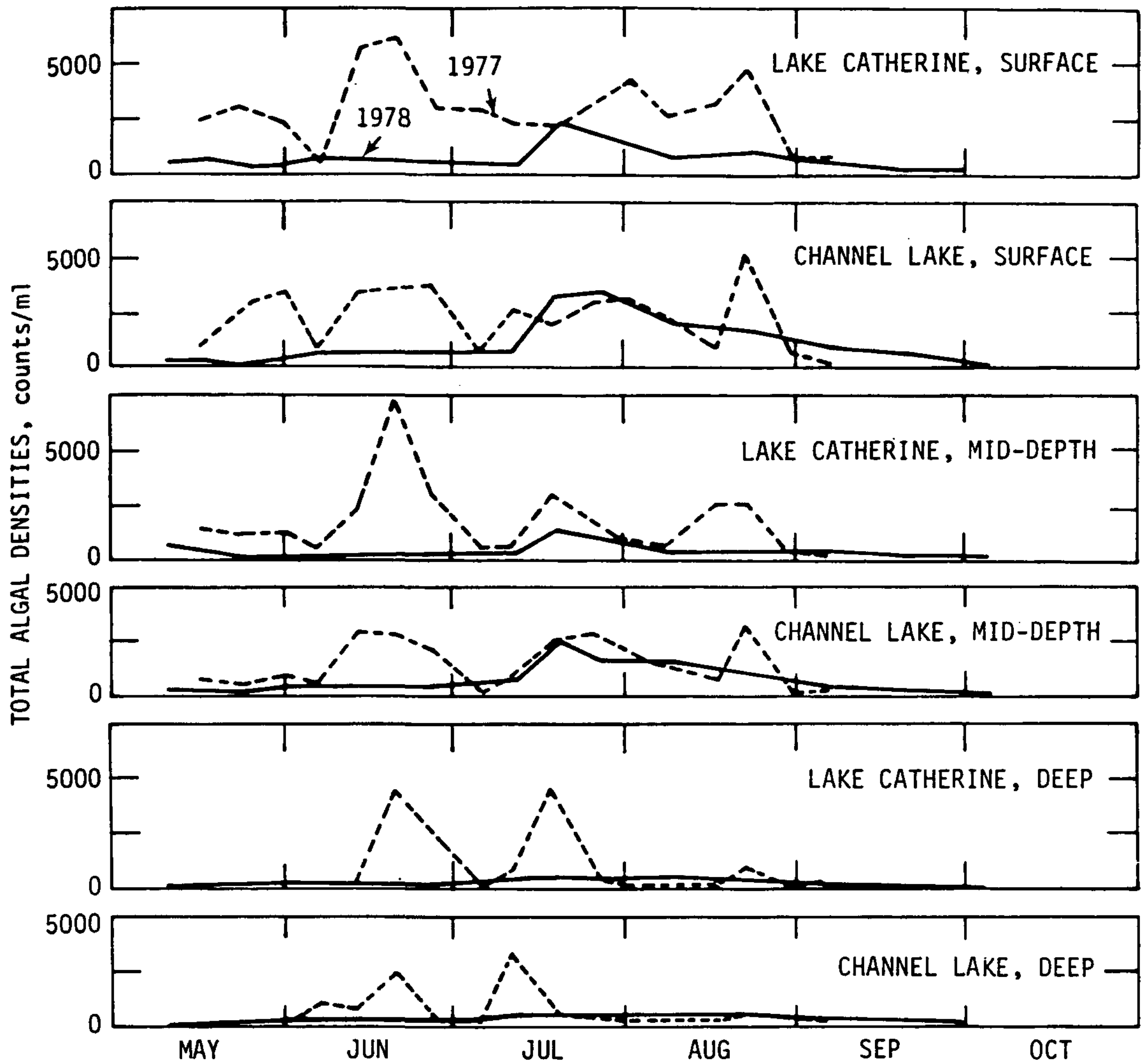

Figure 68. Total algal densities in Lake Catherine and Channel Lake, 1977 and 1978

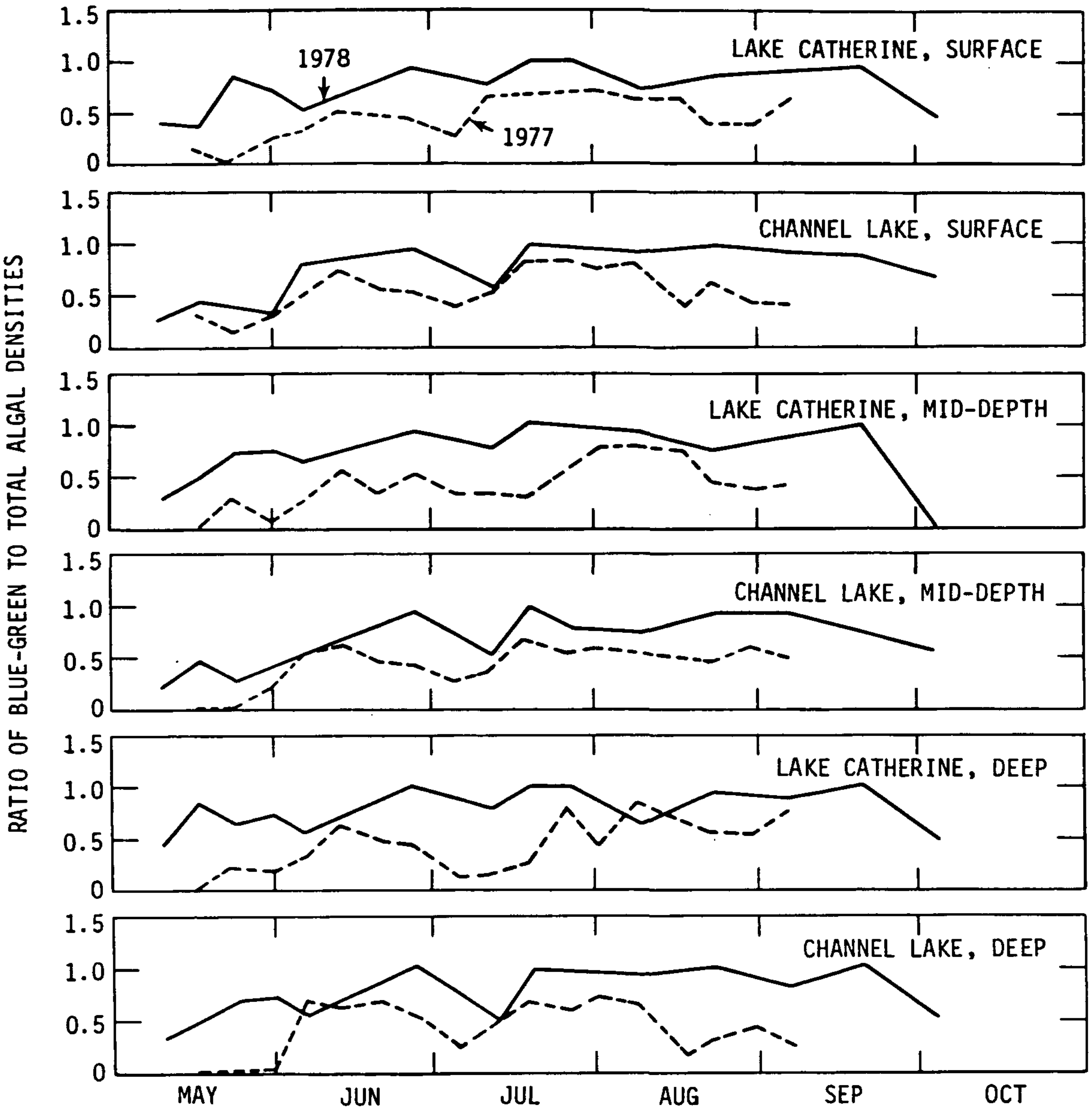

Figure 69. Relative dominance of blue-green algae in Lake Catherine and Channel Lake, 1977 and 1978

Table 17. Algal Types and Densities for Lake Catherine Station 1 and Channel Lake, 1979
(Density in counts per milliliter)

	Surface						Mid-depth						Deep					
	B-G	*G*	*D*	*F*	*O*	*T*	*B-G*	*G*	*D*	*F*	*O*	*T*	*B-G*	*G*	*D*	*F*	*O*	*T*
Lake Catherine Station 1																		
5/9	0	40	2040	0	0	2080	0	70	2680	0	0	2750	0	0	1690	0	0	1690
5/22	0	0	2010	330	0	2340	0	0	1770	170	0	1940	0	0	1500	30	0	1530
6/5	650	1340	0	170	0	2170	1350	270	90	0	0	1710	1060	140	0	0	0	1200
6/21	4750	230	70	250	0	5300	2060	120	300	180	0	2660	0	10	10	0	0	20
7/2	6110	170	60	0	0	6340	2180	90	70	240	0	2580	60	40	20	0	0	120
7/11	4570	120	200	0	0	4890	2710	20	20	0	0	2750	90	0	30	0	0	120
7/17	4330	40	0	210	0	4580	3160	0	50	190	0	3300	130	0	50	0	0	180
8/1	3090	0	430	300	0	3820	1120	0	80	330	0	1530	40	0	30	0	0	70
8/16	4170	40	510	1060	0	5780	2160	0	0	0	0	2160	70	0	20	0	0	90
8/23	4080	0	1300	1470	0	6850	2160	0	0	0	0	2160	60	0	10	10	0	80
8/29	150	0	1350	0	0	1500	0	80	340	0	0	420	10	0	20	0	0	30
9/5	1710	0	1560	0	0	3270	900	0	770	0	0	1670	30	10	100	0	0	140
9/20	290	0	30	190	0	510	0	120	50	70	0	240	0	10	10	10	0	30
10/4	340	10	0	650	0	1000	170	0	40	230	0	440	0	0	20	20	0	40
Channel Lake																		
5/9	0	0	1290	0	0	1290	0	0	1490	0	0	1490	50	20	1810	10	0	1890
5/22	0	0	1340	0	0	1340	0	0	1490	30	0	1520	0	0	1660	0	0	1660
6/5	220	340	50	290	0	900	400	360	0	0	0	760	370	10	0	0	0	380
6/21	5100	0	70	170	0	5340	2400	0	10	80	0	2490	10	0	0	20	0	30
7/2	7960	0	140	0	0	8100	2730	180	0	0	0	2910	40	0	50	10	0	100
7/11	3270	0	290	60	0	3620	2520	0	0	330	0	2850	170	0	30	40	0	240
7/17	6070	0	0	270	0	6340	3800	190	0	490	0	4480	160	0	10	60	0	230
8/1	4840	140	80	480	0	5540	3020	0	0	560	0	3580	200	0	20	40	0	260
8/16	5930	0	0	350	0	6280	810	0	120	460	0	1390	170	0	0	10	0	180
8/23	8960	0	0	810	0	9770	3610	0	210	740	60	4620	760	0	70	110	0	940
8/29	5170	0	0	1710	0	6880	2350	0	280	130	0	2760	130	0	0	20	0	150
9/5	4260	80	220	1380	0	5940	2540	0	30	870	0	3440	190	0	0	0	0	190
9/20	830	0	130	980	0	1940	270	0	0	390	0	660	30	0	10	30	0	70
10/4	1300	70	0	820	0	2190	670	0	60	380	0	1110	50	0	0	40	0	90

Note: B-G = Blue-Greens; G = Greens; D = Diatoms; F = Flagellates; O = Others; and T = Total

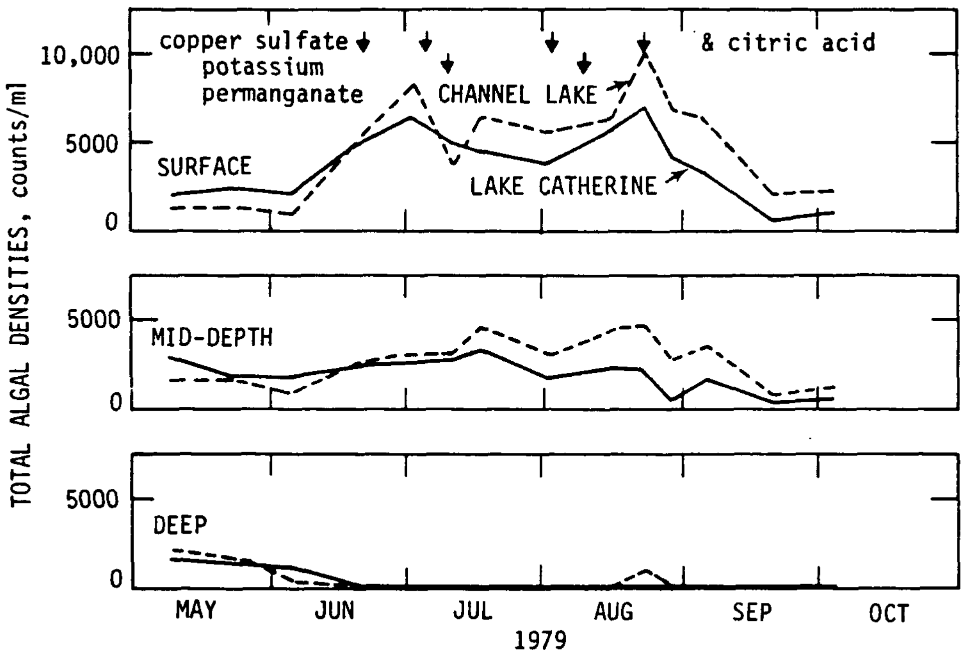

Figure 70. Total algal densities in Lake Catherine station 1 and Channel Lake, 1979

Table 18. Total Surface Algal Densities in Lake Catherine and Channel Lake, 1977

(Counts per milliliter)

Date 1977	Lake Catherine	Channel Lake
5/6	2570	980
5/23	3090	2790
5/31	2290	3500
6/6	570	780
6/13	3100	3340
6/20	6110	3690
6/27	3140	3590
7/5	3030	740
7/11	2790	2690
7/18	2180	1900
7/26		2940
8/1	4180	3670
8/8	2590	2410
8/17	3410	800
8/22	4880	5190
8/30	620	820
9/6	700	200

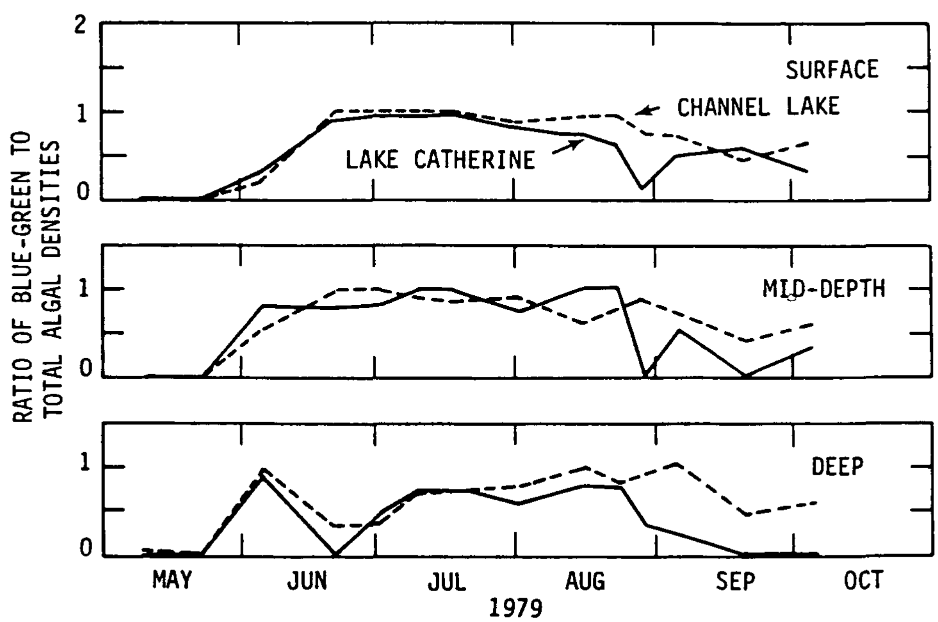

Figure 71. Relative dominance of blue-green algae in Lake Catherine and Channel Lake, 1979

Channel Lake overwhelmed the beneficial effects of aeration and chemical treatment in Lake Catherine. Nevertheless, there was a discernible trend in Lake Catherine toward a decrease in algae (figure 70) and a decrease in the dominance of blue-green algae (figure 71).

1980. The total algal counts and the species distribution of algae found at three different depths in each lake in 1980 are shown in table 19. The chlorophyll-a concentrations observed in the lakes are also included in this table. The temporal variations in total algal counts are plotted in figure 72 and those for chlorophyll-a in figure 73.

Blue-green algae remained the dominant species in both Lake Catherine and Channel Lake. Unlike the 1979 observations in Lake Catherine, when there was a perceptible shift from blue-green dominance to greens and diatoms compared to the observations in Channel Lake, such a trend was not noticeable in 1980. However, the total algal counts in both the lakes during 1980 were less than those observed during 1979. The highest algal count values in Lake Catherine and Channel Lake during 1980 were respectively 2790 and 3680. Highest values observed in these lakes during 1979 were respectively 6850 and 8100.

No definitive conclusion can be drawn concerning the beneficial effects of aeration on algal control in Lake Catherine based on 1980 operation results. Algal counts in the surface samples of Lake Catherine were higher than for Channel Lake in four out of six observations made in 1980. However, the water clarity in Lake Catherine was much higher than in Channel Lake (figure 67). Also, chlorophyll-a concentrations of the surface and mid-depth samples were significantly lower than the values for Channel Lake (table **19).**

Plankton Biomass. Details of observations of plankton biomass and percent ash-free weights in the surface water samples of Lake Catherine and Channel Lake in 1979 are shown in table 20. Until the early part of August 1979, the biomass in Lake Catherine was comparable to or much less than that in Channel Lake, but the trend later reversed. The mean percent ash-free weight of the biomass in Lake Catherine was observed to be 39.3, as opposed to a value of 50.0 for Channel Lake. Similar analyses were not performed during the preaeration periods in these lakes, and consequently a comparison with earlier periods could not be made.

Zooplankton. Samples for zooplankton identification and enumeration were collected during 1979 and 1980.

1979. Table 21 shows the 1979 zooplankton data for Lake Catherine and Channel Lake. The species diversity in these two lakes appears similar. Total zooplankton counts in Lake Catherine were higher on two occasions and lower on two occasions than in Channel Lake. No clear-cut differences could be identified, largely because of the location of sampling station 1 in Lake Catherine with respect to Channel Lake. No observation for phytoplankton or zooplankton was made near the aerator. Sport fishing activities around the aerator were very intense throughout the season, and fishing was reported to be good. It is presumed that, in addition to higher oxygen levels in the vicinity

Table 19. Algal Types and Densities for Lake Catherine Station 1
and Channel Lake, 1980

(Algal density in counts per milliliter; chlorophyll-a in milligrams per cubic meter)

	Surface						*Mid-depth*						*Deep*					
	B-G	***G***	***D***	***F***	***T***	***Chl-a***	***B-G***	***G***	***D***	***F***	***T***	***Chl-a***	***B-G***	***G***	***D***	***F***	***T***	***Chl-a***
Lake Catherine Station 1																		
6/18	2540	140	30	80	2790	10.4	1130	90	10	10	1240	8.1	410	80	50	10	550	5.3
7/7	2170	0	10	0	2180	7.6	2280	10	0	60	2350	12.7	210	10	20	0	240	13.0
7/24	270	0	30	0	300	3.6	390	50	20	100	560	3.3	2060	20	0	70	2150	5.4
8/12	50	210	30	0	290	1.3	0	110	30	10	150	1.4						4.6
9/5	2400	30	130	90	2650	3.6	30	30	10	30	100	3.2	210	20	0	60	290	3.8
9/29	900	130	210	20	1260	20.1	420	60	500	190	1170	20.2	550	120	350	310	1330	19.2
Channel Lake																		
6/18	2260	70	40	30	2400	22.3	330	20	20	0	370	2.7	280	30	0	0	310	4.0
7/7	3590	10	0	80	3680	10.8	2620	20	0	60	2700	15.0	180	10	10	50	250	4.5
7/24	30	0	10	20	60	8.7	40	0	60	30	130	5.5	10	20	0	850	880	4.4
8/12	30	50	0	100	180	0.4	1640	90	20	60	1810	10.0	110	30	10	0	150	14.9
9/5	120	110	50	620	900	12.3	1260	70	50	100	1480	8.4	120	10	30	0	160	3.7
9/29	2610	140	110	0	2860	32.2						292.5	1650	100	60	30	1840	5.3

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

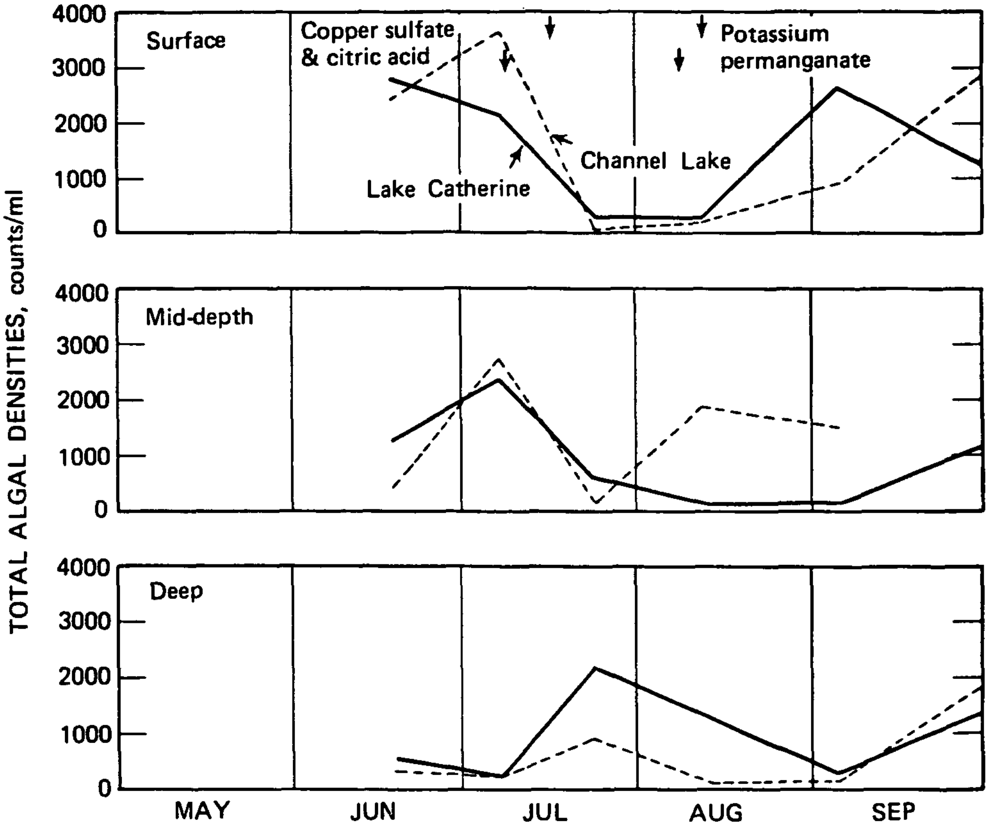

Figure 72. Total algal densities in Lake Catherine station 1 and Channel Lake, 1980

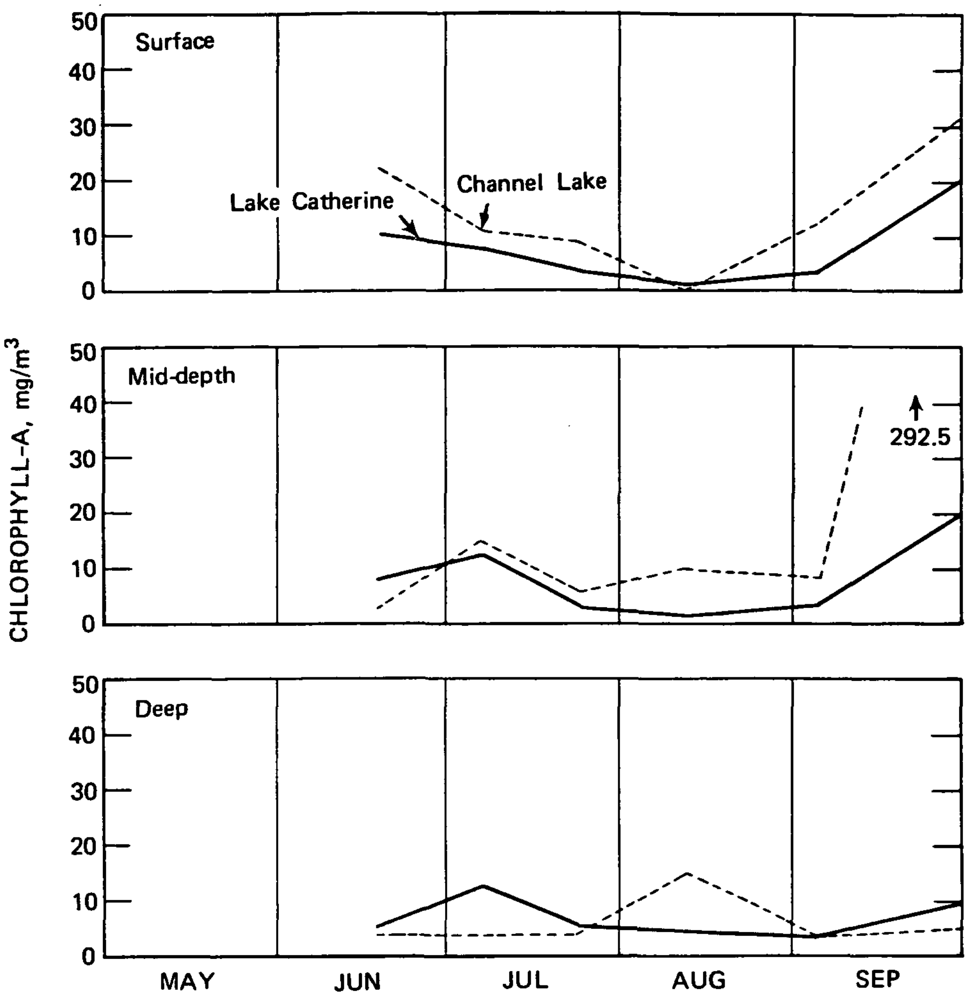

Figure 73. Chlorophyll-a concentrations in Lake Catherine station 1 and Channel Lake, 1980

Table 20. Plankton Biomass in Lake Catherine and Channel Lake, Surface Samples, 1979

	Lake Catherine		*Channel Lake*	
Date 1979	*Plankton biomass, mg/l*	*Percent asb-free weight*	*Plankton biomass, mg/l*	*Percent ash-free weight*
5/22	0.795	39.6	0.735	38.8
6/5	0.820	48.8	1.085	44.2
6/21	1.675	40.6	1.695	41.0
7/2	1.355	30.3	2.830	52.5
7/17	1.180	36.9	2.555	36.6
8/1	1.100	35.0	1.200	45.4
8/22	1.905	37.8	1.040	55.2
9/5	1.315	39.9	2.850	77.7
9/20	3.365	50.5	2.090	72.2
10/4	2.660	33.5	2.190	36.3

Table 21. Zooplankton in Lake Catherine and Channel Lake, 1979

(Counts per liter)

	6/21/79			7/17/79			8/22/79			9/19/79		
	Surface	*Mid-depth*	*Deep*	*Surface*	*Mid-depth*	*Deep*	*Surface*	*Mid-depth*	*Deep*	*Surface*	*Mid-depth*	*Deep*
Lake Catherine, station 1												
Bosmina langirostris	250				350	100	450	300		150	200	
Ceriodapbnia lacustris			150									
Cyclops vernalis												
Daphnia dubia						150	400					
D. longiremis	850	300		300					200			
D. longispina							200					
D. pulex												
Diaptomus pallidus		150										-
D. sp.							150	150				
Senecella calanoides									100	250		
Total	1100	450	150	300	350	250	1200	450	300	400	200	0
Channel Lake station												
Bosmina langirostris	50	300		450		100			200	100	400	100
Ceriodapbnia lacustris												
Cyclops vernalis										300		
Daphnia dubia	50			200	150	50	250					
D. longiremis											150	
D. longispina								450				
D. pulex			300					200	150			
Diaptomus pallidus	150	250	50									
D. sp.				50			500			300		
Senecella calanoides												
Total	250	550	350	700	150	150	750	650	350	700	550	100

of the aerator, fish food organisms would have been adequate. Zooplankton form an important and significant link in the food chain.

1980. Table 22 shows the 1980 zooplankton data for Lake Catherine and Channel Lake. Total zooplankton counts were the highest at the surface samples in both the lakes. Lake Catherine had a higher total count at the surface than Channel Lake. At mid-depth, Channel Lake showed higher zooplankton density than Lake Catherine. At the deep stations in both lakes, cladocerans constituted the only group present.

Benthic Organisms. Benthic samples were obtained on numerous occasions during 1978, 1979, and 1980.

1978. The population of the benthic macroinvertebrate communities in sediments from the two lakes in 1978 is given in table 23. In both lakes, there was more than a tenfold increase in the number or organisms found in 1978 over the number found in 1975 (Kothandaraman et al., 1977). This may have been a result of the slightly elevated dissolved oxygen concentrations observed at the mud-water interface for the year 1978 compared with the values observed in 1975 at the same sampling locations. The highest numbers of organisms and taxa were found near the aerator at Lake Catherine station 2. The overwhelming dominance of *Chaoborus* in the benthic communities was found in all the samples obtained from these lakes.

1979. The population of the benthic macroinvertebrate communities in sediments from the two lakes in 1979 is given in table 24. The benthic population in Lake Catherine was found to be 58 percent *Chaoborus*, 37 percent Chironomidae, 4 percent *Hyalella*, and 1 percent Ceratopogonidae. In Channel Lake the benthos consisted of 94 percent *Chaoborus* and 6 percent Chironomidae. *Hyalella* and Ceratopogonidae were found only in Lake Catherine.

The well-oxygenated, shallow stations (A stations) in both lakes were characteristically dominated by the Chironomidae, while the deep, nearly anoxic stations (C stations) were dominated by *Chaoborus*. The majority of the samples at all the stations were dominated by Chironomidae in Lake Catherine and *Chaoborus* in Channel Lake.

The overall average number of benthic organisms in Lake Catherine and Channel Lake was 608 and 904 per square meter, respectively. A more complex macroinvertebrate benthic community with a healthier proportion of Chironomidae was found in Lake Catherine. Several extremely large *Chironomus* individuals (figure 74) were found in Lake Catherine samples, particularly near the aerator. Only one such individual was found in all the samples from Channel Lake. Increased dissolved oxygen concentration, increased water temperatures in the hypolimnetic zone of Lake Catherine, and other altered environmental factors caused by aeration might have been responsible for the very large growth of the *Chironomus* organisms.

1980. The 1980 population of the benthic macroinvertebrate communities in sediments from the two lakes is given in table 25. Generally, species diversity was the greatest at the inshore stations (C) in both lakes, followed by the

Table 22. Zooplankton in Lake Catherine and Channel Lake, 1980

(Counts per liter)

	Lake Catherine		*Channel Lake*	
	Copepods	*Cladocerans*	*Copepods*	*Cladocerans*
Surface	214	41	90	41
Mid-depth	53	28	69	55
Deep	0	7	0	7

Table 23. Count of Benthic Organisms in Lake Catherine and Channel Lake Sediments, 1978

(Counts per square meter)

	Lake Catherine station 2			*Lake Catherine station 1*			*Channel Lake*		
Organisms	***7/12***	***8/23***	***9/20***	***7/12***	***8/23***	***9/20***	***7/12***	***8/23***	***9/20***
Chaoborus	474	4148	1952	359	359	1134	1019	1191	2440
Chironomidae	29		14	29					
Hirudinea		14							

Table 24. Benthic Macroinvertebrates Found in Lake Catherine and Channel Lake, 1979

(Counts per square meter)

	5/22/79				6/22/1 '9				7/18/ 79				8/22/79				9/19/7 9			
	A	*B*	*C*	*Aer-ator*	*A*	*B*	*C*	*Aer-ator*	*A*	*B*	*C*	*Aer-ator*	*A*	6	*C*	*Aer-ator*	*A*	*B*	*C*	*Aer ator*
Lake Catherine																				
DO near bottom	*6.9*	4.3	1.0	0.8	7.9	6.9	0.1	0.1	7.9	0.2	0.1	0.1	5.2	4.2	0.2	1.6	6.9	7.1	6.0	8.1
Depth (ft)	15	25	34	32	15	20	38	34	11	20	34	32	10	20	38	26	12	18	36	26
Organism																				
Chironomidae	86	14	*29*	115	1263	1335		14	301	459	72	72	72	72		287	14			43
Cbauborus		545	1636	402			344	617			459	388	29	43	316	689			2440	1234
Ceratopogonidae																29				14
Hyalella					43	14			43				273				14	57		
Total organisms	86	559	1665	517	1306	1349	344	631	344	459	531	460	374	115	316	1005	28	57	2440	1291
Channel Lake																				
DO near bottom	6.1	2.2	0.2		NS	NS	0.1		7.2	0.1	0.1		5.6	2.5	0.2		NS	*6.6*	0.3	
Depth (ft)	15	25	34				34		12	20	34		12	18	36			18	34	
Organism																				
Chironomidae	388	43	29						14	14			72	29				14		
Cbauborus		1005	3043				804			29	703		86	43	919			14	3602	
Total organisms	388	1048	3072				804		14	43	703		158	72	919			28	3602	

Note: Sampling locations A, B, C in each lake lie on an east-west transect through the regular sampling station
NS = No Sample

Figure 74. Large-sized Chironomua *found in Lake Catherine (center) compared with normal size*

Table 25. Benthic Macroinvertebrates Found in Lake Catherine and Channel Lake, 1980

(Counts per square meter)

	6/11/80				*7/17/80*				*8/14/80*				*9/11 /80*			
	A	*B*	C	*Aer-ator*	*A*	*B*	C	*Aer-ator*	*A*	*B*	C	*Aer-ator*	*A*	*B*	*C*	*Aer-ator*
Lake Catherine																
DO near bottom	0.1	6.6	8.0	4.2	0.2	3.6	5.2	6.0	0.1	5.5	5.6	4.8	0.2	6.4	6.2	6.8
Depth (ft)	38	20	15	28	38	20	15	28	38	20	15	28	38	20	15	28
Organism																
Cbaoborus				14			29									
Chironomidae							43	29	43			29				
Total organisms	0	0	0	14	0	0	72	29	43	0	0	29	0	0	0	0
Channel Lake																
DO near bottom	0.2	1.6	6.3		0.2	0.2	2.8		0.1	0.2	6.6	-	0.2	0.4	4.9	
Depth (ft)	34	20	15		34	20	15		34	20	15		34	20	15	
Organism																
Cbaoborus	14						29		86							
Chironomidae			14				43									
Total organisms	14	0	14		0	0	72		86	0	0		0	0	0	0

Note: Sampling locations A, B, C in each lake lie on an east-west transect through the regular sampling station aerator site. *Chaoborus* comprised the greatest number of any genera found. Large chironomids of the genus *Chironomus* were found in higher numbers near the aerator. However, unlike in 1979, they were also found in the control lake.

Chemical Characteristics

The thermal stratification occurring in deep lakes and impoundments generally creates three distinct zones with widely differing physical, chemical, and biological characteristics. In the epilimnetic zone, the water is of acceptable chemical quality comparable to the 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 concentrations of reduced substances such as iron (Fe^{++}), manganese (Mn^{++}), ammonia, hydrogen sulfide and other micronutrients (phosphorus, silica, etc.) increase in the oxygen-deprived layers of the impounded waters.

Appendix D presents complete data regarding the water quality characteristics of Lake Catherine and Channel Lake in 1977, 1978, 1979, and 1980.

1977 and 1978. A summary of the chemical characteristics observed in Lake Catherine and Channel Lake in 1978 is shown in table 26. For comparison, results of the monitoring of the lakes during 1977 are also included. A detailed discussion of the limnological characteristics of the Fox Chain, including the chemical characteristics, can be found in the earlier report (Kothandaraman et al., 1977).

A comparison of the values for various chemical parameters, both between the two lakes and between the two years for each lake, reveals that there was no significant change in the values. The mean, minimum, and maximum values were all comparable within practical limits. Aeration of Lake Catherine did not have any impact on such parameters as ammonia, silica, iron, manganese, and phosphorus in the deep samples. The main reason for this is that the aeration device was not placed in the deepest part of the lake.

The temporal variations in the chemical parameters examined for 1978 are shown in figures 75, 76, and 77 for the surface, mid-depth, and deep sampling points, respectively, in the two lakes.

1979. The temporal variations in the chemical parameters monitored for Lake Catherine and Channel Lake at three different water depths for 1979 are shown in figures 78 through 80. Figure 78 indicates that the surface water chemical characteristics of the two lakes were very similar, particularly with respect to pH, sulfate, chlorine demand, total and dissolved phosphorus, ammonia-N, nitrate-N, and total iron. The overall mean and range of values (table 27) were alike except for silica, which is more than double in Channel Lake compared with Lake Catherine. Similar observations hold true for mid-depth water samples (figure 79).

However, the deep water samples of these two lakes are distinctly different, as evidenced by figure 80 and table 27. Such products of decomposition as alkalinity, silica, ammonia-N, and total and dissolved phosphorus were much lower in Lake Catherine than in Channel Lake, while chemical constituents of higher oxidative status, such as sulfate and nitrate, were higher in Lake Catherine. Chlorine demand values of Channel Lake samples were also higher than the values for Lake Catherine.

It was mentioned previously that the aerator was shut down (because of equipment failure) during the critical period of aeration, July 14 to July 26, 1979. If the chemical quality observations at the deep locations of these two lakes are considered for the period August through September, immediately after the resumption of aeration after the prolonged shutdown, the results are more convincing. A summary of the chemical quality characteristics for this period is given in table 28. The releases of phosphorus, nitrogen, and silica from bottom sediments were all reduced by half or more in Lake Catherine. Chlorine demand, which is a measure of the oxygen demand potential, was also significantly reduced in Lake Catherine because of the aeration.

1980. The 1980 temporal variations in chemical parameters monitored for Lake Catherine and Channel Lake at three different water depths are shown in figures 81 through 83. A summary of water quality characteristics in these lakes in 1980 is given in table 29.

Figure 81 and table 29 reveal that the surface water chemical characteristics of the two lakes were very similar, particularly with respect to pH, sulfate, chlorine demand, total and dissolved phosphorus, ammonia-N, nitrate-N, and total iron. The overall mean and range of values (table 29) were alike except for silica, which was much higher in Channel Lake than in Lake Catherine. These observations were similar to those made during 1979.

Water quality characteristics at mid-depth sampling points were similar in these two lakes except for ammonia-N and silica. Even though there were minor differences in temporal variations in the water quality observations (figure 82), the mean and range of values (table 29) were similar. In the case of ammonia-N and silica, values for Channel Lake were twice or more than twice the values observed for Lake Catherine.

In the case of the deep samples, no significant differences in the concentrations of products of decomposition such as ammonia-N, alkalinity, iron, and silica were detected. The only significant difference was in chlorine demand values. The mean chlorine demand values for Lake Catherine and Channel Lake deep water samples were respectively 9.88 and 15.82 mg/l. However, during the 1979 monitoring of the lakes, concentrations of alkalinity, silica, ammonia-N, and total and dissolved phosphorus were much lower in the deep water samples of Lake Catherine than in Channel Lake.

Sediment Characteristics

The results of the 1978, 1979, and 1980 sediment analyses are shown in tables 30, 31, and 32, respectively. The water content of the sediments taken from Lake Catherine was less than for the samples from Channel Lake. Volatile organic solids were less but the percent fixed solids was more in Lake

Catherine samples than in Channel Lake samples. A comparison of the values for Lake Catherine stations 1 and 2 confirms that the degree of sediment stabilization was slightly higher near the vicinity of the aerator (station 2) than at station 1, which is located in the deepest part of the lake. Lake Catherine (station 1) bottom sediments examined in 1975 (table 30) exhibited characteristics similar to those observed in Channel Lake in 1978. There appears to have been a definite trend in the stabilization of the bottom sediments in Lake Catherine as a result of the aeration device.

Results of Chemical Treatment

1978. Results of copper analysis for the only 1978 copper sulfate application are listed in table 33. The copper sulfate was well dispersed throughout the lake, even though the entire quantity was administered from a single location in the lake. This was aided by a strong predominantly southwesterly wind. The distribution of copper in the lake was comparable or better than the previously discussed copper distribution achieved in Mineola Bay of Fox Lake in 1977 (see table 8). (As has been discussed, copper sulfate was applied to Mineola Bay at the rate of 5.4 pounds per acre from a boat crisscrossing the bay.)

After the copper sulfate treatment of the lake, the clarity of the lake - showed significant improvement (figure 65). The dissolved oxygen concentrations in the lake observed a week after the treatment showed a drastic decline in the epilimnion (figure 51h), presumably because of the oxygen demand exertion of the decaying algae. Such an occurrence can be alleviated if the copper sulfate application is followed, after a suitable interval of time, by potassium permanganate treatment.

1979. In 1979 copper sulfate was applied to Lake Catherine on four separate occasions: June 21, July 5, August 2, and August 23. On June 21, the copper sulfate was applied alone, whereas for the remaining three applications, copper sulfate was chelated with citric acid prior to lake application. Results of the copper analyses are shown in table 34. Copper concentrations in the lake water samples were much higher, and copper in solution persisted much longer, when the copper sulfate - citric acid complex was used. Lake transparency appeared to increase after each copper sulfate treatment. However, algal density values in Lake Catherine followed the trend in Channel Lake, revealing the overwhelming impact of Channel Lake as a source of algal infestation for Lake Catherine.

Sunda and Lewis (1978) found that complexation of copper by organic ligands considerably reduced the toxicity of copper to algae in natural waters. These factors, combined with the influence of Channel Lake outflow on Lake Catherine, have compounded efforts to measure the effectiveness of aeration and chemical treatment in Lake Catherine.

Using pure algal cultures of *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* in laboratory studies, Stern et al. (1978) found that copper solubility and cupric ion toxicity were enhanced by the addition of citric acid. They found that a very high ratio of citric acid to copper sulfate (8:1) at a copper concentration of 0.5 mg/l was effective in controlling algae and preventing any regrowth. Such a high dosage rate of citric acid would be economically prohibitive. In Lake Catherine, a theoretical concentration of 1 mg/l of copper for the top 2 feet of lake water was used with a citric acid:copper sulfate ratio of 1/2:1. The costs of copper sulfate and citric acid for each 1979 chemical treatment were $520 and $360, respectively.

Potassium permanganate was applied on July 11 and August 7, 1979, a few days after the application of copper sulfate in each case. Results of analyses of the manganese distribution in the lake are shown in table 35. For each application, 220 pounds of potassium permanganate, at a cost of about $200, was used. The dissolved oxygen levels in the epilimnetic zone of Lake Catherine did not decrease as drastically as they did during the first-year application of copper sulfate. Potassium permanganate presumably oxidized the decaying algal cells, thus relieving the potential demands on the oxygen resources of the lake. Retrospectively, it is felt that a dosage rate of 300 to 400 pounds of potassium permanganate would have been more effective in Lake Catherine.

1980. Copper sulfate chelated with citric acid was applied to Lake Catherine on two occasions in 1980: July 8 and August 8. These copper sulfate applications were followed by potassium permanganate applications on July 16 and August 12. Results of the copper analyses are shown in table 36. Copper in solution persisted much longer when the copper sulfate - citric acid complex was used. Lake transparency appeared to increase after each copper sulfate treatment (figure 67). Because of the potassium permanganate application a few days after the copper sulfate treatment, oxygen depletion in the lake waters due to the oxygen demand of the decaying algal cells was avoided. Concentrations of manganese at the surface and at the five-foot depth of sampling stations 1 to 7 (figure 29) were generally below the detection limit.

Table 26. Summary of Water Quality Characteristics for Lake Catherine and Channel Lake, 1977 and 1978

(Concentrations in milligrams per liter)*

	Turbidity (FTU)		Transparency (inches)		pH	Alkalinity	
	Mean	*Range*	*Mean*	*Range*	*Range*	*Mean*	*Range*
1978							
Catherine							
Surface	3.6	0.0-6.9	48	30-99>	8.1-9.0	163	146-174
Mid-depth	2.3	0.0-7.5			8.0-8.6	165	154-173
Deep	8.9	2.0-30.8			7.4-8.5	196	168-250
Channel							
Surface	3.7	0.0-9.4	40	30-75	8.0-8.9	166	156-172
Mid-depth	2.9	0.0-6.9			7.7-8.7	174	161-214
Deep	7.5	1.0-43.0			7.4-8.5	202	168-246
1977							
Catherine							
Surface	4	2-7	43	33-69	7.9-9.1	167	154-182
Mid-depth	3	1-5			7.7-8.7	174	164-187
Deep	7	2-37			7.1-8.4	216	174-253
Channel							
Surface	6	4-9	36	27-60	8.0-9.0	169	159-177
Mid-depth	4	2-8			7.8-8.5	173	154-192
Deep	16	2-119			7.4-8.5	219	172-245

	Nitrate		Ammonia		Total silica	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
1978						
Catherine						
Surface	0.22	0.03-0.33	0.13	0.01-0.31	1.69	0.23-3.30
Mid-depth	0.22	0.05-0.52	0.24	0.04-0.48	1.60	0.25-3.25
Deep	0.16	0.01-0.31	2.79	0.35-8.70	4.02	0.56-10.97
Channel						
Surface	0.20	0.09-0.36	0.16	0.01-0.39	1.95	0.05-4.82
Mid-depth	0.21	0.10-0.38	0.29	0.10-0.94	1.92	0.11-4.54
Deep	0.20	0.02-0.39	2.73	0.19-10.99	3.85	0.07-9.10
1977						
Catherine						
Surface	0.15	0.04-0.32	0.09	0.02-0.24		
Mid-depth	0.12	0.04-0.26	0.22	0.04-0.54		
Deep	0.11	0.04-0.25	2.65	0.73-4.96		
Channel						
Surface	0.11	0.01-0.32	0.15	0.01-0.30		
Mid-depth	0.12	0.04-0.27	0.25	0.03-0.48		
Deep	0.12	0.07-0.23	6.04	0.35-54.6		

(Continued on next page)

**Except turbidity (FTU), transparency (inches), and pH (dimensionless)*

Table 26. Continued

	Hardness		*Total iron*		*Total manganese*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
1978						
Catherine						
Surface	274	228-330	0.10	0.01-0.69	0.05	0.00-0.20
Mid-depth	278	218-337	0.08	0.01-0.22	0.03	0.01-0.06
Deep	299	271-347	0.50	0.02-2.56	0.32	0.10-0.76
Channel						
Surface	281	247-330	0.07	0.01-0.13	0.02	0.01-0.04
Mid-depth	288	251-337	0.08	0.01-0.18	0.09	0.01-0.23
Deep	303	267-337	0.55	0.02-3.78	0.31	0.03-0.68
1977						
Catherine						
Surface	262	199-327				
Mid-depth	248	113-331				
Deep	288	205-340				
Channel						
Surface	236	107-311				
Mid-depth	238	133-311				
Deep	277	127-427				

	Sulfate		*Total solids*		*Dissolved solids*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
1978						
Catherine						
Surface	52.7	32.3-97.7	356	300-435	339	292-430
Mid-depth	51.5	34.1-90.9	351	287-420	336	276-386
Deep	52.9	33.8-90.5	418	346-631	353	190-413
Channel						
Surface	52.8	37.7-83.7	354	286-406	343	283-400
Mid-depth	54.2	37.1-86.4	359	285-409	346	279-400
Deep	52.6	35.5-87.7	449	339-692	371	330-411
1977						
Catherine						
Surface	51.4	36.7-59.8	352	238-476	285	170-440
Mid-depth	49.5	33.4-59.8	351	252-412	296	206-458
Deep	36.2	21.5-43.2	381	244-646	298	210-432
Channel						
Surface	54.4	44.9-61.3	386	262-664	298	190-458
Mid-depth	53.7	44.9-60.4	355	262-484	295	204-438
Deep	45.9	29.5-60.3	437	305-618	334	214-468

(Concluded on next page}

Table 26. Concluded

	T. phosphorus		*Diss. phosphorus*	
	Mean	*Range*	*Mean*	*Range*
1978				
Catherine				
Surface	0.06	0.03-0.10	0.02	0.00-0.06
Mid-depth	0.06	0.03-0.10	0.03	0.00-0.06
Deep	0.53	0.11-1.36	0.43	0.06-1.19
Channel				
Surface	0.06	0.04-0.10	0.02	0.01-0.04
Mid-depth	0.09	0.04-0.17	0.04	0.02-0.11
Deep	0.59	0.08-1.28	0.49	0.01-1.06
1977				
Catherine				
Surface	0.06	0.03-0.15	0.02	0.01-0.04
Mid-depth	0.08	0.04-0.18	0.04	0.01-0.15
Deep	0.73	0.24-1.26	0.58	0.21-0.93
Channel				
Surface	0.09	0.05-0.16	0.03	0.02-0.04
Mid-depth	0.09	0.06-0.27	0.04	0.02-0.15
Deep	0.72	0.13-1.39	0.54	0.11-1.16

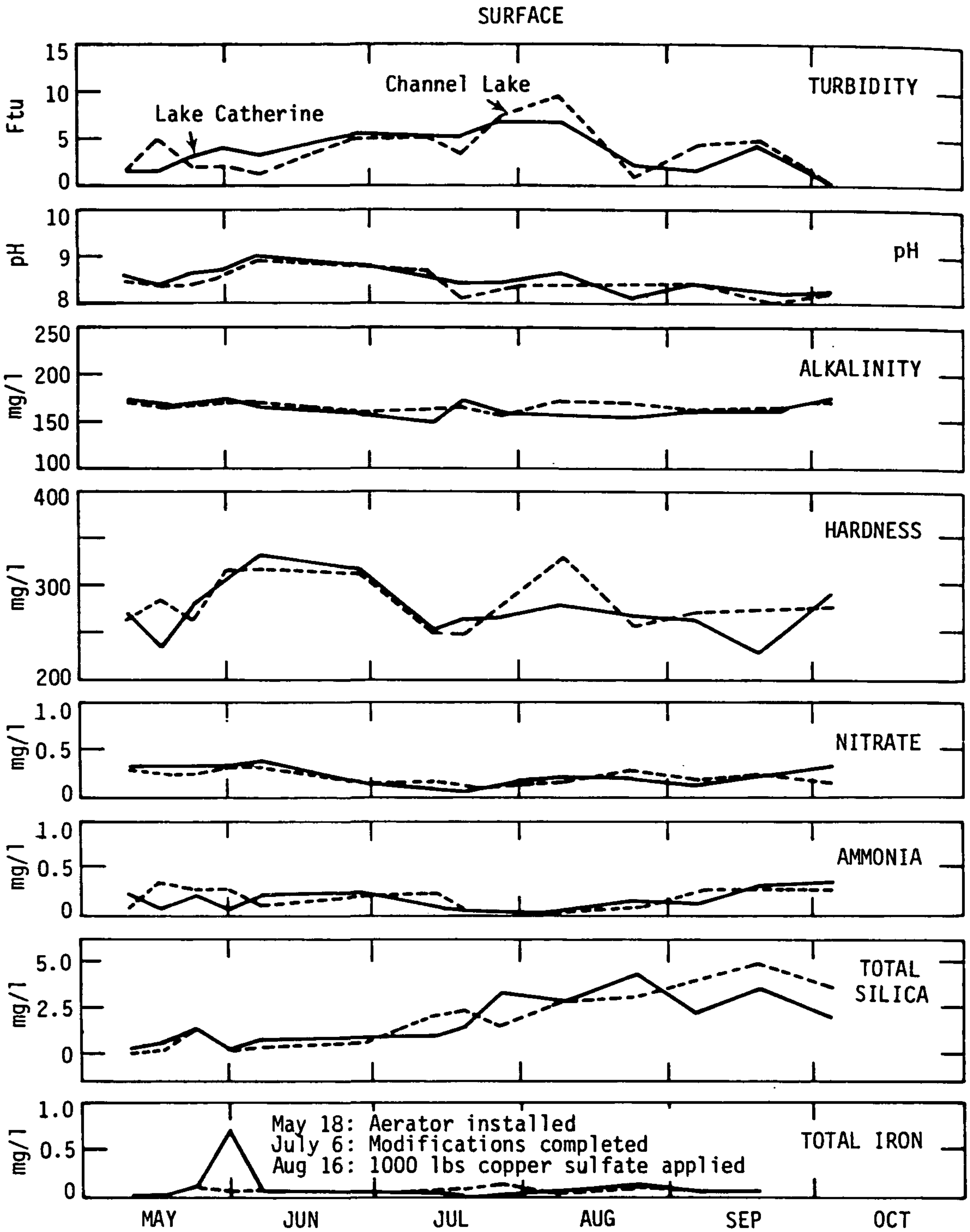

Figure 75. Water quality characteristics at the surface. Lake Catherine station 1 and Channel Lake, 1978

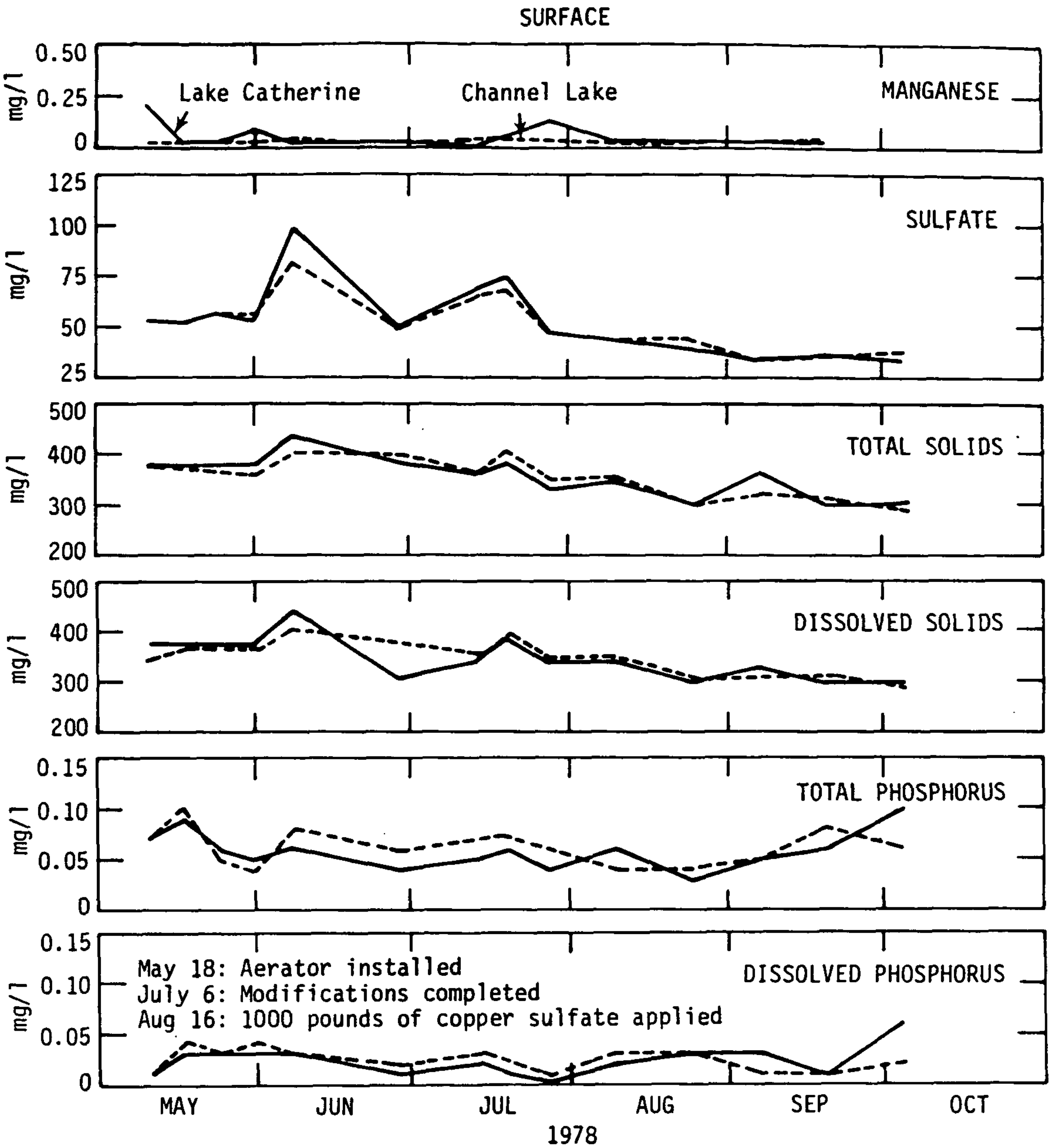

Figure 75. Concluded

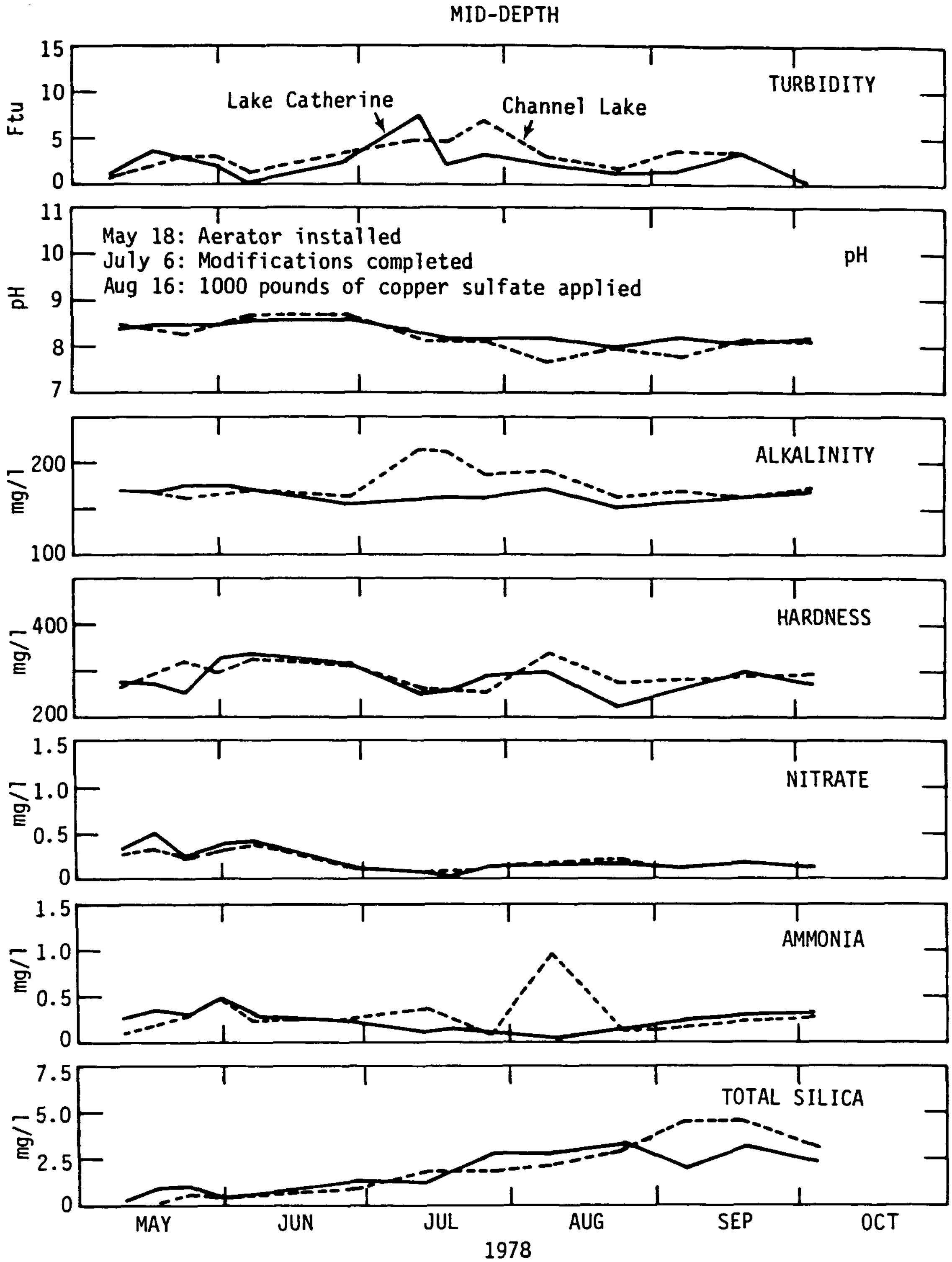

Figure 76. Water quality characteristics at mid-depth, Lake Catherine station 1 and Channel Lake, 1978

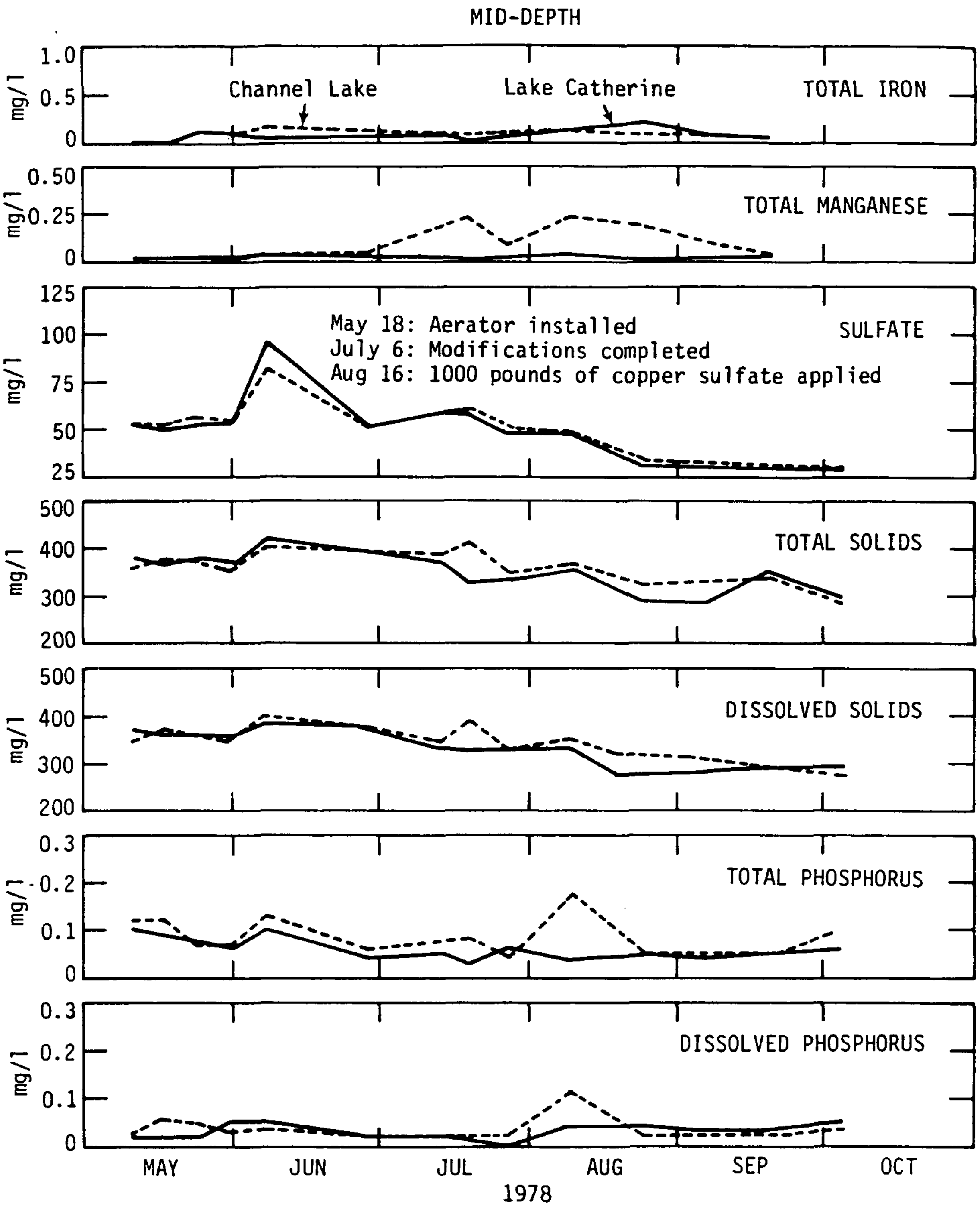

Figure 76. Concluded

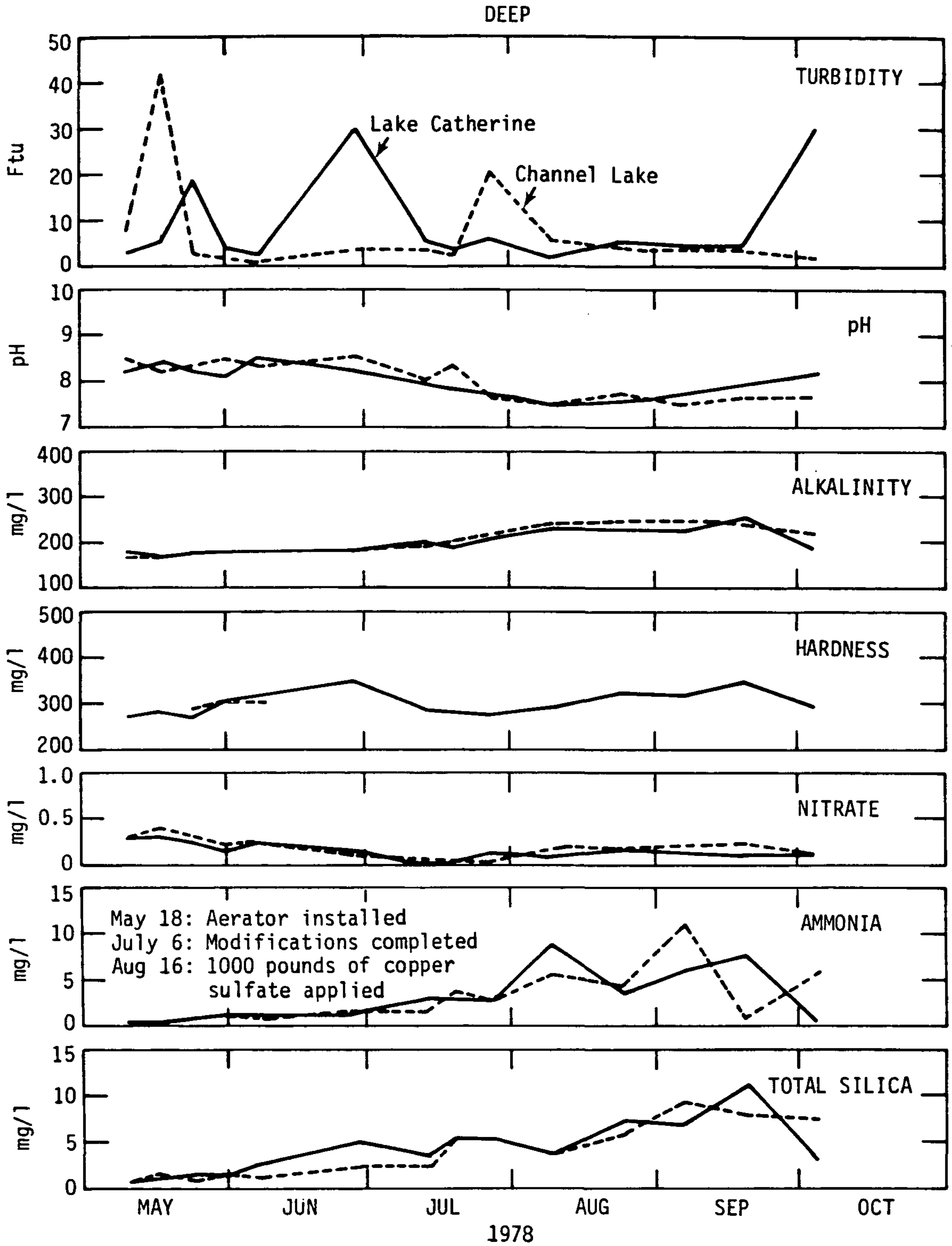

Figure 77. Water quality characteristics at deep location, Lake Catherine station 1 and Channel Lake, 1978

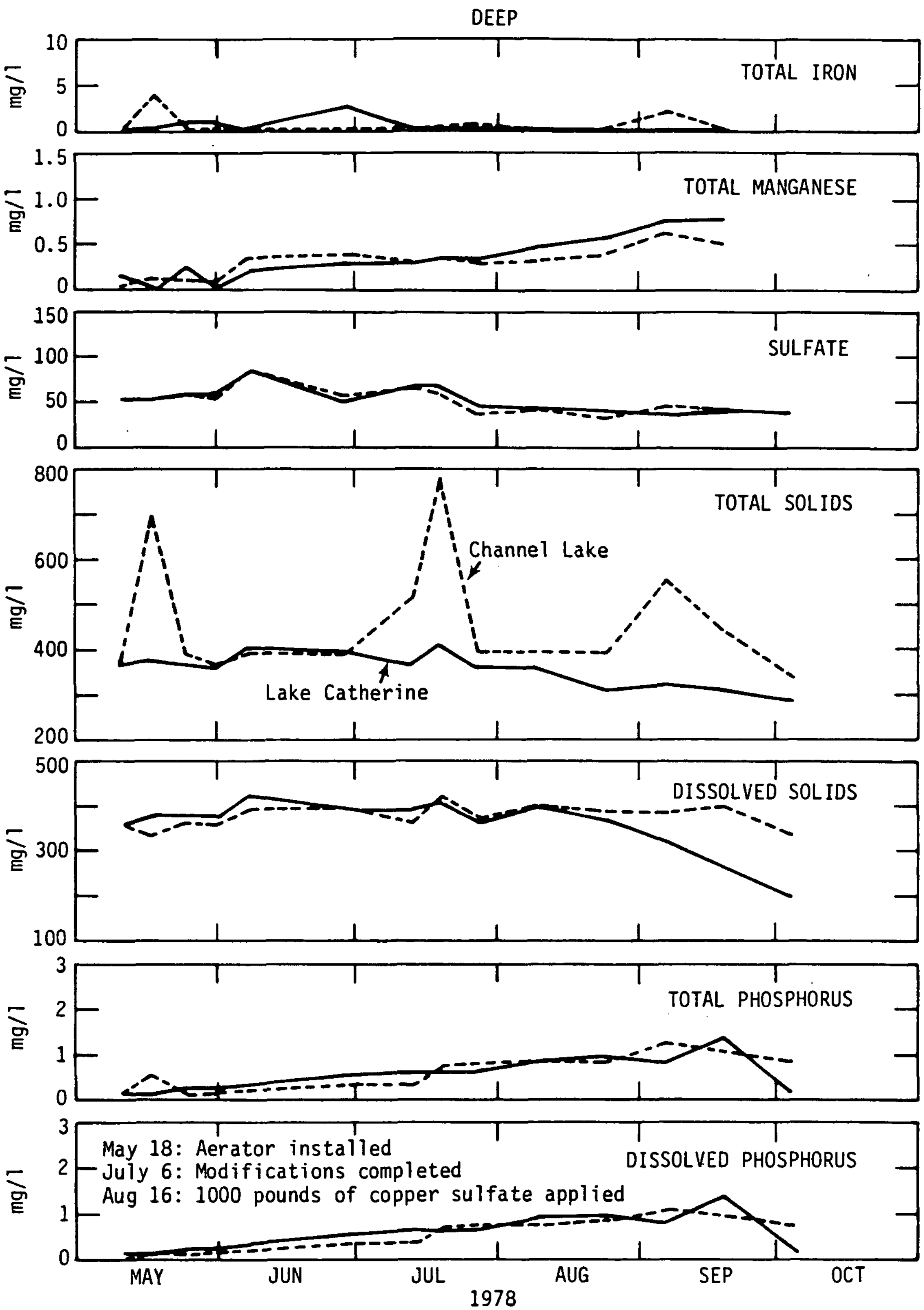

Figure 77. Concluded

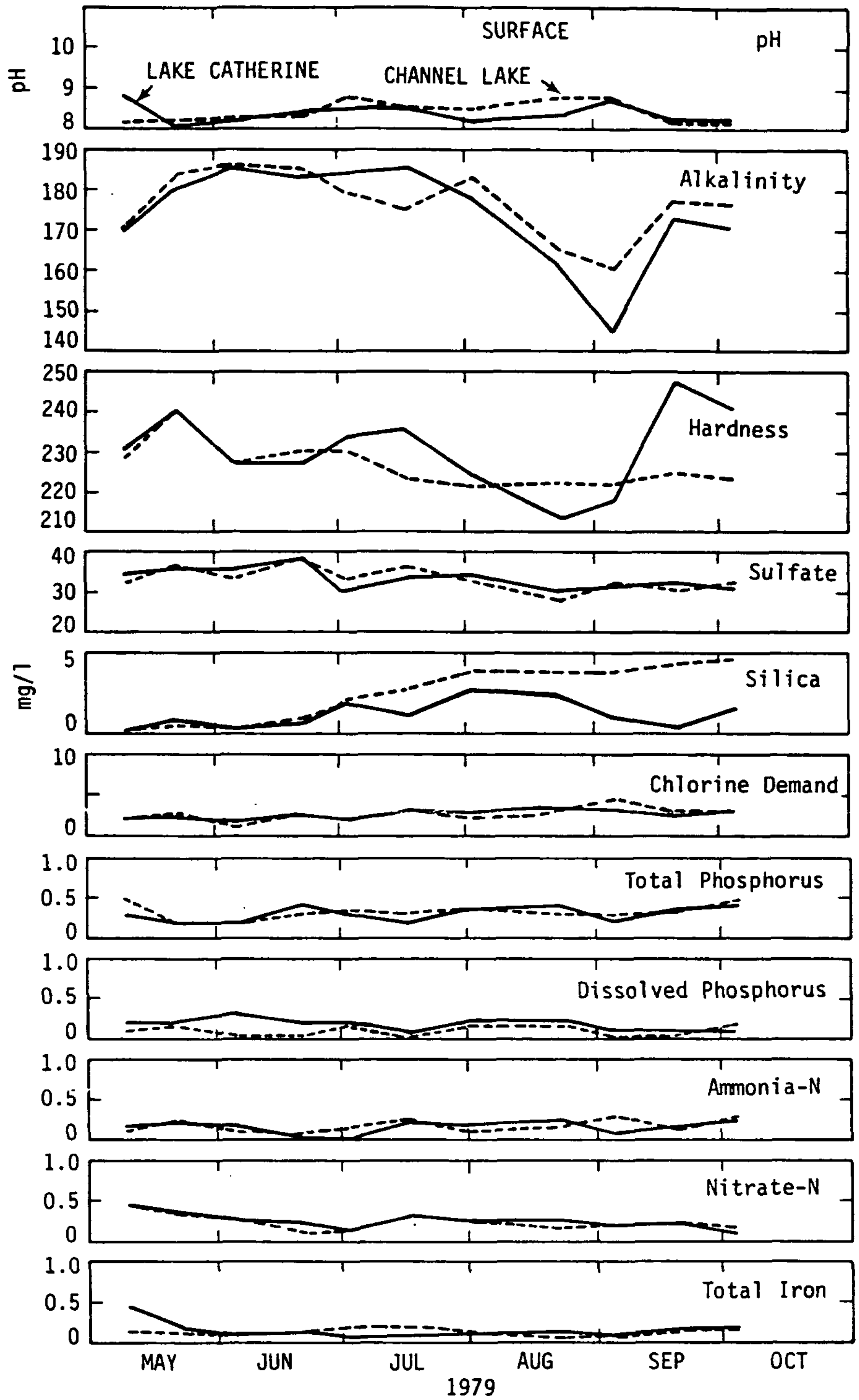

Figure 78. Chemical quality characteristics at the surface, Lake Catherine station 1 and Channel Lake, 1979

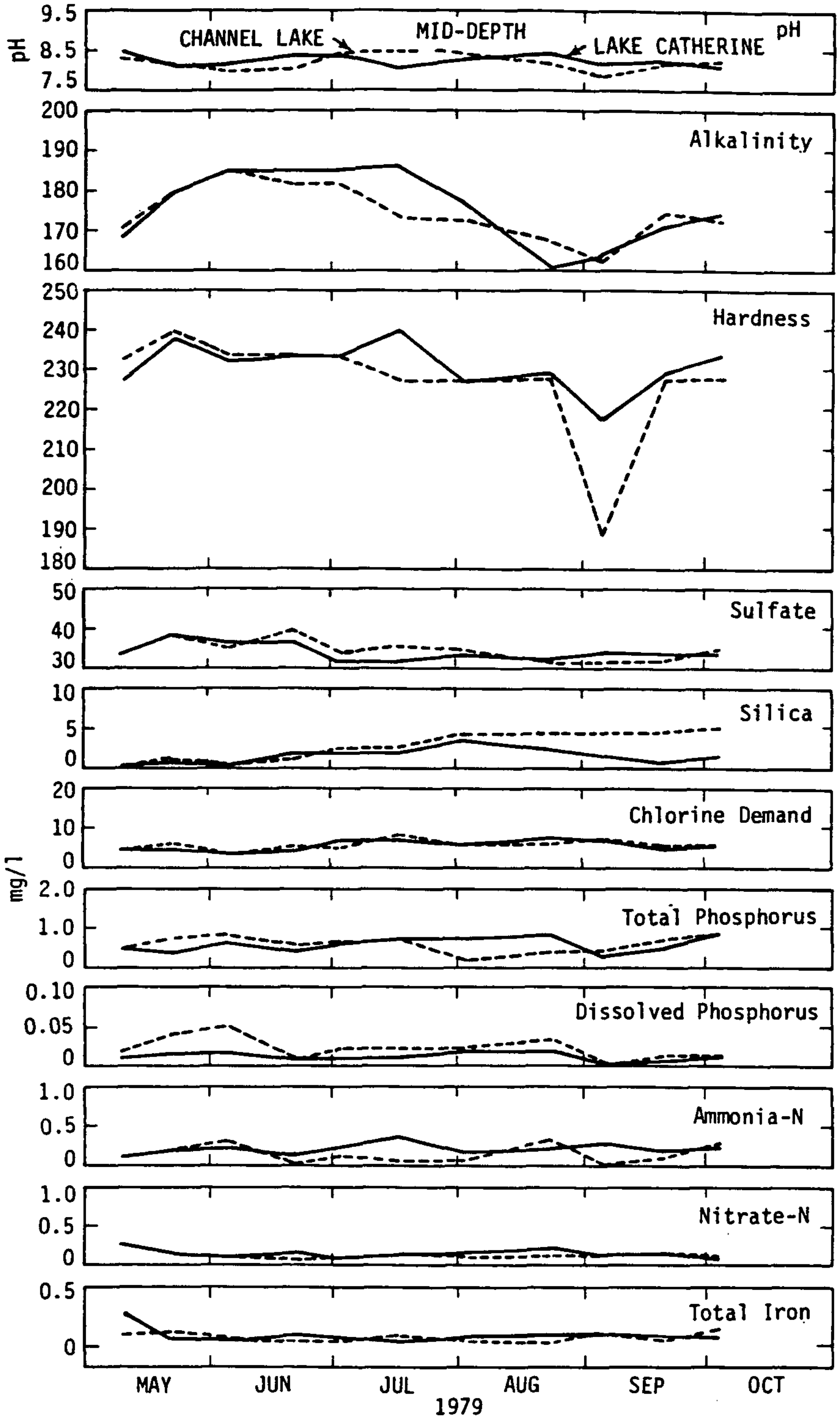

Figure 79. Chemical quality characteristics at mid-depth, Lake Catherine station 1 and Channel Lake, 1979

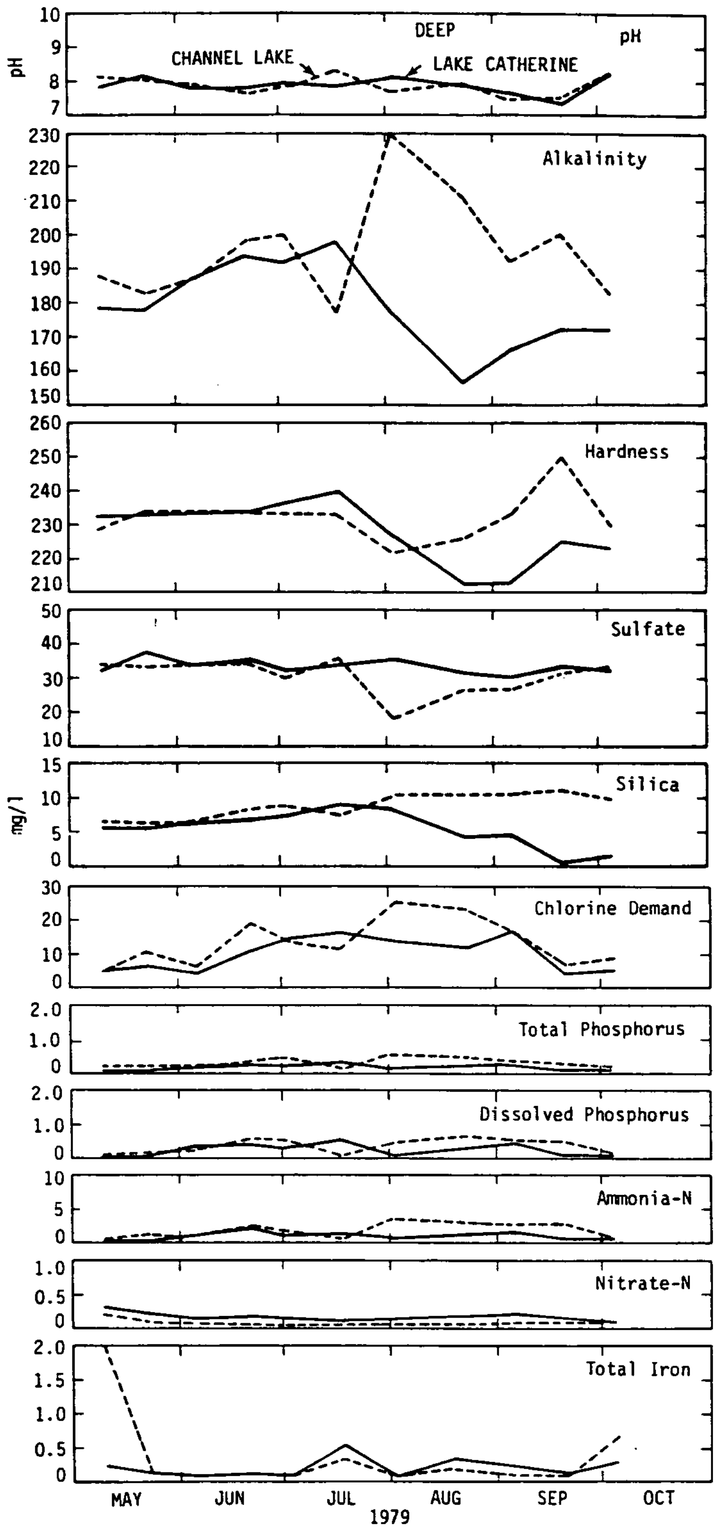

Figure 80. Chemical quality characteristics at deep location, Lake Catherine station 1 and Channel Lake, 1979

Table 27. Summary of Water Quality Characteristics for Lake Catherine and Channel Lake, 1979
(Concentrations in milligrams per liter)*

	pH	*Alkalinity*		*Hardness*		*Sulfate*		*Silica*	
	Range	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine									
Surface	8.10-8.67	174	144-185	230	213-247	33.6	30.4-38.4	1.14	0.13-2.86
Mid-depth	8.03-8.47	176	161-186	231	217-240	33.4	30.7-37.8	1.32	0.26-3.26
Deep	7.63-8.32	179	157-194	228	213-240	33.0	29.8-37.4	2.17	0.36-4.30
Channel									
Surface	8.15-8.79	175	160-186	227	211-240	38.2	28.0-37.8	2.47	0.07-4.55
Mid-depth	7.82-8.48	174	162-185	226	188-239	33.9	30.4-38.6	2.53	0.03-4.61
Deep	7.46-8.28	195	177-230	235	220-260	30.3	17.6-36.0	3.63	1.11-5.67

	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine						
Surface	5.35	3.30-6.78	0.06	0.04-0.08	0.02	0.01-0.03
Mid-depth	5.51	3.90-7.18	0.06	0.03-0.09	0.02	0.02-0.03
Deep	10.15	4.6-16.83	0.15	0.08-0.28	0.11	0.01-0.27
Channel						
Surface	5.66	3.10-9.21	0.06	0.04-0.10	0.02	0.01-0.04
Mid-depth	5.63	3.80-7.76	0.06	0.04-0.09	0.02	0.00-0.05
Deep	11.71	4.88-24.63	0.26	0.12-0.52	0.17	0.01-0.32

	A mmonia-N		*Nitrate-N*		*Total iron*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine						
Surface	0.13	0.01-0.21	0.22	0.11-0.43	0.12	0.04-0.42
Mid-depth	0.19	0.10-0.33	0.21	0.08-0.55	0.13	0.06-0.43
Deep	0.75	0.20-1.85	0.24	0.08-0.64	0.20	0.08-0.53
Channel						
Surface	0.16	0.10-0.27	0.21	0.09-0.42	0.09	0.03-0.13
Mid-depth	0.14	0.00-0.29	0.20	0.09-0.54	0.10	0.02-0.21
Deep	1.52	0.29-3.14	0.18	0.09-0.44	0.35	0.08-2.00

**Except pH (dimensionless)*

Table 28. Summary of Chemical Quality Characteristics for August-September 1979 at Deep Locations, Lake Catherine and Channel Lake

Parameters	*Mean*	*Range*	*Mean*	*Range*
pH		7.62-8.32		7.48-8.20
Alkalinity	169	157-177	202	182-230
Hardness	220	213-227	239	220-260
Sulfate	32.0	29.8-34.8	26.6	17.6-32.5
Silica	2.66	0.36-4.30	5.30	4.73-5.67
Chlorine demand	10.64	4.83-16.83	15.63	6.25-24.63
Total phosphorus	0.14	0.09-0.24	0.32	0.13-0.52
Dissolved phosphorus	0.08	0.01-0.21	0.21	0.04-0.32
Ammonia-N	0.56	0.20-1.39	2.12	0.29-3.14
Nitrate-N	0.14	0.08-0.20	0.15	0.12-0.20
Total iron	0.21	0.08-0.35	0.23	0.08-0.67

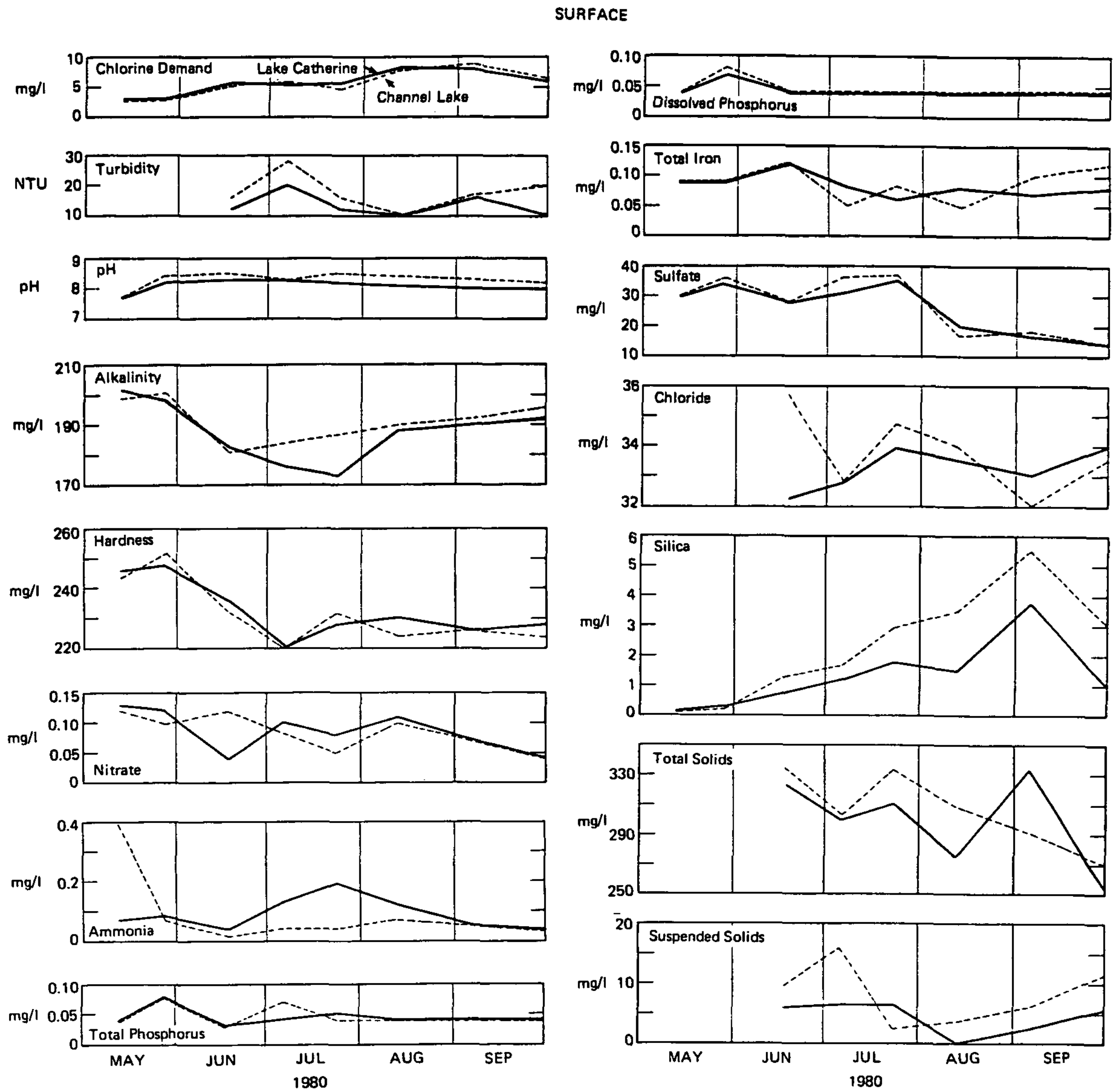

Figure 81. Chemical quality characteristics at the surface, Lake Catherine station 1 and Channel Lake, 1980

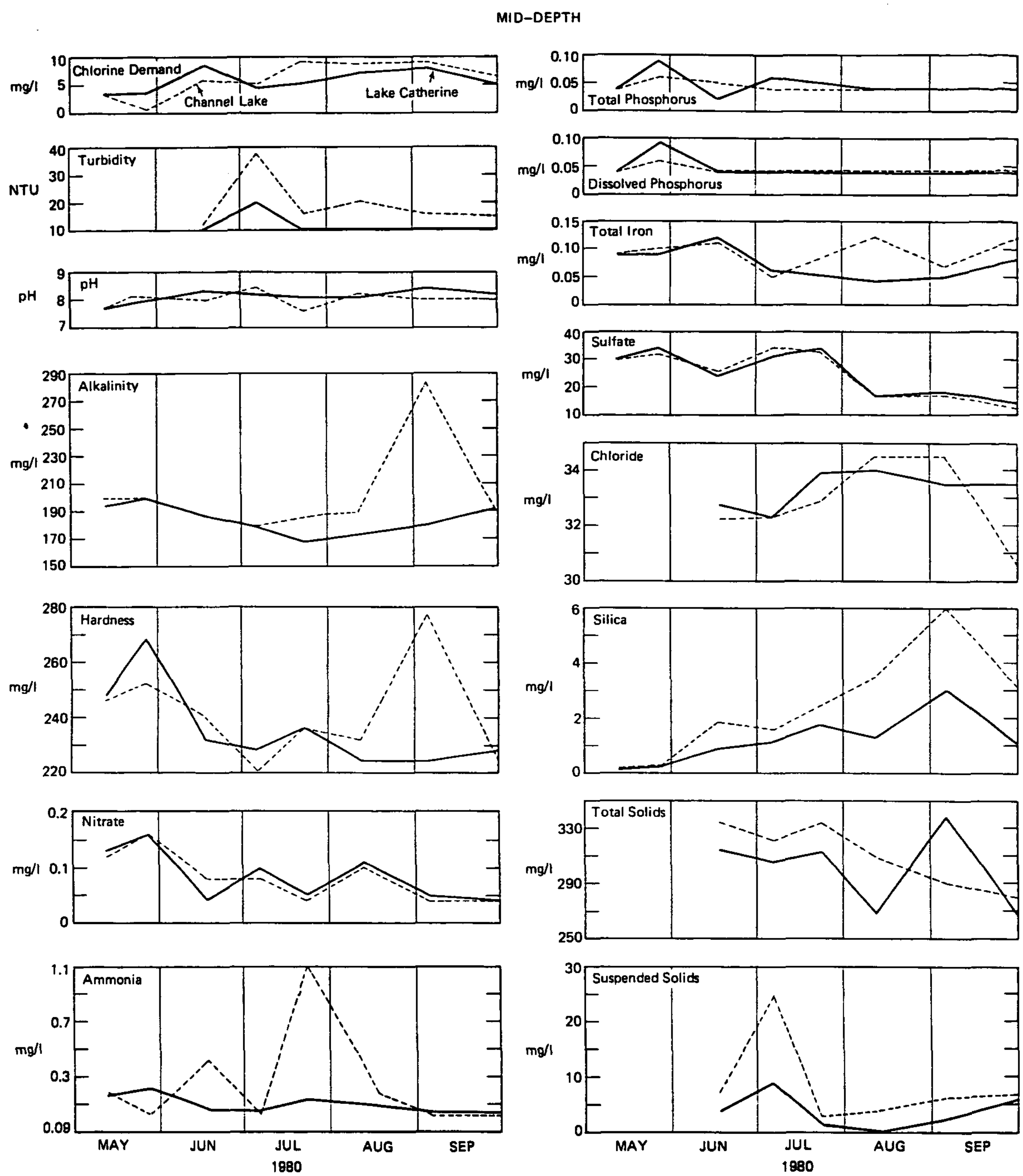

Figure 82. Chemical quality characteristics at mid-depth, Lake Catherine station 1 and Channel Lake, 1980

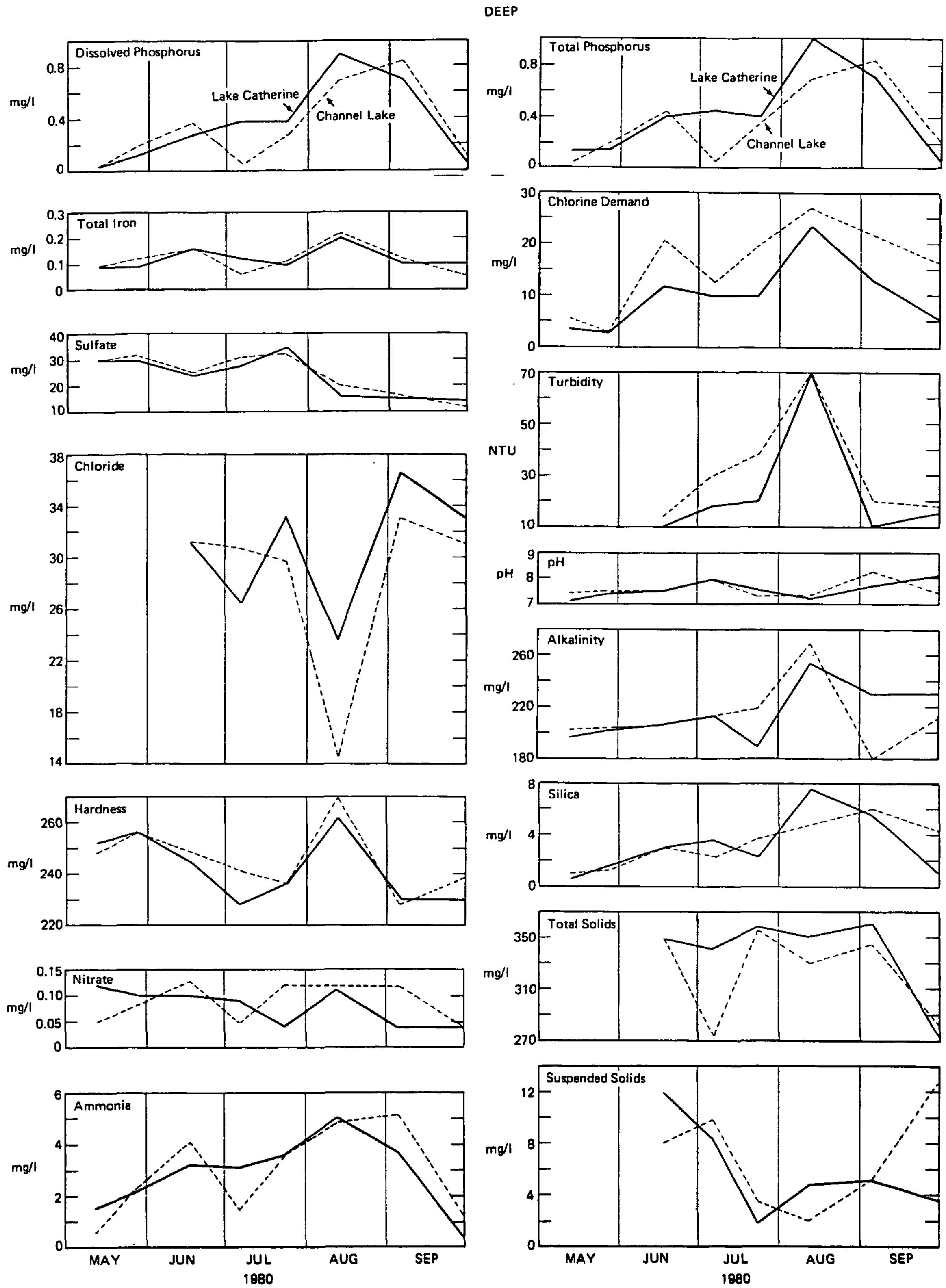

Figure 83. Chemical quality characteristics at deep location, Lake Catherine station 1 and Channel Lake, 1980

Table 29. Summary of Water Quality Characteristics for Lake Catherine and Channel Lake, 1980
(Concentrations in milligrams per liter)*

	Transparency (inches)		*Turbidity (NTU)*		*pH*	*Chlorine demand*	
	Mean	*Range*	*Mean*	*Range*	*Range*	*Mean*	*Range*
Catherine							
Surface	71.0	32.0-137.0	13	10-20	7.7-8.3	5.56	2.88-8.18
Mid-depth			12	10-20	7.7-8.4	5.66	3.44-8.00
Deep			24	10-70	7.1-8.1	9.88	2.75-23.45
Channel							
Surface	40.0	32.0-53.0	18	10-28	7.7-8.5	5.39	1.72-8.68
Mid-depth			20	12-28	7.6-8.4	6.09	0.69-9.15
Deep			32	14-70	7.3-8.2	15.82	2.75-27.00

	Alkalinity		*Hardness*		*Nitrate-N*		*Ammonia-N*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine								
Surface	191	181-201	233	220-248	0.09	<0.05-0.13	0.09	<0.05-0.19
Mid-depth	184	168-199	236	224-268	0.09	<0.05-0.16	0.10	<0.05-0.21
Deep	210	189-254	242	228-262	0.08	<0.05-0.12	2.78	<0.05-5.00
Channel								
Surface	188	173-202	232	220-252	0.09	<0.05-0.12	0.09	<0.04-0.39
Mid-depth	201	179-283	241	220-278	0.09	<0.05-0.16	0.25	0.02-1.10
Deep	213	180-269	246	228-270	0.09	<0.05-0.13	2.93	0.59-5.18

	T. Phosphorus		*D. Phosphorus*		*Total iron*		*Sulfate*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine								
Surface	<0.05	0.03-0.08	<0.05	<0.05-0.07	0.08	0.06-0.12	26	14-35
Mid-depth	<0.05	0.02-0.09	<0.05	<0.05-0.09	0.08	<0.05-0.12	25	14-34
Deep	0.41	<0.05-1.00	0.36	<0.05-0.90	0.12	<0.10-0.20	24	14-35
Channel								
Surface	<0.05	<0.05-0.08	<0.05	<0.05-0.08	0.09	<0.10-0.12	27	14-37
Mid-depth	<0.05	<0.05-0.06	<0.05	<0.05-0.06	0.09	0.08-0.12	25	12-33
Deep	0.36	<0.05-0.84	0.32	<0.05-0.84	0.12	0.05-0.22	25	11-32

	Chloride		*Silica*		*Total solids*		*Susp. solids*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine								
Surface	33.24	32.22-34.00	1.30	0.20-3.75	299	253-333	4.5	0.0-6.4
Mid-depth	33.33	32.32-34.00	1.18	0.15-3.00	301	266-315	3.5	0.0-8.8
Deep	30.63	23.5 -36.50	3.11	0.58-7.50	339	272-361	6.0	1.8-12.0
Channel								
Surface	33.80	32.00-35.75	2.28	0.15-5.50	307	270-334	8.2	2.4-16.0
Mid-depth	32.78	30.50-34.50	2.36	0.15-6.00	311	279-333	9.3	2.8-24.8
Deep	28.34	14.50-33.00	3.32	1.00-6.00	323	274-356	6.9	2.0-12.8

**Except transparency (inches), turbidity (NTU), and pH (dimensionless)*

Table 30. Bottom Sediments Composition for Lake Catherine and Channel Lake, 1978 Compared with 1975 Data
(Composition in percent)

Date	*Location*	*Water content*	*Volatile solids*	*Fixed solids*
7/12/78	Catherine station 1	76.8	8.4	91.6
	Catherine station 2	72.9	8.2	91.8
	Channel	80.2	11.2	88.8
8/23/78	Catherine station 1	77.3	10.2	.89.9
	Catherine station 2	73.0	9.5	90.5
	Channel	79.6	13.7	86.3
9/20/78	Catherine station 1	77.6	8.8	91.2
	Channel	83.1	10.3	89.7
9/9/75	Catherine station 1	75.0	13.3	86.7

Table 31. Bottom Sediments Composition for Lake Catherine and Channel Lake, 1979
(Composition in percent)

Date 1979	*Location*	*Water content*	*Volatile solids*	*Fixed solids*
5/22	Catherine station 1	77.0	11.2	88.8
	Catherine station 2	73.9	12.0	88.0
	Channel	80.9	15.1	84.9
6/25	Catherine station 1	77.2	11.2	88.8
	Catherine station 2	75.5	10.7	89.3
	Channel	80.0	14.3	85.7
7/18	Catherine station 1	77.1	9.2	90.8
	Catherine station 2	73.4	9.8	90.2
	Channel	80.2	13.5	86.5
8/22	Catherine station 1	77.6	11.7	88.3
	Catherine station 2	60.0	9.9	90.1
	Channel	77.4	13.9	86.1
9/19	Catherine station 1	76.1	9.8	90.2
	Catherine station 2	69.9	8.3	91.7
	Channel	80.4	12.3	87.7

Table 32. Bottom Sediments Composition for Lake Catherine and Channel Lake, 1980
(Composition in percent)

Date 1980	*Location*	*Water content*	*Volatile solids*	*Fixed solids*
6/10	Catherine station 1	77.9	12.6	87.4
	Catherine station 2	79.0	11.6	88.4
	Channel	84.4	17.2	82.8
7/11	Catherine station 1	78.6	10.9	89.1
	Catherine station 2	71.0	9.9	90.1
	Channel	81.8	15.2	84.8
8/14	Catherine station 1	80.2	12.0	88.0
	Catherine station 2	71.6	10.9	89.1
	Channel	83.3	16.1	83.9
9/10	Catherine station 1	78.6	12.0	88.0
	Catherine station 2	72.1	10.8	89.2
	Channel	81.8	16.3	83.7

Table 33. Copper Concentrations in Lake Catherine, 1978

(Concentrations in milligrams per liter)

Station number	*Soon after application 8/16/78*	*Day after application 8/17/78*
1A	0.02	0.02
2A	0.20	0.04
3A	0.06	0.06
3B	0.10	0.08
4A	0.02	0.06
4B	0.08	0.06
5A	0.49	<0.02
5B	0.08	<0.02
6A	0.10	<0.02
6B	0.18	0.02
7A	0.06	<0.02
7B	0.22	

Note: "A " samples were taken at the surface; "B" samples were taken at 5-foot depths

Table 34. Copper Concentrations in Lake Catherine, 1979

(Concentrations in milligrams per liter)

Locations	*6/21/79**	*6/22/79*	*7/5/79**	*7/6/79*	*7/11/79*	*8/2/79**	*8/3/79*	*8/7/79*	*8/23/79**	*8/24/79*
1A	0.08	0.03	0.82	0.11	0.03	0.23	0.10	0.04	0.07	0.08
1B	0.23	0.08	0.07	0.15	0.07	0.29	0.12	0.22	0.09	
2A	0.08	0.02	0.02	0.13	0.03	0.16	0.09	0.01	0.03	
2B	0.29	0.03	0.11	0.15	0.05	0.26	0.11	0.05	0.21	0.12
3A	0.00	0.02	0.28	0.10	0.02	0.06	0.07	0.02	0.08	0.02
3B	0.25	0.03	0.07	0.19	0.02	0.80	0.07	0.14	0.10	0.08
4A	0.00	0.03	0.04	0.02	0.02	0.02	0.00	0.01	0.02	0.07
4B	0.02	0.02	0.12	0.15	0.05	0.12	0.11	0.07	0.06	
5A	0.00	0.00	0.02	0.07	0.02	0.03	0.01	0.02	0.02	0.02
5B	0.10	0.02	0.07	0.07	0.02	0.22	0.06	0.09	0.10	0.10
6A	0.02	0.02	0.06	0.03	0.00	0.00	0.02	0.02	0.02	0.02
6B	0.04	0.02	0.07	0.07	0.06	0.12	0.05	0.09	0.08	0.08
7A	0.00	0.00	0.09	0.15	0.02	0.01	0.04	0.03	0.06	0.02
7B	0.04	0.02	0.09	0.10	0.05	0.06	0.05	0.06	0.04	0.13

Note: "A " samples were taken at the surface: "B" samples were taken at 5-foot depths
** Date of copper sulfate application*

Table 35. Manganese Concentrations in Lake Catherine, 1979

(Concentrations in milligrams per liter)

Locations	*7/11/79**	*7/12/79*	*8/7/79**	*8/8/79*
1A	0.11	0.03	0.04	0.03
1B	0.06	0.07	0.06	0.06
2A	0.04	0.04	0.05	0.05
2B	0.04	0.04	0.04	0.05
3A	0.03	0.04	0.05	0.05
3B	0.08	0.03	0.05	0.06
4A	0.03	0.01	0.03	0.05
4B	0.11	0.07	0.03	0.04
5A	0.01	0.03	0.04	0.03
5B	0.03	0.03	0.04	0.01
6A	0.01	0.01	0.04	0.04
6B	0.01	0.03	0.04	0.02
7A	0.01	0.01	0.04	0.08
7B	0.01	0.03	0.04	0.04

Note: "A" samples were taken at the surface; "B" samples were taken at 5-foot depths

** Date of potassium permanganate application*

Table 36. Copper and Manganese Concentrations in Lake Catherine, 1980

(Concentrations in milligrams per liter)

Locations	*7/8/80 Copper*	*7/17/80 Manganese*	*8/14/80 Copper*	*8/14/80 Manganese*
1A	0.06	*	0.04	*
1B	0.14	*	0.05	*
2A	0.02	*	0.03	*
2B	0.03	*	0.04	*
3A	0.02	*	0.06	*
3B	0.07	*	0.04	*
4A	0.02	*	0.04	0.06
4B	0.04	*	0.04	0.06
5A	0.02	*	0.04	*
5B	0.03	*	0.04	*
6A	0.02	*	0.05	*
6B	0.03	*	0.04	*
7A	0.02	*	0.05	*
7B	0.07	*	0.04	*

Note: "A"samples were taken at the surface; "B" samples were taken at 5-foot depths

** Below detection limit*

SUMMARY

Aluminum sulfate was applied successfully to Bluff Lake on August 9 and 10, 1977. A total of 43.2 tons of commercial liquid alum (approximately 50 percent aluminum sulfate) was applied. A dosage rate of 100 mg/l of $Al_2(SO_4)_3$ and 15.8 mg/l as Al^{3+} was used for the top 2 feet of water. Except for the immediate but transient improvement in lake transparency as assessed by secchi disc measurement, aesthetic conditions in the lake did not improve. Phosphorus concentrations in the deep waters of the lake were reduced significantly after the alum application. Generally, it is concluded that alum treatment for nutrient inactivation in the Fox Chain is not a viable technique.

Mineola Bay in the Fox Lake was chemically treated with copper sulfate on three occasions. On each occasion, a total of 1100 pounds of copper sulfate was applied at the rate of 5.4 pounds per acre. The algal counts decreased significantly after each treatment but tended to increase within a week. Nevertheless, the algal counts observed in Mineola Bay were generally less than for the untreated part of Fox Lake adjacent to Mineola Bay. The method did not prove to be an unqualified success. As with Bluff Lake, it was discovered that chemical control in a small portion of the lake system is ineffective because of the interconnection of the Chain's waters. However, chemical treatment in combination with aeration proved to be a worthwhile effort in Lake Catherine, and it is probable that its full potential can be realized when a comprehensive management scheme for improving the Chain's water quality is implemented.

An aeration-destratification system developed by the Aquatic Environmental Controls Company (AECC) of Newberry Springs, California, was selected and installed in Lake Catherine on May 18, 1978. The system consists of a multistage deep well pump, AECC aeration unit, air hoses, and a variable pitch mounting skid to support the aerator on the lake bottom. The AECC system was selected instead of the compressed air system or the raft-mounted mechanical aerator system because of its quiet operation and the reliability of deep well pumps. Because the lake shore is completely developed for year-round residence, noise level was an important factor in the selection of the aerator system. The only obstruction created by the system on the lake surface is a lighted warning buoy which supports two air hoses as part of the aeration system.

The system did not perform adequately following its installation on May 18. Satisfactory operation of the system began on July 6, 1978, after modifications were made.

During 1978, the first year of aeration in Lake Catherine, the aerator was able to destratify the lake's volume to a depth of 26 feet, the depth at which the aerator was located. Oxygen concentrations of 2 mg/l or more were maintained above this depth, whereas in the control lake (Channel Lake) oxygen was practically depleted at depths below 18 feet. Beneficial effects of the aerator were perceived in the water layers between the 16- and 26-foot depths from the surface. More than 5000 pounds of oxygen were maintained during critical summer months in this water zone, which otherwise would have been nearly anoxic. A total of 45,800 kilowatt-hours of electrical energy at a total power cost of $1750 was used in the operation of the aerator.

The aerator did not improve the clarity as measured by secchi disc in Lake Catherine, but the start-up operations of the aerator did not cause an undue increase in the turbidity of the lake waters.

The algal densities observed in the two lakes during the 1978 investigation were less than the values observed in the recent past. Unlike in the previous years, no surface algal scums were noted in either of the two lakes. During its first year of operation, the aeration in Lake Catherine did not cause a shift in the algal dominance from troublesome blue-green algae to greens or diatoms.

A significant increase in the number of taxa and number of organisms was found in the benthic macroinvertebrate community in the vicinity of the aerator. Improved sports fishing was reported by the local citizens.

The aeration-destratification of Lake Catherine was continued for the second year during 1979. The aerator was reinstalled at a depth of 34 feet and operation was started on May 10, 1979. The aerator was able to destratify to a depth of 32 feet; however, the oxygen demand of the bottom sediments was much higher than the rate of oxygen replenishment by the aerator. Consequently, the anaerobic zone in Lake Catherine progressed gradually upward. In contrast, the anaerobic zone in Channel Lake expanded abruptly during mid-June.

Because of an extended period of aerator shutdown from July 14 to July 26, 1979, stratification in Lake Catherine, especially dissolved oxygen depletion, was as intense as in Channel Lake. Dissolved oxygen conditions recovered in the deeper waters of Lake Catherine after the aerator system was repaired and restarted.

The temperature regime of Lake Catherine waters produced by the mixing conditions created by the aerator was more stable and thus less subject to deterioration during downtime of the aeration unit. Generally the influence of the aerator was limited to about 18 feet below the water surface. As shown in figure 84, the water temperature differences between the two lakes magnified with increasing water depth. Earlier measurements (1977) in Lake Catherine showed that water temperatures at the 30-foot depth during summer stratification varied from 10.6 to 12.2°C. During most of the summer of 1979, the water temperature at the 30-foot water depth was 20°C or greater. The significant increase in the heat budget of lower strata waters, as shown in figure 84, reflects the mixing capability of the aeration. However, this increase in bottom water temperatures probably stimulated increased biological activity at the lake bottom, leading to demand for dissolved oxygen in excess of the aeration's capability to furnish it. Thus during aeration unit downtime, the stability of the thermal regime most likely contributed to the instability of the dissolved oxygen regime.

Chemical control of algae using copper sulfate was tried on four occasions during the second year of aerator operation. Except during the first application, copper sulfate was chelated with citric acid prior to lake application. One thousand pounds of copper sulfate and 500 pounds of citric acid were used for each treatment. Higher concentrations of copper ions were detected in the lake and for a longer duration when copper sulfate was chelated with citric acid than when copper sulfate was applied without the chelating agent. Shortly

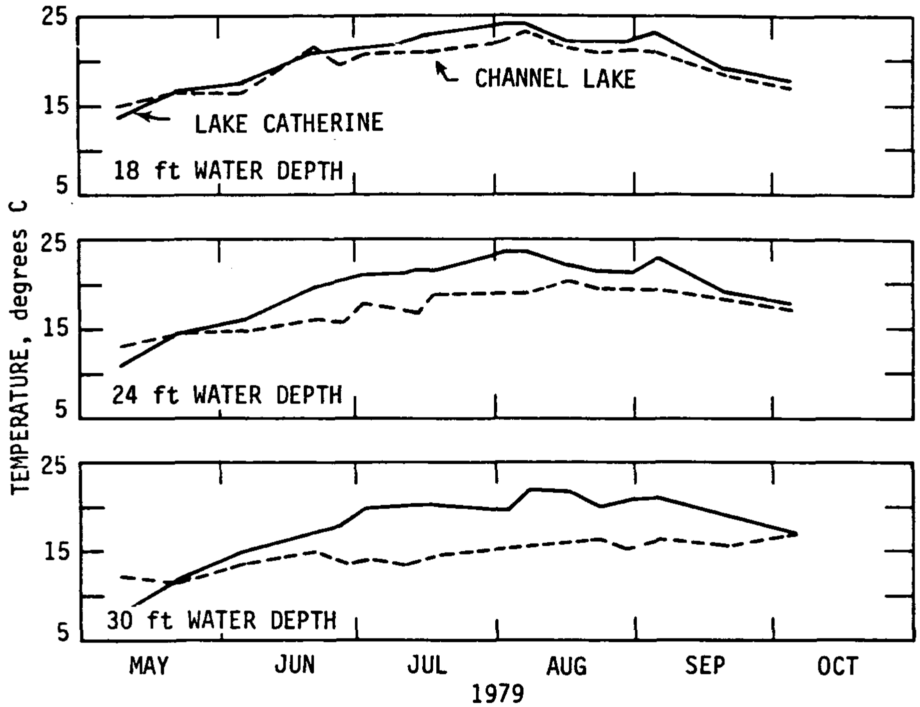

Figure 84. Temporal variations in water temperatures in Lake Catherine station 1 and Channel Lake at three water depths, 1979

after the second and third applications of copper sulfate, 220 pounds of potassium permanganate was applied to the lake, mainly to oxidize the decaying algal matter after copper sulfate treatment, thereby reducing the demand on oxygen resources of the lake.

Secchi disc readings improved significantly after each copper sulfate application but decreased after a week or 10 days. Although the algal densities were smaller in Lake Catherine than in Channel Lake, the temporal variations in total algal counts in Lake Catherine closely paralleled those in Channel Lake. In spite of the overwhelming influence of Channel Lake on Lake Catherine, a shift in the dominance of blue-green algae to greens and diatoms was detected in Lake Catherine.

A significant increase in the number of taxa was found in the benthic macroinvertebrate community in Lake Catherine. Several Chironomus were found in Lake Catherine that were much larger than any found in the lake in the previous three years of monitoring.

There was a significant change in chemical quality characteristics of the deep waters in Lake Catherine during the second year of aeration. Concentrations of the products of anaerobic decomposition of lake bottom sediments, such as ammonia, phosphorus, and silica, were markedly less in Lake Catherine than in the control lake.

The aeration-destratification of Lake Catherine was continued for the third year from May 15 to September 30, 1980. Because of the destratification in Lake Catherine, water temperatures in the lake were higher at depths between 15 and 30 feet than the temperatures in Channel Lake. Generally, the influence of the aerator was limited to this vertical segment of the lake, as far as the temperature and dissolved oxygen resources are concerned. The significant increase in the heat budget of the lower strata waters, as shown in figure 85, reflects the mixing capability of the aerator. The oxygen levels in Lake Catherine improved significantly up to a depth of 25 feet from the surface compared to Channel Lake. The aerator was installed at a depth of 24 feet in the lake.

Chemical control of algae with chelated copper sulfate was attempted on two occasions during 1980. Each copper sulfate treatment was followed shortly by a potassium permanganate application. Secchi disc readings improved significantly after the chemical treatment and remained higher than in the control lake. Total algal counts in both Lake Catherine and Channel Lake were considerably less than the previous years, and blue-green algae remained the dominant species in the lakes during summer months. Chlorophyll-a concentrations in Lake Catherine were significantly lower than the values observed for Channel Lake.

Unlike the results for the 1979 aerator operation, no significant differences in the concentrations of products of decomposition such as ammonia-N, alkalinity, iron, and silica were found in the deep water samples of Lake Catherine and Channel Lake. The only significant difference was in chlorine demand values. The mean chlorine demand values for Lake Catherine and Channel Lake deep water samples were respectively 9.88 and 15.82 mg/l.

Water content of the sediments taken from Lake Catherine was less than in the samples from Channel Lake. The volatile organic fraction of the solids was also less in Lake Catherine. There appears to have been a definite trend in the stabilization of bottom sediments in Lake Catherine as a result of aeration-destratification of the lake.

In general, the aeration system demonstrated its capability to destratify the thermal regime and induce oxygenation of Lake Catherine waters down to its location level. There is also evidence that increased water temperatures and allied dissolved oxygen have stabilized the organic content of the bottom sediments to some degree. It is probable that the full potential of the aeration and chemical treatment would be realized if a comprehensive management scheme for improving the Chain's water quality were implemented.

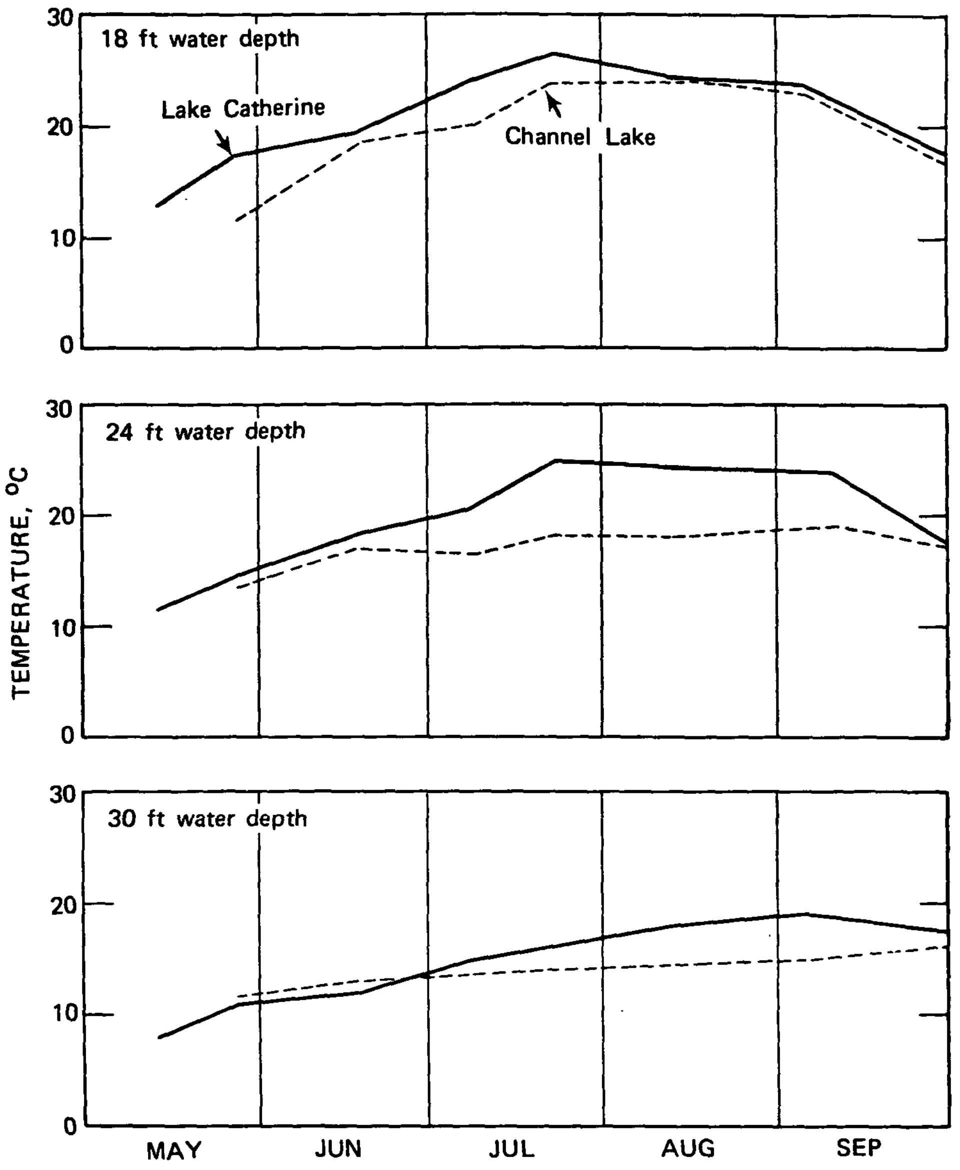

Figure 85. Temporal variations in water temperatures in Lake Catherine station 1 and Channel Lake at three water depths, 1980

FOX CHAIN OF LAKES OVERALL WATER QUALITY MANAGEMENT PLAN

In their very advanced stage of eutrophication, the Fox Chain of Lakes experiences severe water quality and other attendant problems. The most obvious of these problems, which attracts widespread public attention, is the profuse algal blooms that the lake system experiences year after year. Public apprehension regarding the curtailment of recreational activities, the lowering of property values, the cancellation of resort trade, and the impairment of the picturesque beauty of the Chain will continue unallayed if timely action is not taken to reverse or at least retard this eutrophic trend in the Fox Chain.

The detailed limnological study carried out jointly by the State Water Survey and State Geological Survey (Kothandaraman et al., 1977) indicates that the Fox Chain of Lakes receives nutrients like phosphorus and nitrogen that are several orders of magnitude greater than the amounts these lakes could assimilate without giving rise to water quality problems. The influx of nitrogen and phosphorus into the lakes through the Fox River accounts for about 70 percent of total input to the lakes. The study found that the addition of both nitrogen and phosphorus to lake water samples increased the algal biomass by several orders of magnitude. Curbing either phosphorus or nitrogen in the water samples was found essentially to impede the growth of algae under laboratory conditions. Controlling phosphorus influx to the lakes is technically and economically feasible for the purpose of controlling algal blooms.

Illinois has made rapid strides in instituting phosphorus removal from the point source waste discharges within the Illinois portion of the Chain's watershed. Also, when the regional wastewater treatment plant catering to the villages of Round Lake and Fox Lake is fully commissioned, effluent will be diverted around the Chain system. Because of the enormity of the watershed area for the Fox Chain (1184 square miles), it is unlikely that the nutrient input from nonpoint sources can be brought below acceptable levels. As a matter of fact, the nutrient release from the anaerobic bottom sediments of deep lakes in the Chain during summer months is sufficient in itself to sustain algal blooms in the lakes. Therefore in-lake treatment techniques to improve the water quality will be indispensable for a long time to come.

Among the traditionally used or advocated in-lake treatment techniques of dredging, nutrient inactivation/precipitation, dilution and dispersion, lake bottom sealing, artificial destratification, sediment exposure and desiccation, harvesting of nuisance organisms, chemical control of nuisance organisms, and biological control of nuisance organisms, only aeration/destratification and chemical control were found to be economically and technically feasible methods of managing the water quality in the Fox Chain.

As the depth of organic silt in the lake bottoms extends more than 30 to 40 feet, dredging to reach a stable bottom is not a practical solution. As was discussed previously, nutrient inactivation using aluminum sulfate (alum) proved to be inapplicable in the Fox Chain. Dilution and dispersion is a possibility, if Lake Michigan waters can be used for this purpose. Sociopolitical impacts and impacts on the Illinois Waterway will have to be carefully weighed. Sediment exposure and desiccation and lake bottom sealing are impractical. Biological control of nuisance organisms is yet to be proved as a viable method. Biological control methods do nothing to alleviate anaerobic conditions in the hypolimnetic zones of the stratified deep lakes of the Chain during the summer months.

In view of the significant and tangible benefits observed in Lake Catherine during the pilot demonstration investigation, aeration in combination with chemical treatment should form the core of the management plan. To recapitulate the beneficial effects of such a management technique in Lake Catherine, it was found that the aerator installed in the lake contributed to an increase in oxygen content in the deeper waters, an increase in lake transparency, a decrease in algal density, increased fishing in the vicinity of the aerator, improvement in the diversity of benthic organisms, and a decrease in the nutrient release from the bottom sediments.

As the aerators are effective in deep lakes which tend to stratify during summer months, it is proposed that seven aerators of the type used in Lake Catherine be installed in the Fox Chain: two in Channel Lake, two in Lake Marie, and one each in Bluff Lake, Mineola Bay, and Pistakee Bay. Information about the surface areas and maximum depths of these lakes and bays, and about- the numbers and types of aeration units proposed, is given in table 37.

Estimated capital costs of installation of seven aerators in the Fox Chain are shown in table 38. All the aerators would be similar in capacity and design features to the one installed in Lake Catherine. They could all be procured and installed at the same time, if funds for the task permitted. If not, installation of the aerators could be phased over several years. Initially, aerators should be installed in Channel Lake so that the water quality in the two northern deep lakes could be managed to their mutual benefit. It was found during the 1979 investigations that the trend in algal densities in Channel Lake had a profound impact on the algal densities in Lake Catherine, even though chemical control of algae in Lake Catherine was implemented at that time. The strategy for phasing in the aerators is to manage the deep lakes in the northern tier progressively, with the exception of Pistakee Bay. Pistakee Bay experiences the worst water quality conditions among the Fox Chain of Lakes and should receive consideration after Channel Lake.

The total estimated capital cost of the aerator installations is $121,700. This is based on the premise that materials and components for the aerator systems will be procured, and the aerators will be assembled and installed, by a state agency. Manpower costs are not included. If the work is contracted out, cost will be more than double or triple to account for Labor costs, profit, and overheads.

The annual operating and maintenance costs of the aerators in the Fox Chain of Lakes, including the costs of chemical applications using the aerators, are shown in table 39. These costs are shown for phases corresponding to the phases of installation of aerators in the lakes. Chemical treatment of Lake Catherine, Channel Lake, and Lake Marie is contemplated initially along

Table 37. Proposed Aeration Units and Related Accessories

Lake	*Area, acres* ,	*Maximum depth, feet*	*Number of aeration units*	*Power cable length, feet*	*Size of cable*
Channel	318	35		1,000	1
				1,500	1
Lake Marie	516	31		1,200	1
				1,500	1
Bluff	92	27		700	2
Mineola Bay	200	22		1,500	1
Pistakee Bay	220	30		600	2

Table 38. Estimated Capital Costs of Aerator Installations in the Fox Chain of Lakes

(Costs in 1978 dollars)

Phase	*Lake*	*Aerator cost*	*Cost of cable*	*Cost of bringing power to site*	*Total cost of individual phase*
1	Channel Lake	10,000	4,000	2,000	
		10,000	6,000	1,000	33,000
2	Pistakee Bay	10,000	1,800	2,000	13,800
3	Lake Marie	10,000	4,800	2,000	
		10,000	6,000	1,000	33,800
4	Bluff Lake	10,000	2,100	2,000	14,100
5	Mineola Bay	10,000	6,000	2,000	18,000
Total		70,000	30,700	12,000	111,700
			Cost of a barge-mounted crane and a raft		10,000
				Grand total	121,700

Table 39. Estimated Costs of Operation and Maintenance of the Aerators, Including Chemical Applications in the Fox Chain of Lakes

(Costs in 1978 dollars)

Phase	*Lake*	*Power cost*	*Chemical treatment cost* $CuSO_4$ *+ Citric acid +* $KMnO_4$	*Chemical treatment cost* $CuSO_4$ *+ Citric acid*	*Annual cost Scheme (a)*	*Annual cost Scheme (b)*
1	Catherine	2,500	6,000	4,200	8,500	6,700
	Channel	5.000	12,700	9,000	17,700	14,000
2	Pistakee Bay	2,500	only aeration		2,500	2,500
3	Lake Marie	5,000	20,640	14,500	25,640	19,500
4	Bluff Lake	2,500	only aeration		2,500	2,500
5	Mineola Bay	2,500	only aeration		2,500	2,500
Total		20,000	39,340	27,700	59,340	47,750

with aeration in these lakes. Unless chemical control of algae in the entire lake system is instituted, beneficial effects of chemical treatment in Pistakee Bay, Bluff Lake, and Mineola Bay will not be realized because of the impacts of adjoining untreated bodies of water on these three segments of the Chain.

In estimating the operating and maintenance costs of the aerators in the lakes, the following assumptions are made:

1) Aerators will be operated for five months, from early May to early October, at a power cost of $500/month/aerator.
2) Four chemical applications will be needed during summer months.
3) Each chelated copper sulfate application followed by potassium permanganate will cost $10 per acre. Each chelated copper sulfate application alone will cost $7 per acre.
4) Costs of personnel services for operating and maintaining the units are not included. At least three full-time personnel will be needed to carry out the management options. At least one of these three should be an accomplished scuba diver.
5) Provisions for unforeseen contingencies have not been made in these estimates.

Table 39 shows chemical treatment costs in two columns. The first column_ shows the cost for applying chelated copper sulfate and citric acid followed by potassium permanganate. Even though potassium permanganate is an algicide, it was used in the pilot demonstration studies as an oxidizing agent to oxidize the decaying algal cells after the copper sulfate treatments so the oxygen resources of the epilimnetic zone were not unduly depleted. The need for potassium permanganate application is determined by closely monitoring oxygen levels in the lakes after each copper sulfate application. Values in the second column represent chemical costs without potassium permanganate treatment. Thus, columns (a) and (b) under the annual cost heading represent the maximum and minimum operating costs depending on whether potassium permanganate is used (a) or is not used (b). The actual cost will be somewhere in between these values, depending on the actual number of potassium permanganate applications.

The cost of chemical treatment to control algae in areas other than Lake Catherine, Channel Lake, Lake Marie, and Grass Lake will be approximately $50,000 per application. At least four chemical applications will be required during the summer months. Because the dominant algae in Grass Lake are still diatoms, no chemical treatment is needed in this lake. The cost of chemical treatment of Lake Catherine, Channel Lake, and Lake Marie has already been shown in table 39.

Another important aspect in the total water quality management of the Fox Chain of Lakes is the control of algae in the interconnecting channels, bay areas, and small channels dug to create waterfront properties. The total length of these channels is estimated to be about 30 miles (Kothandaraman et al., 1977). As the water movements in these channels are insignificant, they act as a nursery for algal blooms. Methods for controlling algae and inducing sufficient water movement to impede algal growths in these channels must be evolutionary in nature before a dependable scheme can be worked out.

The task of improving the water quality in the Fox Chain as a whole is a tremendous one. The problems have existed for centuries and have been aggravated by rapid industrialization and by population growth and attendant anthropogenic activities in the watershed. Only a massive and sustained commitment in human and financial resources can rejuvenate the Fox Chain of Lakes system.

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Appendix A

Temperature, Dissolved Oxygen, and Algal Types and Density, Bluff Lake

Appendix A–1. Temperature and Dissolved Oxygen, Bluff Lake (Station 1)

Depth (ft)	5/31/77 Temp	5/31/77 DO	6/6/77 Temp	6/6/77 DO	6/13/77 Temp	6/13/77 DO	6/20/77 Temp	6/20/77 DO	6/27/77 Temp	6/27/77 DO	7/5/77 Temp	7/5/77 DO
0	23.0	8.3	21.3	8.6	18.5	7.8	23.2	9.3	25.7	9.6	27.0	11.4
2	23.0	8.3	21.3	8.7	18.5	7.8	23.2	9.6	25.7	9.1	26.5	11.6
1	23.0	8.5	21.3	8.7	18.2	7.7	23.2	9.8	24.8	9.3	26.5	11.4
6	23.0	8.5	21.3	8.6	18.2	7.6	23.2	10.0	24.8	9.1	26.1	10.8
8	23.0	8.5	21.3	8.5	18.1	7.5	23.2	10.0	24.5	7.6	25.0	7.6
10	23.0	8.5	21.3	8.5	18.0	7.4	21.8	6.6	24.0	1.1	21.2	6.9
12	23.0	8.5	21.3	8.5	17.7	7.4	20.6	1.1	22.5	0.8	23.1	1.5
14	23.0	8.4	21.2	8.5	17.8	7.1	19.2	1.7	21.0	0.1	22.8	1.1
16	18.0	0.7	18.2	0.7	17.5	3.1	17.8	1.1	19.1	0.3	21.8	1.0
18	17.0	0.3	17.5	0.4	17.2	0.5	17.3	1.0	18.7	0.2	19.5	0.8
20	15.3	0.3	15.8	0.3	17.1	0.5	17.0	1.0	17.5	0.2	18.8	0.7
22	14.0	0.3	14.0	0.3	16.5	0.2	16.6	0.7	16.5	0.2	17.0	0.7
24	14.0	0.3	13.6	0.3	14.1	0.2	16.0	0.6	16.0	0.2	16.0	0.7
26			13.2	0.3	13.5	0.2	15.0	0.6	15.5	0.2	15.2	0.7

Depth (ft)	7/11/77 Term	7/11/77 DO	7/13/77 Temp	7/13/77 DO	7/26/77 Temp	7/26/77 DO	8/1/77 Temp	8/1/77 DO	3/8/77 Temp	3/8/77 DO	8/11/77 Temp	8/11/77 DO
0	26.6	7.1	27.0	5.9	25.0	10.2	24.4	8.0	24.0	5.7	23.8	6.1
2	26.0	7.1	27.0	5.8	25.0	10.2	24.4	8.0	24.0	5.7	23.8	6.1
1	26.0	7.0	26.9	5.7	25.0	10.0	24.4	8.0	24.0	5.6	23.8	6.2
6	25.7	7.2	26.9	5.5	25.2	9.8	24.4	8.0	24.0	5.6	23.8	6.2
3	25.5	6.6	26.8	5.2	25.0	5.8	24.2	7.9	24.0	5.6	23.8	6.1
10	25.0	6.1	26.8	5.1	25.0	4.5	24.2	7.0	24.0	4.7	23.5	2.9
12	24.5	4.7	25.0	2.1	24.8	4.6	24.0	6.0	23.6	1.6	23.2	1.6
14	23.3	3.4	24.0	1.1	24.5	4.2	23.8	5.5	23.6	1.0	23.1	1.2
16	21.9	0.9	21.6	1.1	24 .0	1.2	23.8	5.2	23.5	0.4	23.1	0.8
13	19.9	0.7	19.5	1.0	20.8	0.4	22.2	1.5	23.1	0.4	22.8	0.4
20	13.0	0.7	18.2	1.0	19.5	0.3	19.6	1.2	21.1	0.4	21.0	0.4
22	16.7	0.7	17.6	1.0	17.5	0.3	17.6	0.8	18.4	0.4	18.5	0.4
21	15.0	0.7	16.0	1.0	16.5	0.3	16.8	0.7	16.8	0.4	17.0	0.4
26	15. 2	0.7	15.8	1.0	16.0	0.3	16.2	0.7	16.2	0.4	16.0	0.5
27							16.0	0.6				

Depth (ft)	3/17/77 Temp	3/17/77 DO	8/22/77 Temp	8/22/77 DO	3/30/77 Temp	3/30/77 DO	9/6/77 Temp	9/6/77 DO	9/27/77 Temp	9/27/77 DO
0	23.5	7.5	22.2	8.8	23.6	10.7	23.0	10.6	17.4	6.4
2	23.5	7.7	22.2	8.8	23.6	10.7	23.0	10.9	17.4	6.1
4	23.5	7.7	22.2	8.8	23.4	10.8	23.0	10.8	17.4	6.1
6	23.2	7.6	22.2	8.8	23.2	10. 4	23.0	10.4	17.4	6.0
8	23.2	7.5	22.2	8.4	22.2	8.0	22.5	9.2	17.3	6.0
10	23.2	7.5	22.0	8.2	22.2	7.4	22.0	7.6	17.2	6.0
12	23.1	7.3	21.4	6.5	21.8	5.8	31.8	7.3	17.2	6.0
14	22.3	3.7	21.0	6.2	21.6	5.4	21.3	7.0	17.2	6.0
16	22.8	2.0	21.0	6.2	21.2	3.4	21.5	3.7	17.2	6.0
18	28.8	2.0	21.0	5.8	21.0	2.0	21.3	2.1	17.0	6.0
20	22.5	1.2	20.8	1.7	20.2	1.2	21.0	0.8	17.0	6.0
22	20.0	0.7	20.2	1.3	20.2	0.8	20.5	0.4	17.0	5.8
24	17.5	0.5	20.0	1.3	19.8	0.4	19.2	0.3	17.0	5.0
26	17.0	0.5	17.0	0.9	19.2	0.4	19.0	0.2	17.0	4.6

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix A-2. Temperature and Dissolved Oxygen, Bluff Lake Bay Area (Station 2)

Depth (ft)	7/20/77 Temp	7/20/77 DO	8/11/77 Temp	8/11/77 DO	8/17/77 Temp	8/17/77 DO	8/22/77 Temp	8/22/77 DO
0	28.8	8.4	23.2	6.4	24.0	8.6	23.5	11.9
1	28.8	8.4	23.2	6.3	23.8	8.5	23.4	12.4
2	28.8	8.4	23.5	6.3	23.8	8.5	23.2	12.6
3	28.6	8.4	23.5	6.3	23.5	8.5	23.2	12.6
4	28.3	8.4	23.5	6.3	23.2	7.6	23.1	12.3
5	28.3	7.5	23.5	6.3	23.0	7.2		

Depth (ft)	8/30/77 Temp	8/30/77 DO	9/6/77 Temp	9/6/77 DO	9/27/77 Temp	9/27/77 DO
0	24.8	16.0	24.0	12.0	17.0	5.7
1	24.8	16.0	24.3	12.1	17.0	5.6
2	24.6	15.9	24.0	12.2	17.0	5.6
3	24.2	14.2	23.7	12.2	17.0	5.6
4	23.8	12.6	23.5	11.4	17.0	5.6
5	23.8	12.0	22.5	8.2	17.0	5.6

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix A-3. Algal Types and Density, Bluff Lake (Density in counts/ml)

	Surface					Hid-depth					Deep					Bay area				
Date	B-G	0	D	F	0	B-G	G	D	F	0	B-G	G	D	F	0	B-G	G	D	F	0
5/31/77	170	3290	120	170	0	0	2150	170	80	0	0	80	160	0	0					
6/6/77	1320	830	250	60	0	1610	1010	700	0	0	110	70	60	0	0					
6/13/77	1960	920	550	0	0	1210	110	560	0	0	110	50	10	0	0					
6/20/77	2580	1160	350	0	0	1120	1330	160	0	0	1110	110	120	0	0					
6/27/77	2170	660	670	0	0	2660	330	190	0	0										
7/5/77	1980	620	110	10	0	1610	80	160	0	0	1620	170	350	0	0					
7/11/77	1310	2770	1100	0	0	2220	2210	880	0	0	830	1810	970	0	0					
7/18/77	4240	1170	350	0	0	2370	1610	90	0	0	1010	1190	170	0	0					
7/20/77																3800	980	210	30	0
7/26/77	1230	2130	560	0		1980	2130	380	0	0	910	1710	270	0	0					
8/9/77	3990	2360	270	0	0	2070	1270	170	0	0	1270	1210	150	0	0					
8/10/77	1520	0	280	20	0	2110	90	60	0	0	110	30	50	0	0					
8/11/77	4960	510	370			2290	120	260	0	0	60	50	90	0	0	170	90	60	0	0
8/17/77	2480	560	280	110	0	710	20	220	0	0	190	180	80	0	0	1860	630	230	0	0
8/22/77	1720	1900	150	10	0	110	280	130	0	0	210	310	150	0	0	2180	510	620	0	0
8/30/77	1680	500	80	10	0	130	10	10	0	0	80	30	30	0	0	2100	250	970	0	0
9/6/77	1160	510	1010	0	30	250	370	120	0	0	10	50	10	0	0	230	210	230	0	0
9/27/77	960	100	130	0	0	310	150	110	0	0	60	0	30	0	0	1170	580	300	0	0

Note: B-G - blue-greens; G - greens; D - diatoms; F - flagellates; and O - others

Appendix B

Temperature, Dissolved Oxygen, and Algal Types and Density, Fox Lake

Appendix B-1. Temperature and Dissolved Oxygen, Mineola Bay, Fox Lake

Depth	5/16/77		5/23/77		5/31/77		6/2/77		6/3/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	22.8	6.2	21.8	7.6	22.9	10.0	19.5	9.0	19.1	11.2
1	22.8	5.9	21.6	8.0	23.0	10.0	19.5	9.0	19.1	11.0
2	22.4	6.6	21.0	7.5	23.0	10.0	19.5	9.0	19.1	10.8
3	22.2	6.0	23.7	6.7	23.0	10.0	19.5	9.0	19.1	11.0
1	.22.2	6.0	23.0	5.6	23.0	10.0	19.5	8.8	19.1	10.6
5	22.0	5.2	23.0	5.3	23.0	10.0	19.5	8.3	19.1	9.8
6	21.2	1.6	22.9	5.2	23.0	10.0			19.1	9.0
7					23.0	10.0				

Depth	6/6/77		6/13/77		6/20/77		6/27/77		6/28/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	20.7	8.8	17.8	10.1	23.1	10.0	21.2	7.8	25.0	8.0
1	20.8	8.7	17.8	10.1	23.6	10.2	21.2	7.8	25.0	7.7
2	20.8	8.7	17.6	10.5	23.6	10.6	21.2	7.8	25.0	7.3
3	20.7	8.7	17.5	10.5	23.6	10.7	21.2	7.9	21.8	6.6
1	20.7	8.7	17.5	10.5	23.6	11.0	21.2	7.7	21.8	6.3
5	20.7	8.7	17.5	10.1	23.6	11.0	21.1	7.8	21.5	5.0
6	20.7	8.7	17.2	8.0	23.6	10.8	21.0	6.9	21.2	2.3

Depth	7/5/77		7/11/77		7/18/77		7/20/77		7/26/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	27.0	10.2	26.0	7.5	26.1	5.1	27.5	5.1	25.0	12.0
1	27.0	10.2	26.0	7.7	26.1	5.1	27.5	5.0	25.0	12.1
2	27.0	10.2	25.9	7.7	26.1	5.1	27.2	1.9	25.0	12.1
3	27.0	10.2	25.2	7.2	26.1	5.3	27.0	1.9	25.0	12.0
1	26.8	10.2	25.0	5.6	26.1	5.3	27.0	3.9	25.0	12.0
5	26.8	9.8	21.6	3.5	26.1	5.3	26.8	3.8	25.0	11.2
6	26.0	7.1	21.5	2.2	26.1	3.9	26.5	2.2	25.0	10.0

Depth	8/1/77		8/8/77		8/17/77		8/22/77		8/30/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	21.2	9.1	23.2	6.3	22.5	7.3	21.6	7.9	23.9	6.6
1	21.2	9.1	23.2	6.3	22.5	7.3	21.6	7.9	23.9	6.6
2	21.2	9.1	23.2	6.3	22.5	7.3	21.6	7.8	23.9	6.6
3	21.2	9.1	23.2	6.1	22.5	7.5	21.1	7.9	23.8	6.1
1	21.2	9.1	23.2	6.1	22.5	7.5	21.1	7.9	23.1	6.3
5	21.2	9.1	23.2	5.5	22.5	7.5	21.0	7.7	22.9	5.3
6	21.0	5.5	23.2	1.1	22.2	7.3	20.9	7.1	22.1	1.6

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix B-2. Temperature and Dissolved Oxygen, Fox Lake Control Station

Depth (ft)	6/2/77 Temp	6/2/77 DO	6/3/77 Temp	6/3/77 DO	6/6/77 Temp	6/6/77 DO	6/13/77 Temp	6/13/77 DO	6/20/77 Temp	6/20/77 DO
0	19.0	8.9	19.1	11.2	21.0	8.6	18.0	9.6	23.4	10.0
1	19.0	8.9	19.1	11.2	21.0	8.6	18.0	9.6	23.6	10.2
2	19.0	8.7	19.1	11.2	21.0	8.8	17.8	9.7	23.6	10.6
3	19.0	8.7	19.1	11.2	21.0	8.8	17.8	9.7	23.6	10.7
4	19.0	8.7	19.1	11.0	21.0	8.8	17.8	9.7	23.6	11.0
5	18.9	8.7	19.1	11.0	21.0	8.8	17.8	9.7	23.6	11.0
6	18.9	8.7	19.1	9.4	21.0	8.6			23.6	10.8
7					21.0	7.8				
8					21.0	7.8				

Depth (ft)	6/27/77 Temp	6/27/77 DO	6/28/77 Temp	6/28/77 DO	7/5/77 Temp	7/5/77 DO	7/11/77 Temp	7/11/77 DO	7/18/77 Temp	7/18/77 DO
0	24.0	7.4	25.0	8.0	27.8	11.9	25.8	9.4	26.1	5.8
1	24.0	7.4	25.0	7.7	27.8	11.8	25.7	9.4	26.1	5.8
2	24.0	7.5	25.0	7.3	27.8	11.8	25.7	9.6	26.1	5.8
3	24.0	7.5	24.8	6.6	27.5	11.5	25.5	9.6	26.1	5.8
4	24.0	7.5	24.8	6.3	27.5	11.3	25.4	9.4	26.1	5.8
5	24.0	7.4	24.5	5.0	27.2	11.0	25.0	9.3	26.1	5.8
6			24.2	2.3	27.0	8.1	24.8	6.4	26.1	5.7

Depth (ft)	7/20/77 Temp	7/20/77 DO	7/26/77 Temp	7/26/77 DO	8/1/77 Temp	8/1/77 DO	8/8/77 Temp	8/8/77 DO	8/17/77 Temp	8/17/77 DO
0	28.0	8.8	25.0	11.4	24.0	8.2	23.4	7.4	22.5	7.8
1	28.0	8.7	25.0	11.4	24.0	8.2	23.4	7.4	22.5	7.8
2	28.0	8.7	25.0	11.4	24.0	8.4	23.4	7.4	22.5	7.8
3	27.9	8.5	25.0	11.4	23.8	8.3	23.4	7.4	22.5	7.8
4	27.9	8.3	25.0	11.2	23.8	8.3	23.4	7.4	22.5	7.8
5	27.6	7.2	24.8	11.0	23.8	8.3	23.4	7.4	22.5	7.8
6	27.3	5.9			23.7	7.3	23.4	6.9	22.5	7.8

Depth (ft)	8/22/77 Temp	8/22/77 DO	8/30/77 Temp	8/30/77 DO
0	22.0	9.4	24.2	8.0
1	22.0	9.4	24.2	8.3
2	21.9	9.4	24.0	8.5
3	21.5	9.3	24.0	8.5
4	21.0	8.8	23.1	7.2
5	20.8	8.1	22.8	6.6

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix B–3. Algal Types and Density, Fox Lake
CDensity in counts/ml)

	Mineola Bay					Control				
Date	B-G	G	D	P	0	B-G	G	D	F	0
5/17/77	160	1360	500	80	50					
5/24/77	420	1400	150	0	0					
6/2/77	310	1340	1090	80	0	560	1950	1170	90	0
6/3/77	430	320	480	0	0	400	610	560	0	0
6/6/77	160	1530	2640	0	0	260	1830	2690	0	0
6/13/77	980	1190	1520	0	0	810	1710	1370	0	0
6/20/77	940	1310	1500	60	0	400	650	1170	10	0
6/27/77	850	1150	870	0	0	1640	1000	160	0	0
6/28/77	230	120	80	0	0	850	580	870	0	0
7/5/77	670	120	2740	0	0	1290	790	2430	0	0
7/11/77	4200	190	440	1110	120	6790	380	170	1800	0
7/18/77	3200	1910	760	0	0	2190	1390	530	0	0
7/20/77	2690	580	300	0	0					
7/26/77						1340	410	240	0	0
8/1/77	1550	360	90	10	0	970	600	180	0	0
8/8/77	1240	210	670	60	0	1820	280	910	0	0
8/17/77	670	130	70	0	0	310	150	220	10	0
8/22/77	1210	1650	580	0	0	1470	1460	560	0	0
8/30/77	80	30	20	10	0	70	80	80	0	0

Note: B-G = blue-greens; G = greens; D = diatoms; F - flagellates;
and 0 = others

Appendix C

Temperature and Dissolved Oxygen, Lake Catherine and Channel Lake, 1977, 1978, 1979, 1980

Appendix C-1. Temperature and Dissolved Oxygen, Lake Catherine, 1977

Depth	5/16/77		5/23/77		5/31/77		6/6/77		6/13/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	21.4	7.8	23.9	9.2	23.0	8.6	21.2	8.6	18.2	8.5
2	21.4	6.8	23.8	8.6	23.0	8.1	21.1	8.6	18.1	8.2
1	21.4	6.6	23.5	7.9	23.0	7.2	21.0	8.7	18.0	8.1
6	21.0	6.0	23.1	7.1	23.0	6.6	21.0	8.7	18.0	8.1
8	20.9	5.4	23.1	6.9	23.0	5.8	21.0	8.7	17.9	8.1
10	20.0	4.9	22.5	6.0	23.0	5.1	21.0	9.0	17.8	8.0
12	18.0	4.9	20.9	1.9	21.8	1.1	21.0	9.0	17.6	7.6
14	16.6	4.6	17.1	5.1	17.9	3.9	19.2	5.9	17.4	7.3
16	15.8	4.3	15.1	1.8	16.1	3.8	17.8	3.2	17.2	6.5
18	15.4	4.1	11.6	1.2	15.0	3.7	17.2	2.2	16.9	5.8
20	14.3	3.7	12.1	1.0	11.0	3.1	15.5	0.9	16.1	0.7
22	13.3	2.7	12.1	3.1	13.3	2.3	13.2	0.6	13.4	0.4
21	11.8	2.7	12.0	2.6	12.1	2.2	11.8	0.1	12.2	0.3
26	11.2	1.7	11.2	2.0	11.5	2.0	11.0	0.3	11.3	0.4
28	10.8	1.6	10.9	1.8	11.0	1.8	10.8	0.3	10.7	0.3
30	10.7	1.4	10.8	1.6	10.6	1.6	10.8	0.3	10.5	0.3
32	10.2	1.4	10.2	1.5	10.2	1.5	10.3	0.3	10.5	0.3
3'	10.0	1.3	10.1	1.1	10.0	1.1	10.0	0.3	10.1	0.3
36	10.0	1.3	9.9	1.3	10.0	1.1	10.0	0.3	9.8	0.3
37	9.9	1.1								
38			9.9	1.3	10.0	1.1	10.0	0.3	9.8	0.2
40							10.0	0.3		

Depth	6/20/77		6/27/77		7/5/77		7/11/77		7/18/77	
(ft)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	22.5	8.9	27.5	9.6	27.5	9.2	25.9	7.2	26.6	6.0
2	22.5	8.9	26.5	9.5	27.2	9.3	25.9	6.6	26.8	6.1
4	22.4	8.6	26.0	9.8	27.0	9.3	25.9	6.6	26.8	6.0
6	22.4	8.7	25.5	10.0	27.0	9.3	25.8	6.7	26.6	6.1
8	22.4	8.7	25.0	9.5	26.8	7.3	25.6	6.6	26.6	6.1
10	22.3	8.6	24.0	7.5	24.5	6.6	25.0	5.6	26.5	6.0
12	22.2	8.5	22.0	4.9	22.5	6.1	24.0	3.1	26.0	3.6
14	14.0	6.1	21.0	3.4	22.0	5.2	22.0	1.4	23.8	0.9
15	17.9	4.5	19.2	2.3	21.2	3.6	21.0	0.7	22.2	0.8
18	17.0	2.7	17.0	1.2	19.5	2.2	20.0	0.7	20.2	0.8
20	16.2	2.9	15.8	0.8	19.0	0.9	16.7	0.7	18.3	0.8
22	15.0	0.6	14.0	0.5	17.5	0.8	15.0	0.7	14.2	0.9
24	13.3	0.3	13.1	0.5	14.2	0.8	13.7	0.7	13.2	0.9
26	11.2	0.3	12.0	0.5	13.1	0.8	12.7	0.7	12.6	0.9
29	11.0	0.2	11.1	0.5	12.5	0.7	11.4	0.7	12.0	0.9
30	10.9	0.3	10.8	0.4	12.0	0.7	11.0	0.7	11.4	1.0
32	10.9	0.2	10.5	0.4	11.2	0.7	10.8	0.7	11.0	1.0
34	10.4	0.2	10.2	0.3	10.8	0.6	10.4	0.9	10.9	1.0
36	10.2	0.2	10.2	0.3	10.2	0.6	10.4	0.9		
38	10.0	0.2			10.0	0.7				

Appendix C–1. Concluded

Denth (ft)	7/26/77 Temp	DO	3/1/77 Temp	DO	9/9/77 Temp	DO	8/17/77 Temp	DO	8/22/77 Temp	DO.
0	24.8	7.1	24.7	7.7	24.0	7.3	22.8	7.0	21.6	7.3
2	24.8	7.1	24.7	8.0	24.0	7.3	22.8	6.5	21.6	7.3
4	24.8	7.1	24.7	8.0	24.0	7.3	22.8	6.5	21.6	7.3
6	24.8	7.1	24.7	7.8	24.0	7.3	22.8	6.5	21.6	7.3
B	24.3	7.1	24.7	7.8	24.0	7.3	22.8	6.5	21.6	7.3
10	24.8	6.8	24.3	7.9	24.0	7.3	22.5	6.2	21.6	7.3
12	24.8	6.8	24.3	7.8	24.0	7.3	22.5	6.2	21.6	7.2
14	24.0	1.5	24.0	7.4	24.0	7.3	22.5	6.1	21.6	7.2
16	21.5	0.5	22.6	3.6	23.8	0.7	22.2	6.0	21.2	6.6
13	19.5	0.4	22.0	0.7	21.1	0.6	22.0	3.8	21.0	4.4
20	17.0	0.3	18.0	0.6	15.8	0.5	20.2	1.5	20.5	1.6
22	16.0	0.3	16.3	0.6	15.3	0.5	17.5	0.9	18.0	1.3
24	13.8	0.3	14.0	0.7	14.2	0.4	15.0	0.6	15.0	0.9
26	13.3	0.3	13.9	1.1	13.2	0.4	13.0	0.4	13.5	0.9
28	12.2	0.4	12.1	0.8	12.0	1.0	12.5	0.4	12.8	0.7
30	11.8	0.4	11.8	0.9	11.4	1.0	12.0	0.4	12.0	0.7
32	11.5	0.4	11.2	0.9	11.0	1.1	11.0	0.4	11.6	0.5
34	11.0	0.4	11.7	0.8	10.9	1.1	11.0	0.4	11.2	0.6
36	11.0	0.4	10.3	0.3	10.6	1.3	11.0	0.3	11.0	0.4
37										
38	10.8	0.4	10.6	0.8			11.0	0.3		

Depth (ft)	9/30/77 Temp	DO	9/6/77 Temp	DO
0	23.1	8.1	23.5	3.8
3	23.0	3.2	23.3	8.5
4	23.0	3.3	23.1	3.9
6	23.0	3.3	23.0	8.8
9	22.8	8.4	22.8	8.6
10	22.4	3.0	22.4	8.0
12	22.1	7.9	22.1	6.3
14	22.0	6.4	22.0	6.5
16	21.8	5.8	22.0	4.9
19	21.2	2.1	21.9	3.7
20	19.4	0.6	21.4	1.6
22	19.4	0.3	21.1	1.2
24	16.2	0.3	20.9	0.6
26	14.6	0.3	19.4	0.3
28	13.0	0.3	17.9	0.3
30	12.2	0.3	15.4	0.2
32	11.6	0.3	14.4	0.2
34	11.4	0.3	14.2	0.2
36	11.0	0.3		

Note: Temperature In degrees Celsius; Dissolved oxygen in mg/l

Appendix C-2. Temperature and Dissolved Oxygen, Channel Lake, 1977

Depth (ft)	3/16/77 Temp	DO	5/23/77 Temp	DO	5/31/77 Temp	DO	6/6/77 Temp	DO	6/13/77 Temp	DO
0	21.8	7.7	23.2	10.5	23.5	9.0	20.9	8.5	18.8	7.8
2	21.8	8.1	23.1	10.8	23.5	9.0	20.9	8.1	18.7	7.3
1	21.14	7.9	23.1	10.0	23.5	9.0	20.9	8.1	18.3	7.8
6	21.0	7.2	23.0	9.6	23.5	8.1	20.9	8.3	18.2	7.7
8	20.9	6.8	22.8	8.1	23.5	8.0	20.9	8.1	18.2	7.7
10	20.8	6.2	22.1	7.2	23.5	7.9	20.9	8.3	18.1	7.7
12	19.8	6.0	21.1	6.1	22.5	1.1	20.9	8.1	18.0	7.6
11	17.7	5.3	19.5	6.2	20.9	2.0	20.9	8.3	17.9	7.1
16	16.4	5.l	18.1	5.1	18.0	1.5	20.1	8.1	17.8	7.1
18	16.4	5.7	16.1	5.0	17.5	1.1	19.6	5.9	17.8	7.1
20	15.2	1.5	15.8	1.1	15.7	1.2	17.8	2.6	17.7	7.1
22	15.0	1.0	15.0	1.2	15.0	1.0	17.0	0.7	17.5	7.0
24	14.9	3.9	15.0	3.7	11.8	1.0	15.0	0.7	17.1	6.0
26	14.7	3.4	11.1	3.1	11.0	0.8	11.0	0.3	15.9	O.e
28	14.0	3.2	11.0	2.3	13.5	0.5	13.3	0.3	15.0	0.7
30	13.7	2.1	13.1	2.0	13.5	0.5	13.0	0.3	13.5	0.6
32	13.2	1.9	13.1	1.7	13.0	0.1	12.9	0.3	13.0	0.1
3"	13.0	1.1	12.0	1.5	12.8	0.1	12.8	0.3	12.9	0.3
36	12.1	1.1			12.5	0.3				

Depth (ft)	6/20/77 Temp	DO	6/27/77 Temp	DO	7/5/77 Temp	DO	7/11/77 Temp	DO	7/18/77 Temp	DO
0	22.6	9.2	26.0	9.5	27.0	10.0	26.0	7.2	26.6	5.9
2	22.6	9.2	25.5	9.5	26.5	10.0	25.9	7.3	26.6	5.8
1	22.6	9.1	25.0	9.7	26.2	9.9	25.9	7.3	26.6	5.8
6	22.7	9.1	21.8	9.9	26.0	9.8	25.7	7.3	26.6	5.8
8	22.7	9.1	21.5	9.1	25.5	9.1	25.5	6.9	26.6	5.7
10	22.7	9.1	21.2	6.1	25.0	9.1	25.1	6.7	26.6	5.6
12	21.7	8.4	21.5	3.1	21.5	7.3	25.0	6.0	26.6	5.6
14	16.2	5.1	19.8	1.5	23.0	5.6	23.2	1.1	26.1	5.5
16	18.0	1.0	18.2	1.1	21.5	2.6	22.1	0.7	26.1	1.1
18	17.4	2.B	18.0	0.7	20.8	1.6	20.5	0.8	21.0	1.1
20	17.4	1.7	17.2	0.5	20.1	1.0	19.0	0.7	19.1	1.0
22	17.0	1.6	17.0	0.1	18.0	0.8	17.9	0.7	18.2	1.0
21	16.8	0.7	16.5	0.1	17.0	0.8	17.0	0.7	17.2	1.0
26	16.2	0.6	16.0	0.3	16.5	0.8	16.2	0.7	16.8	1.0
28	15.0	0.3	15.0	0.3	16.0	0.7	15.1	0.7	16.6	1.0
30	11.0	0.3	11.0	0.2	15.2	0.5	11.8	0.7	15.2	1.0
32	13.8	0.3	13.5	0.2	11.5	0.1	11.2	0.7		
34					13.8	0.1	11.0	0.7		
36					13.5	0.1				
38					13.2	0.1				

Appendix C–2. Concluded

Depth (ft)	7/26/77 Temp	7/26/77 DO	8/1/77 Temp	8/1/77 DO	8/9/77 Temp	8/9/77 DO	8/17/77 Temp	8/17/77 DO	8/22/77 Temp	8/22/77 DO
0	20.8	7.0	24.7	8.0	23.8	7.8	22.8	6.5	22.0	6.7
2	20.8	6.0	24.7	8.0	24.0	7.6	22.8	5.3	22.0	6.7
4	20.8	i.6	24.7	8.5	24.0	7.6	22.8	6.1	22.0	6.6
6	20.8	6.5	24.7	8.0	24.0	7.6	22.8	5.9	22.0	6.0
8	20.8	6.0	24.0	8.3	24.0	7.6	22.8	5.8	22.0	6.0
10	20.8	6.0	24.2	8.2	24.0	7.6	22.8	5.7	22.0	6.0
12	20.8	6.0	24.0	6.7	24.0	7.5	22.8	5.7	22.0	6.1
10	20.8	6.3	23.8	6.6	24.0	7.0	22.8	5.6	22.0	6.1
16	20.0	0.5	23.8	6.0	24.0	7.3	22.8	5.5	21.9	6.0
18	21.8	0.6	23.4	3.2	23.1	2.1	22.8	5.5	21.8	6.0
20	20.0	0.0	21.2	1.2	22.2	1.5	22.5	5.3	21.2	0.6
22	13.0	0.3	18.5	0.8	18.7	1.5	22.1	5.1	21.0	0.0
24	17.0	0.3	17.8	0.7	17.1	1.6	19.0	0.6	20.9	0.0
26	16.2	0.3	16.0	0.7	16.2	1.6	17.5	O.O	18.9	2.1
28	15.2	0.0	15.9	0.7	15.2	1.7	16.0	0.0	16.2	1.0
30	10.5	0.0	14.8	0.7	14.2	1.7	15.0	0.0	15.0	1.3
32	14.0	0.0	14.2	0.7	14.0	1.7	10.1	0.3	10.6	1.1
34	14.0	0.0	14.0	0.7					10.1	1.1
36			14.0	0.7						

Depth (ft)	3/30/77 Temp	3/30/77 DO	9/6/77 Temp	9/6/77 DO
0	23.5	3.8	23.3	9.0
2	23.3	8.8	23.3	9.3
4	23.1	8.9	23.0	9.3
6	23.0	8.8	22.5	7.8
8	22.8	3.6	22.2	6.7
10	22.0	8.0	22.1	6.0
12	22.1	6.9	22.0	6.2
14	22.0	6.5	22.0	6.2
16	22.0	0.9	22.0	0.8
18	21.9	3.7	22.0	5.2
20	21.0	1.5	21.8	0.9
22	21.1	1.2	21.5	0.2
24	20.9	0.6	21.0	0.6
26	19.0	0.3	20.5	0.3
28	17.9	0.3	17.0	0.2
30	15.0	0.2	16.0	0.2
32	10.0	0.2	10.5	0.2
34	10.2	0.2	10.5	0.2

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C–3. Temperature and Dissolved Oxygen, Lake Catherine Station 1, 1978

Depth (feet)	5-17-78 DO	5-17-78 Temp	5-24-78 DO	5-24-78 Temp	5-31-78 DO	5-31-78 Temp	6-6-78 DO	6-6-78 Temp	6-27-78 DO	6-27-78 Temp	7-12-78 DO	7-12-78 Temp	7-19-78 DO	7-19-78 Temp
0	10.0	12.8	9.4	14.8	6.2	22.9	10.6	21.0	9.9	25.4	7.4	22.8	8.1	24.6
2	10.1	12.4	9.4	14.8	6.2	23.2	11.0	21.0	10.0	25.4	7.4	22.8	8.2	24.6
4	10.2	12.2	9.4	14.8	6.9	22.6	11.0	21.0	10.2	25.4	7.4	22.8	8.3	24.6
6	10.2	12.0	9.4	14.8	10.4	21.8	11.0	21.0	9.9	24.0	7.4	22.8	8.2	24.6
8	10.1	11.9	9.0	14.9	10.2	21.4	11.0	20.8	8.2	22.2	7.4	22.8	7.3	24.2
10	9.0	11.4	8.7	14.9	10.2	20.0	10.9	20.2	7.B	22.2	7.4	22.8	5.9	24.0
12	9.0	11.4	8.4	14.8	10.2	18.5	10.0	20.0	7.4	22.2	7.4	22.8	5.4	23.8
14	9.0	11.3	8.1	14.4	10.0	17.1	8.6	19.1	7.0	22.0	7.4	22.8	4.9	23.6
16	8.8	11.2	7.7	14.1	9.4	16.8	6.3	18.2	6.6	21.9	7.4	22.8	4.4	23.2
18	8.4	11.2	7.6	14.6	8.8	15.2	5.3	16.6	6.5	21.4	7.2	22.8	4.1	23.2
20	8.4	11.2	6.6	12.1	8.5	15.0	4.6	16.0	6.0	21.2	4.3	22.2	4.0	23.0
22	8.3	11.0	6.4	11.8	8.4	14.1	4.3	15.0	5.8	20.8	2.4	22.0	2.3	22.5
24	8.0	11.0	6.2	11.5	7.8	13.5	2.4	14.6	1.9	20.0	0.9	21.0	1.2	21.6
26	7.9	10.9	6.2	11.1	7.4	12.8	2.1	13.0	0.5	17.0	0.4	19.0	0.5	20.2
28	7.6	10.9	3.2	10.9	6.1	12.0	0.7	12.0	0.3	14.2	0.2	16.0	0.3	18.1
30	7.4	10.9	1.7	10.6	5.6	11.5	0.4	11.2	0.3	13.0	0.2	14.2	0.2	15.2
32	7.2	10.8	0.8	10.5	3.9	11.2	0.3	11.0	0.2	12.4	0.2	13.2	0.2	13.4
34	7.2	10.8	0.6	10.2	3.4	11.0	0.2	10.8	0.2	12.0	0.2	11.9	0.2	13.4
36	7.2	10.8	0.3	10.2	2.5	11.0	0.2	10.6	0.2	11.8	0.2	11.6	0.2	12.2
38	6.8	10.6	0.3	10.0	1.4	10.2	0.2	10.2	0.2	11.5	0.2	11.6		
40	6.0	10.5					0.2	10.1						

Depth (feet)	7-27-78 DO	7-27-78 Temp	8-9-78 DO	8-9-78 Temp	8-23--78 DO	8-23--78 Temp	9-6-78 DO	9-6-78 Temp	9-20-78 DO	9-20-78 Temp	10-4-78 DO	10-4-78 Temp
0	5.6	23.6	8.6	24.6	8.0	25.0	7.6	24.5	10.0	24.5	6.8	16.9
2	5.6	23.6	8.7	24.6	7.8	25.0	7.6	24,5	10.2	24.4	6.8	16.9
4	5.5	23.6	8.7	24.6	7.6	25.0	7.6	24.5	10.3	24.2	6.6	16.9
6	5.4	23.6	8.7	24.2	6.9	24.9	7.6	24.2	10.0	23.6	6.6	16.9
8	5.3	23.6	8.0	23.8	5.8	24.2	6.8	24.2	8.1	23.0	6.5	16.9
10	5.1	23.6	6.6	23.0	5.3	24.1	6.6	24.0	7.6	22.2	6.5	16.9
12	5.1	23.6	6.1	23.0	5.0	24.0	6.2	23.9	7.2	22.2	6.5	16.9
14	4.9	23.6	5.9	23.0	4.7	23.9	5.8	23.6	6.8	22.0	6.5	16.9
16	4.6	23.6	5.5	22.9	4.6	23.7	5.4	23.6	6.2	21.9	6.5	16.9
18	3.7	23.4	4.9	22.7	4.4	23.6	5.1	23.2	5.9	21.8	6.4	16.9
20	3.0	23.2	4.4	22.6	2.6	23.2	4.8	23.2	5.6	21.8	6.4	16.9
22	2.6	23.0	3.2	22.0	2.4	23.0	4.6	23.2	5.3	21.7	6.3	16.9
24	2.1	22.6	2.0	21.9	2.2	23.0	3.9	23.0	5.1	21.4	6.3	16.9
26	0.3	21.8	1.2	21.2	1.4	22.5	1.6	22.3	3.2	21.1	6.3	16.9
28	0.3	19.8	0.6	19.2	0.6	21.8	0.8	21.8	2.9	21.0	6.2	16.9
30	0.3	16.6	0.5	16.0	0.3	19.8	0.6	19.0	2.3	21.0	6.0	16.8
32	0.3	14.9	0.4	14.0	0.2	17.9	0.4	17.0	1.3	17.5	5.9	16.8
34	0.3	13.1	0.4	13.2	0.2	16.5	0.4	15.7	1.1	16.2	5.8	16.5
36	0.3	12.8	0.4	12.9	0.2	15.3	0.3	14.4	1.0	15.4	1.6	14.2
38	0.3	12.6	0.4	12.1	0.2	14.0	0.3	13.8	0.8	13.8		
40	0.3	12.4										

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C-4. Temperature and Dissolved Oxygen, Lake Catherine Station 2, 1978

Depth (feet)	5-17-78 DO	5-17-78 Temp	5-24-78 DO	5-24-78 Temp	5-31-78 DO	5-31-78 Temp	6-6-78 DO	6-6-78 Temp	6-27-78 DO	6-27-78 Temp	7-12-78 DO	7-12-78 Temp	7-19-78 DO	7-19-78 Temp
0	10.4	12.8	9.6	16.1	9.0	23.0	10.9	21.2	9.8	25.2	5.9	22.2	7.5	24.4
2	10.6	12.8	9.4	16.0	9.6	22.9	11.0	20.4	9.8	25.0	6.3	22.2	7.5	24.4
4	10.7	12.7	9.4	16.0	10.4	22.8	10.9	20.4	9.0	23.8	6.3	22.2	7.5	24.4
6	10.6	12.2	9.4	16.0	10.4	21.5	10.4	19.8	8.3	23.2	6.4	22.2	7.5	24.2
8	10.6	12.2	9.4	16.0	10.4	20.5	10.0	19.6	6.6	22.2	6.4	22.2	6.2	23.9
10	10.2	11.9	9.2	15.8	10.4	19.2	9.7	19.4	6.5	22.0	6.4	22.2	5.9	23.9
12	9.6	11.8	9.0	15.2	10.4	18.5	9.5	19.2	6.5	21.9	6.4	22.2	5.8	23.8
14	9.2	11.5	8.6	14.8	10.4	17.8	7.2	18.2	6.5	21.8	6.4	22.2	5.6	23.7
16	9.2	11.5	8.2	14.2	10.4	16.4	5.7	16.6	6.3	21.3	6.5	22.2	5.3	23.4
18	8.6	11.2	7.6	13.8	10.2	15.4	4.8	14.9	5.9	21.2	6.5	22.2	4.9	23.3
20	8.4	11.2	7.1	13.0	9.8	15.2	4.1	14.8	5.8	21.0	5.9	22.2	3.9	22.9
22	8.0	11.1	6.4	11.9	8.8	14.9	3.4	13.9	5.5	21.0	5.4	22.2	1.6	22.2
24	7.9	11.0	6.2	11.4	8.7	13.9	3.2	13.9	4.4	20.2	1.6	20.8	0.9	21.2
26	7.7	11.0	4.4	11.0	7.5	12.6	0.7	12.7			0.9	19.0	0.4	20.9
28	7.1	11.0			5.4	12.0					0.6	16.0		

Depth (feet)	7-27-78 DO	7-27-78 Temp	8-9-78 DO	8-9-78 Temp	8-23-78 DO	8-23-78 Temp	9-6-78 DO	9-6-78 Temp	9-20-78 DO	9-20-78 Temp	10-4-78 DO	10-4-78 Temp
0	4.9	23.0	8.9	25.0	5.1	24.2	6.5	23.9	10.2	24.5	7.3	16.2
2	4.9	23.1	8.9	25.0	4.7	24.2	6.5	23.9	10.3	24.5	6.6	16.6
4	4.9	23.1	8.6	24.6	4.6	24.1	6.4	23.9	10.4	24.5	6.3	16.6
6	4.8	23.1	8.6	24.3	4.3	24.0	6.2	23.9	10.0	23.8	6.2	16.7
8	4.8	23.1	7.9	24.0	4.0	23.9	6.0	23.6	9.4	23.6	6.0	16.8
10	4.7	23.1	7.3	23.8	3.9	23.7	5.4	23.3	9.4	23.2	6.0	16.9
12	4.7	23.1	6.8	23.7	3.9	23.5	5.2	23.2	8.2	22.9	5.9	16.9
14	4.6	23.1	6.5	23.2	3.6	23.5	5.1	23.2	7.0	22.2	5.9	16.9
16	4.6	23.1	4.9	22.9	3.3	23.5	5.0	23.1	6.6	22.2	5.8	16.9
18	4.7	23.1	4.4	22.8	3.0	23,2	4.8	23.1	6.4	22.0	5.8	16.9
20	4.6	23.1	3.6	22.2	2.9	23.1	4.8	23.1	6.0	22.0	5.7	16.9
22	4.3	23.1	2.2	21.9	2.6	23,1	4.7	23,1	5.2	21.7	5.7	16.9
24	1.2	22.6	1.3	21.6	2.0	23.0	2.8	22.9	4.6	21.6	5.7	16.9
26	0.9	21.6			0.5	22.8	0.9	22.4	2.7	21.4		
28	0.7	21.6					0.5	22.2				

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C-5. Temperature and Dissolved Oxygen, Channel Lake, 1978

Depth Feet	5-17-78 DO	5-17-78 Temp	5-24-78 DO	5-24-78 Temp	5-31-78 DO	5-31-78 Temp	6-6-78 DO	6-6-78 Temp	6-27-78 DO	6-27-78 Temp	7-12-78 DO	7-12-78 Temp	7-19-78 DO	7-19-78 Temp
0	9.1	12.2	9.4	16.5	9.4	24.1	10.6	22.0	10.4	25.6	7.4	22.9	7.4	24.6
2	9.1	12.2	8.6	16.2	9.0	24.1	10.6	22.0	10.4	25.6	7.6	22.9	7.5	24.6
4	9.0	12.2	8.4	16.2	10.0	24.1	11.2	22.0	10.2	25.4	7.6	22.9	7.6	24.6
6	9.0	11.9	8.2	16.1	10.0	22.8	11.2	21.9	9.1	23.8	7.6	22.9	7.6	24.6
8	8.8	11.7	8.1	16.0	10.0	22.3	11.0	21.9	7.8	23.2	7.6	22.9	6.9	24.2
10	8.6	11.6	7.8	15.8	10.0	21.8	11.0	21.2	6.8	22.7	7.6	22.9	6.7	24.2
12	8.3	11.5	7.5	15.0	9.4	18.2	10. 8	21.2	6.4	22.3	7.6	22.9	6.0	24.0
14	8.3	11.5	6.8	14.8	8.4	16.0	4.4	17.9	5.6	21.8	7.6	22.9	1.6	22.6
16	8.2	11.4	6.4	13.6	8.0	14.8	2.7	16.2	1.9	20.8	2.9	21.1	0.5	22.0
18	8.2	11.4	5.8	12.4	6.9	13.9	2.4	14.8	0.7	19.2	0.7	19.8	0.4	20.8
20	8.1	11.3	5.6	12.0	6.6	13.0	1.3	13.2	0.2	18.8	0.3	18.4	0.2	19.5
22	8.1	11.3	5.6	11.9	5.8	12.5	0.8	12.6	0.2	17.2	0.2	17.2	0.2	18.0
24	8.1	11.2	5.6	11.8	5.4	12.2	0.7	12.1	0.2	15.8	0.1	15.0	0.2	16.2
26	8.1	11.2	5.0	11.6	5.4	12.0	0.7	11.9	0.2	14.9	0.1	14.9	0.2	14.8
28	7.8	11.2	2.8	11.2	1.4	11.6	0.5	11.9	0.1	13.9	0.1	13.8	0.1	13.8
30	7.6	11.2	0.8	11.2	1.0	11.4	0.4	11.5	0.1	13.0	0.1	12.6	0.1	12.9
32	6.8	11.1	0.6	11.0	0.8	11.2	0.3	11.3	0.1	12.2	0.1	12.1	0.1	12.1
34	4.3	11.0	0.4	11.0	0.6	11.1	0.2	11.0	0.1	11.7	0.1	12.0	0.1	12.1
36							0.2	11.0	0.1	11.3			0.1	12.0
38							0.2	11.0	0.1	11.3				

Depth Feet	7-27-78 DO	7-27-78 Temp	8-9-78 DO	8-9-78 Temp	8-23-78 DO	8-23-78 Temp	9-6-78 DO	9-6-78 Temp	9-20-78 DO	9-20-78 Temp	10-4-78 DO	10-4-78 Temp
0	5.9	23.2	8.1	24.2	10.4	25.0	8.9	24.5	11.6	23.7	6.2	16.5
2	5.6	23.2	8.2	24.2	10.4	25.0	9.0	24.5	11.8	23.7	6.6	16.5
4	5.5	23.2	8.2	24.2	10.4	24.9	9.1	24.5	11.8	23.5	6.3	16.5
6	5.4	23.2	8.2	24.2	10.4	24.9	9.1	24.3	10.8	23.0	6.3	16.5
8	5.4	23.2	8.0	24.0	10.0	24.5	8.2	24.0	9.2	22.4	6.2	16.5
10	5.2	23.2	7.8	23.4	9.8	24.5	8.0	23.8	8.3	21.9	6.2	16.5
12	5.2	23.2	6.9	23.0	8.9	24.2	7.8	23.8	7.4	21.8	6.2	16.5
14	5.2	23.2	5.6	22.6	8.5	24.0	6.7	23.2	7.2	21.4	6.2	16.5
16	4.7	23.2	2.9	22.0	8.1	24.0	4.7	23.0	6.2	21.2	6.2	16.5
18	1.4	23.0	0.9	21.0	4.8	23.3	1.6	22.2	5.9	21.0	6.2	16.5
20	0.5	20.6	0.6	20.9	0.2	22.8	1.0	22.0	4.5	21.0	6.2	16.5
22	0.2	19.0	0.5	19.8	0.2	22.0	0.8	20.8	3.2	20.9	6.2	16.5
24	0.2	17.2	0.4	17.8	0.2	19.9	0.5	19.0	2.2	20.8	6.2	16.5
26	0.3	18.0	0.4	16.2	0.2	17.5	0.4	17.8	1.8	18.2	6.2	16.5
28	0.2	14.9	0.4	14.8	0.2	16.2	0.3	16.2	1.4	17.8	2.8	16.2
30	0.2	14.0	0.4	13.0	0.2	15.3	0.3	15.0	1.3	16.5	0.7	15.9
32	0.2	13.4	0.4	12.6	0.2	13.9	0.3	14.2	1.1	15.0	0.5	15.4
34	0.2	13.0	0.4	12.2	0.2	13.2	0.3	13.8	1.0	14.0	0.4	13.8
36	0.2	12.6	0.3	12.2	0.2	13.0	0.3	13.2	0.9	13.6	0.4	13.0
38	0.2	12.4							0.9	13.2		

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C-6. Temperature and Dissolved Oxygen, Lake Catherine Station 1, 1979

Depth	*5/9/79*		*S/22/79*		*6/5/79*		*6/21/79*		*6/27/79*		*7/2/79*		*7/11/79*		*7/12/79*		*7/17/79*	
	DO	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*
0	11.8	15.4	8.0	17.9	8.4	20.3	8.4	22.0	10.5	23.8	9.2	24.9	7.3	25.9	7.5	25.4	8.6	25.2
2	12.2	15.4	8.0	17.9	8.4	20.3	8.4	22.0	10.4	23.8	9.2	24.8	7.4	25.9	7.2	25.4	8.4	25.0
4	12.2	15.4	7.9	17.8	8.4	20,2	8.4	22.0	10.2	23.0	9.3	23.6	7.4	25.8	5.0	25.0	8.5	25.0
6	12.2	15.4	7.9	17.6	8.4	20.2	8.3	22.0	7.3	21.8	8.1	22.8	4.5	24.8	4.2	24.0	8.4	25.0
8	12.2	15.4	7.8	17.5	8.4	20.2	8.3	22.0	6.5	21.4	7.7	22.3	3.3	23.2	3.0	23.6	8.1	24.9
10	12.2	15.2	7.8	17.2	8.4	20.1	8.2	22.0	6.2	21.4	6.8	22.1	2.7	23.0	2.6	23.2	7.9	24.9
12	12.4	15.0	7.2	16.9	7.5	19.2	8.2	22.0	5.5	21.0	6.5	22.0	2.5	22.8	2.3	23.0	7.9	24.9
14	12.8	14.0	6.9	16.9	7.1	18.7	8.2	21.8	5.1	20.9	5.8	21.9	2.1	22.2	2.1	22.8	1.2	23.5
16	12.9	13.9	6.9	16.8	6.5	18.0	7.6	21.6	4.9	20.9	5.8	21.9	1.8	22.0	1.7	22.2	0.5	23.0
18	12.9	13.8	6.9	16.6	6.1	17.4	7.4	21.2	4.8	20.8	4.2	21.4	1.9	21.8	1.6	22.0	0.3	22.8
20	13.0	13.2	6.8	16.2	5.7	17.0	6.9	21.0	4.4	20.6	3.6	21.1	1.8	21.5	1.6	21.9	0.2	22.1
22	13.0	11.9	6.0	15.6	5.3	16.6	5.6	20.0	3.8	20.4	3.0	21.0	1.7	21.4	1.6	21.8	0.2	22.0
24	12.0	10.9	4.6	14.7	4.8	15.9	4.4	19.8	2.8	20.2	2.1	20.9	1.7	20.6	0.5	21.6	0.2	21.8
26	9.8	9.2	4.1	14.0	4.1	15.7	3.5	19.0	1.6	19.8	1.4	20.4	0.1	20.1	0.1	21.0	0.1	21.4
28	8.4	8.2	3.9	13.5	3.8	15.4	1.3	18.0	0.3	19.0	0.5	20.1	0.1	20.0	0.1	20.8	0.1	21.0
30	8.2	8.0	3.5	12.9	1.4	14.8	0.3	17.2	0.3	17.8	0.4	19.9	0.1	19.9	0.1	19.8	0.1	20.3
32	7.4	8.0	2.9	12.2	0.3	14.1	0.2	16.8	0.1	15.5	0.2	19.2	0.1	19.9	0.1	18.0	0.1	19.9
34	6.6	7.5	1.0	9.2	0.2	14.0	0.1	15.9	0.1	14.1	0.2	17.2	0.1	19.9	0.1	15.9	0.1	18.2
36	6.1	7.2			<0.1	13.3	0.1	14.2	0.1	13.8	0.1	15.1	0.1	19.9				
38	6.0	7.2			<0.1	12.9	0.1	13.9			0.1	14.0						
40	5.4	7.0									0.1	13.9						
Secchi inchee	33		78		84		36		33		42		48		42		39	

Depth	*8/2/79*		*9/7/79*		*8/16/79*		*8/23/79*		*8/29/79*		*9/5/79*		*9/20/79*		*10/4/79*	
	DO	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*	*DO*	*Temp*
0	3.8	24.2	5.8	25.6	5.5	22.1	8.4	22.6	8.4	23.0	10.0	25.8	7.0	19.2	6.2	17.7
2	3.8	24.2	5.7	25.6	5.4	22.1	8.4	22.6	8.4	23.0	10.2	25.0	6.8	19.2	6.0	17.7
4	3.7	24.2	5.6	25.6	5.1	22.1	8.2	22.6	8.4	22.9	10.2	24.0	6.8	19.2	5.9	17.7
6	3.5	24.1	5.6	25.4	5.0	22.0	7.7	22.4	8.4	22.9	6.9	23.5	6.8	19.2	5.9	17.7
8	3.2	24.0	5.5	25.4	4.9	22.0	5.6	22.0	8.4	22.8	5.7	23.2	6.9	19.2	5.8	17.7
10	2.9	24.0	5.4	25.2	4.9	22.0	5.2	22.0	8.3	22.7	5.2	23.2	6.9	19.2	5.7	17.7
12	2.9	24.0	4.1	25.1	5.2	22.0	5.0	21.9	6.8	22.1	4.9	23.2	6.9	19.2	5.6	17.7
14	3.4	24.0	3.1	24.4	5.2	22.0	4.8	21.9	6.9	22.0	5.8	23.1	6.9	19.2	5.6	17.7
16	3.4	24.0	2.4	24.1	4.9	21.9	4.6	21.9	6.2	22.0	5.7	23.1	6.9	19.2	5.5	17.7
18	3.4	24.0	1.7	23.9	4.8	21.9	4.2	21.8	4.6	22.0	4.9	23.1	7.1	19.2	5.5	17.7
20	3.4	24.0	1.5	23.9	4.8	21.9	4.2	21.7	3.5	21.8	4.6	23.1	7.1	19.2	5.4	17.7
22	3.2	23.9	1.3	23.8	4.8	21.9	3.9	21.6	3.3	21.8	3.1	23.0	7.2	19.2	5.4	17.7
24	0.7	23.8	1.0	23.8	4.8	21.9	3.3	21.3	1.8	21.5	2.2	22.8	7.2	19.2	5.3	17.7
26	0.3	23.0	0.9	23.8	3.3	21.9	2.2	21.1	0.9	21.3	0.8	22.1	7.4	19.1	5.3	17.7
28	0.2	20.8	0.2	23.6	3.0	21.8	0.7	21.0	0.6	21.2	0.2	21.6	7.4	19.1	5.2	17.5
30	0.1	19.8	0.2	22.0	4.5	21.6	0.4	20.9	0.2	21.0	0.2	21.0	7.4	19.0	5.2	17.5
32	0.1	19.2	0.1	19.9	3.2	21.2	0.3	20.4	0.1	20.8	0.2	20.5	7.3	19.0	5.2	17.5
34	0.1	18.2	0.1	18.9			0.3	20.2	0.1	20.3	0.2	20.0	7.1	19.0	5.1	17.5
36	0.1	17.2	0.1	18.2			0.2	20.1	0.1	20.0	0.2	19.2	6.0	19.0	5.1	17.5
38	0.1	16.2	0.1	17.8			0.2	19.2	0.1	19.3	0.2	18.5				
40																
Secchi inches	36		39		63		39		51		33		30		27	

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C-7. Temperature and Dissolved Oxygen, Lake Catherine Station 2, 1979

Depth	5/9/79		S/2Z/79		6/S/79		6/21/79		6/27/79		7/2/79		7/11/79		7/12/79		7/17/79	
	DO	Temp	DO	Temp	DO	Tamp	DO	Temp	DO	Tamp	DO	Tamp	DO	Temp	DO	Temp	DO	Temp
0	12.8	15.0	7.9	18.0	9.0	20.9	8.5	22.0	9.3	23.0	9.8	25.0	6.7	25.2	7.5	25.6	9.8	24.9
2	12.8	14.9	8.0	18.0	9.0	20.9	8.6	22.0	9.3	23.0	10.4	24.2	5.7	24.8	6.2	25.0	9.6	25.0
4	12.8	14.9	7.9	17.6	8.8	20.5	8.6	22.0	8.3	21.9	10.2	24.0	5.5	24.2	4.8	24.6	9.4	25.0
6	12.8	14.8	7.5	16.8	8.7	20.5	8.8	21.8	7.6	21.9	8.2	22.4	5.2	24.2	4.1	24.0	9.6	24.9
8	12.8	14.2	7.2	16.5	8.4	20.1	8.4	21.8	6.8	21.5	6.8	22.1	3.8	23.1	3.6	23.8	9.3	24.9
10	12.8	14.2	7.0	16.5	8.3	20.0	8.4	21.6	6.1	21.5	6.7	22.1	3.2	23.0	2.9	23.2	8.8	24.9
12	12.9	14.0	6.8	16.5	8.3	19.9	8.2	21.5	5.9	21.2	5.9	22.0	2.6	22.8	2.7	23.0	7.1	24.9
14	12.9	14.0	6.7	16.3	7.9	19.5	8.2	21.5	5.6	21.1	5.6	21.8	2.3	22.2	2.4	22.6	0.4	24.2
16	12.9	13.9	6.5	16.2	7.1	18.6	8.0	21.4	5.2	21.0	5.3	21.2	1.9	22.0	1.9	22.2	0.2	22.4
18	12.9	13.8	6.5	16.1	6.3	18.0	6.9	21.0	4.5	20.7	4.0	21.2	1.6	21.9	1.4	22.0	0.2	22.0
20	12.9	13.8	6.2	16.0	5.7	17.2	6.5	20.9	4.4	20.6	3.6	21.1	1.6	21.6	1.2	21.8	0.2	21.9
22	12.9	13.4	6.0	16.0	5.1	16.5	5.2	20.0	3.8	20.4	3.3	21.0	1.0	21.3	1.2	21.6	0.2	21.8
24	11.2	10.0	5.6	15.8	5.0	16.3	3.6	19.1	3.5	20.2	2.2	20.8	1.0	21.2	0.5	21.6	0.1	21.5
26	10.8	10.0	4.6	14.5	4.8	16.1	2.9	18.8	2.1	19.9	1.4	20.4	0.7	21.2	0.3	21.3	0.1	21.0
28	8.8	8.8	4.1	14.2	2.7	15.0	2.1	18.5	0.3	18.5	0.6	20.0	0.4	21.0	0.1	21.0	0.1	21.0
30	8.2	8.1	3.2	14.2	1.5	14.6	0.7	17.3	0.3	17.0	0.4	20.0	0.2	20.2	0.1	20.1	0.1	20.4
32	7.4	7.8	0.8	10.4	0.4	14.2	0.2	16.2	0.1	16.0	0.3	19.0	0.1	18.8	0.1	19.0	0.1	19.9
34							0.1	15.6										
36																		
Secchi inches	33		69		72		43		36		30		48		42		27	

Depth	8/2/79		8/7/79		8/16/79		8/23/79		8/29/79		9/S/79		9/20/79		10/4/79	
	DO	Temp	DO	Temp	DO'	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	5.8	24.2	4.7	25.4	5.4	22.0	7.2	22.5	9.8	25.0	9.6	26.2	8.1	19.0	6.8	17.5
2	5.7	24.2	4.3	25.2	5.4	22.1	5.2	21.9	9.8	23.9	7.0	24.4	8.1	19.0	6.5	17.5
4	5.0	24.0	4.1	25.0	5.4	22.1	5.2	21.9	9.2	23.5	6.4	23.8	8.1	19.0	6.3	17.5
6	4.9	24.0	3.9	24.9	5.4	22.0	5.1	21.9	7.6	23.0	6.3	23.5	8.1	19.0	6.2	17.5
8	4.9	24.0	3.4	24.7	5.2	22.0	5.3	22.0	6.8	22.8	6.1	23.5	8.1	19.0	6.1	17.5
10	4.8	24.0	3.1	24.6	5.1	22.0	5.3	22.0	6.5	22.6	6.3	23.4	8.1	19.0	5.9	17.5
12	4.9	24.0	3.1	24.6	5.4	22.0	5.4	22.0	6.5	22.6	5.7	23.2	8.1	19.0	5.9	17.5
14	4.9	24.0	3.1	24.6	5.4	22.0	5.2	21.9	6.8	22.2	5.4	23.1	8.1	19.0	5.8	17.5
16	4.7	24.0	2.4	24.1	5.3	22.0	4.1	21.8	6.7	22.1	5.0	23.1	8.1	19.0	5.8	17.5
18	4.6	24.0	2.1	24.0	5.2	22.0	3.7	21.6	6.4	22.0	4.9	23.0	8.1	19.0	5.7	17.5
20	4.5	24.0	2.1	24.0	5.2	22.0	2.4	21.5	5.8	22.0	4.5	23.1	8.1	19.0	5.7	17.5
22	4.6	24.0	1.7	24.0	5.3	22.0	2.2	21.2	3.6	21.9	1.3	22.5	8.1	19.0	6.0	17.0
24	4.6	24.0	1.7	23.9	5.4	22.0	1.8	21.1	1.7	21.5	1.1	22.1	8.1	19.0	6.0	17.0
26	0.4	23.8	1.2	23.8	5.4	22.0	1.6	21.1	0.3	21.3	0.8	22.0	8.1	19.0		
28																
30																
32																
34																
36																
Seoohi inches	27		54		59		39		45		33		27		27	

Note: Temperature in degrees Celsius; Dissolved oxygen in mg/l

Appendix C-8. Temperature and Dissolved Oxygen, Channel Lake, 1979

Depth	S/9/79		5/22/79		6/5/79		6/21/79		6/27/79		7/2/79		7/11/79		7/12/79		7/17/79	
	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	10.6	15.4	6.9	18.0	9.0	20.6	8.4	22.0	12.8	23.2	10.8	24.0	11.4	26.2	11.4	26.0	7.8	24.8
2	10.6	15.4	6.7	18.0	9.0	20.5	8.4	22.0	12.8	23.0	11.8	24.0	11.6	26.2	10.6	25.8	7.8	24.8
4	10.6	15.4	6.7	17.8	9.0	20.5	8.2	22.0	12.6	22.8	10.4	22.8	11.8	26.0	10.1	25.6	7.8	24.8
6	10.7	15.4	6.6	17.8	9.0	20.5	8.1	22.0	9.7	21.8	9.1	22.4	11.8	26.0	5.3	24.5	7.6	24.8
8	10.8	15.2	6.6	17.8	9.0	20.5	7.9	22.0	9.7	21.7	8.3	22.2	4.1	23.0	3.2	23.4	7.5	24.6
10	10.8	15.1	6.6	17.8	9.0	20.5	7.8	22.0	9.6	21.5	8.3	22.1	2.1	22.0	0.3	22.6	7.5	24.6
12	10.8	15.0	6.6	17.8	9.0	20.4	7.8	22.0	7.6	21.2	7.6	22.0	1.4	21.8	0.2	21.8	7.2	24.6
14	10.7	15.0	6.1	17.2	7.5	19.1	7.8	22.0	7.2	21.0	6.7	22.0	0.1	21.6	0.1	21.5	0.6	22.0
16	10.7	14.9	6.1	17.0	5.2	17.1	7.7	22.0	5.6	20.8	4.6	21.8	0.1	21.2	0.1	21.0	0.2	21.3
18	10.7	14.8	5.3	16.8	4.6	16.5	7.5	21.9	2.9	19.9	3.2	21.0	0.1	20.6	0.1	20.7	0.1	20.9
20	10.7	14.7	5.3	16.2	3.8	15.7	6.0	21.0	0.4	18.8	2.1	21.0	0.1	20.0	0.1	19.9	0.1	20.1
22	10.7	14.7	5.3	16.0	3.3	15.2	0.8	18.0	0.2	17.8	0.4	19.8	0.1	17.9	0.1	18.0	0.1	19.2
24	10.7	13.6	2.9	15.0	2.5	15.0	0.6	16.2	0.1	16.0	0.2	18.1	0.1	16.9	0.1	17.2	0.1	18.8
26	10.7	12.9	1.5	13.8	1.7	14.8	0.2	15.4	0.1	14.8	0.1	17.1	0.1	16.0	0.1	15.5	0.1	17.2
28	10.9	12.8	0.8	13.0	0.5	14.5	0.1	14.9	0.1	14.0	0.1	15.0	0.1	14.1	0.1	14.4	0.1	15.5
30	10.8	12.5	0.4	12.2	0.1	14.3	0.1	14.9	0.1	13.8	0.1	14.3	0.1	13.4	0.1	13.9	0.1	14.5
32	10.8	11.2	0.3	11.0	<0.1	14.1	0.1	13.8	0.1	13.4	0.1	13.8	0.1	13.2	0.1	13.5	0.1	14.0
34	8.2	10.2	0.2	11.0	<0.1	14.0	0.1	13.5			0.1	13.2	0.1	13.2			0.1	13.5
36	5.6	9.0																
38	4.9	8.9																
40																		
Secchi inches	44		81		75		36		27		27		24		24		24	

Depth	8/2/79		8/7/79		8/16/79		8/23/79		8/29/79		9/5/79		9/20/79		10/4/79	
	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	6.2	24.1	9.4	25.8	6.4	21.8	10.6	22.9	10.8	23.5	10.6	26.0	7.4	18.9	6.2	17.2
2	6.2	24.2	9.4	25.4	6.4	21.8	10.8	22.9	11.4	23.2	10.6	25.5	7.2	18.9	5.9	17.2
4	6.2	24.2	9.3	25.4	6.2	21.5	10.8	22.9	11.4	23.1	9.6	24.2	7.0	18.9	5.3	17.2
6	5.1	24.1	9.2	25.2	6.1	21.5	10.6	22.8	11.3	23.1	8.5	23.8	6.9	18.9	5.2	17.2
8	4.8	24.0	9.0	25.2	6.0	21.5	10.6	22.8	11.4	23.1	7.8	23.5	6.7	18.9	5.2	17.2
10	4.8	24.0	8.8	25.2	5.9	21.5	10.2	22.8	11.2	23.1	3.2	23.1	6.7	18.9	5.1	17.2
12	4.6	24.0	8.3	25.1	5.9	21.4	5.6	21.4	6.7	21.9	1.5	22.8	6.6	18.9	5.0	17.2
14	5.1	24.0	8.2	24.9	5.9	21.4	4.0	21.1	2.6	21.2	0.8	22.5	6.6	18.9	4.9	17.2
16	5.1	23.8	4.9	24.2	4.2	21.2	3.1	21.0	1.8	21.1	0.2	22.1	6.6	18.9	4.8	17.2
18	0.3	22.0	3.5	23.6	3.5	21.2	2.5	20.9	0.4	21.1	0.2	21.0	6.6	18.9	4.9	17.2
20	0.1	20.8	0.3	20.7	3.1	21.2	0.9	20.8	0.2	20.2	0.2	20.2	6.4	18.9	4.9	17.2
22	0.1	19.9	0.3	20.2	2.2	21.1	0.4	20.2	0.2	20.0	0.2	20.0	2.3	18.8	4.9	17.2
24	0.1	19.0	0.3	19.0	0.5	20.8	0.3	19.9	0.2	19.9	0.2	19.5	0.8	18.8	4.9	17.1
26	0.1	17.8	0.3	18.1	0.3	19.2	0.3	19.8	0.2	19.2	0.2	19.0	0.5	18.4	4.9	17.1
28	0.1	16.2	0.2	16.9	0.2	17.0	0.2	18.2	0.2	17.3	0.2	17.0	0.3	18.1	4.9	17.1
30	0.1	15.1	0.2	15.2	0.2	16.0	0.2	16.5	0.2	15.5	0.2	16.2	0.3	15.8	4.9	17.1
32	0.1	14.0	0.2	15.0	0.2	16.0	0.2	15.3			0.2	15.5	0.2	15.0	5.1	17.0
34	0.1	13.8	0.2	14.6	0.2	14.9	0.2	14.9			0.2	15.0	0.3	14.9		
36	0.1	13.8	0.2	14.2			0.2	14.5								
38			0.2	14.2												
40																
Secchi inches	30		24		37		36		33		27		30		27	

Note: Temperature la degrees Celsius; Dissolved oxygen in mg/l

Appendix C-9. Temperature and Dissolved Oxygen, Lake Catherine Station 1, 1980

	5-13-80		5-27-80		6-18-80		7-8-80		7-23-80		8-12-80		9-5-80		9-30-80	
Depth	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	10.0	14.5	10.4	21.0	9.7	20.5	9.8	24.5	8.0	28.0	6.2	26.5	7.0	25.0	8.4	19.0
2	10.0	14.5	10.4	20.5	9.7	20.5	9.6	25.5	7.2	27.5	6.2	26.0	6.4	25.0	8.2	18.5
4	9.2	14.5	10.0	20.0	9.7	20.5	9.6	25.5	6.6	27.0	6.0	26.0	6.4	24.5	8.2	18.5
6	9.2	14.5	10,0	20.0	9.4	20.5	9.4	25.5	6.4	27.0	6.0	25.0	6.2	24.5	8.4	18.0
8	8.6	14.5	10.0	20.0	7.5	20.0	9.2	25.5	6.4	27.0	5.7	25.0	6.4	24.5	8.4	18.0
10	8.5	14.5	9.0	19.0	7.7	19.5	8.6	25.5	6.4	26.5	5.7	25.0	6.0	24.0	8.2	18.0
12	8.6	14.0	8.8	19.0	7.1	19.5	7.8	24.5	5.8	26.5	5.6	25.0	6.2	24.0	8.0	18.0
14	8.0	14.0	8.0	18.5	6.8	19.5	7.2	24.5	5.2	26.5	5.6	25.0	6.2	24.0	7.6	17.5
16	7.6	13.5	7.8	18.0	6.5	19.5	7.0	24.0	5.4	26.5	5.6	25,0	6.4	24.0	8.0	17.5
18	7.0	13.0	7.8	17.5	6.3	19.5	6.4	24.0	5.2	26.5	5.6	24.5	6.2	24.0	8.0	17.5
20	7.0	13.0	7.6	17.0	5.7	19.0	5.2	23.0	3.6	26.0	5.5	24.5	6.4	24.0	8.2	17.5
22	6.4	12.5	6.4	15.5	6.0	19.0	0.2	22.0	1.0	25.5	5.5	24.5	6.2	24.0	8.0	17.5
24	5.4	11.5	5.2	14.5	2.8	18.5	0.2	21.0	0.6	25.0	5.5	24.5	6.4	24.0	8.2	17.5
26	3.4	10.5	4.5	13.0	0.2	17.0	0.2	19.0	0.2	21.0	0.2	23.0	5.2	24.0	8.2	17.5
28	0.7	9.0	1.2	12.0	0.1	15.0	0.2	17.0	0.2	17.5	0.1	20.5	2.4	23.0	8.2	17.5
30	0.2	8.0	0.2	11.0	0.1	12.0	0.2	15.0	0.2	16.0	0.1	18.0	0.2	19.0	7.4	17.5
32	0.2	8.0	0.2	10.0	0.1	11.0	0.2	13.0	0.2	16.0	0.1	15.5	0.2	17.5	4.5	17.5
34	0.1	8.0	0.2	9.5	0.0	10.5	0.2	12.0	0.2	16.0	0.1	13.5	0.2	15.5		
36	0.1	8.0	0.2	9.0	0.0	10.5	0.2	11.0			0.1	12.5	0.2	14.5		
38			0.2	9.0	0.0	10.0					0.1	12.5				
40			0.2	9.0	0.0	10.0										

DO - Dissolved Oxygen in mg/l
Temp - Temperature in C

Appendix C-10. Temperature and Dissolved Oxygen, Lake Catherine Station 2, 1980

	5-13-80		5-27-80		6-18-80		7-8-80		7-23-80		8-12-80		9-5-80		9-30-80	
Depth	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	9.4	15.0	9.0	21.5	8.4	21.5	8.5	24.5	7.6	27.0	5.4	26.0	6.2	26.0	6.8	19.0
2	9.4	15.0	8.8	20.0	8.2	20.5	10.0	25.0	6.2	27.0	5.3	26.0	6.2	25.0	6.6	18.0
4	8.7	14.5	8.4	19.5	8.3	20.5	8.8	26.0	6.2	27.0	5.3	25.5	6.4	25.0	6.6	18.0
6	8.3	14.5	8.4	19.0	8.3	20.5	8.4	26.0	6.2	27.0	5.0	25.5	6.4	25.0	6.4	18.0
8	7.8	14.0	8.4	18.5	8.3	20.5	8.0	25.5	6.2	26.5	5.0	25.5	6.8	24.5	6.5	18.0
10	7.5	14.0	7.6	18.5	7.6	20.0	8.3	25.5	5.8	26.0	5.1	25.5	6.6	24.5	6.4	18.0
12	7.6	14.0	8.4	18.5	7.5	20.0	8.3	25.5	6.0	26.0	5.0	25.0	6.6	24.5	6.4	18.0
14	7.5	14.0	8.0	18.0	7.6	20.0	8.0	25.0	6.0	26.0	5.0	25.0	6.6	24.0	6.4	18.0
16	7.2	13.5	7.6	18.0	7.8	19.5	7.2	25.0	6.0	26.0	4.9	25.0	7.0	24.0	6.0	18.0
18	7.5	13.5	7.6	18.0	7.3	19.5	6.4	24.0	6.0	26.0	4.8	25.0	6.8	24.0	6.2	18.0
20	7.5	13.5	8.0	18.0	6.8	19.5	3.5	23.0	6.0	26.0	4.8	24.5	6.8	24.0	6.2	18.0
22	7.7	13.5	5.4	15.5	5.8	19.5			6.0	26.0	4.8	24.5	6.8	24.0	6.2	17.5
24	7.3	13.5	5.2	15.0	3.2	19.0			6.0	26.0	4.8	24.5	6.8	24.0	5.9	17.5
26	7.5	13.5														

DO - Dissolved Oxygen in mg/l
Temp - Temperature in °C

Appendix C-11. Temperature and Dissolved Oxygen, Channel Lake, 1980

	5-27-80		6-18-80		7-8-80		7-23-80		8-12-82		9-5-80		9-30-80	
Depth	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
0	8.6	22.0	9.7	22.5	9.9	25.0	7.6	27.5	7.8	26.0	8.0	22.0	8.8	17.5
2	8.6	22.0	9.7	22.0	9.8	25.0	7.6	27.5	7.8	26.0	7.4	23.0	8.4	17.5
4	8.6	21.5	9.6	21.5	9.4	25.0	7.6	27.0	7.6	25.5	7.4	23.5	8.4	17.0
6	8.6	21.0	9.7	21.5	9.2	25.0	7.4	27.0	7.4	25.0	7.2	23.5	7.5	17.0
8	8.6	21.0	9.7	21.5	9.2	25.0	7.0	26.5	7.0	25.0	6.8	23.5	7.4	17.0
10	8.7	20.5	9.7	21.0	9.0	25.0	6.6	26.5	7.0	25.0	7.0	23.5	7.4	17.0
12	6.2	17.0	8.7	20.5	8.6	25.0	7.0	26.5	6.6	25.0	7.0	23.5	6.9	17.0
14	6.0	16.0	6.6	20.0	3.6	23.5	2.8	26.0	6.6	25.0	6.4	23.5	6.8	17.0
16	5.4	16.0	4.4	19.0	0.6	22.0	1.8	25.5	6.6	24.5	3.4	23.0	6.9	17.0
18	4.6	15.5	2.1	18.5	0.2	20.0	0.2	24.0	0.8	24.0	0.4	23.0	7.2	17.0
20	2.8	14.5	0.4	18.0	0.2	19.0	0.2	20.0	0.2	22.0	0.4	21.0	6.3	17.0
22	1.2	14.0	0.1	17.5	0.2	17.5	0.2	18.0	0.2	20.0	0.4	20.0	6.3	17.0
24	0.4	13.5	0.1	17.0	0.2	16.5	0.2	18.0	0.2	18.0	0.4	19.0	6.0	17.0
26	0.4	13.0	0.0	14.5	0.2	15.5	0.2	16.0	0.2	17.0	0.4	17.5	0.8	16.5
28	0.6	12.0	0.0	13.5	0.2	14.0	0.2	15.0	0.2	15.5	0.4	16.0	0.1	16.5
30	0.6	11.5	0.0	13.0	0.2	13.5	0.2	14.0	0.1	14.5	0.4	15.0	0.1	16.0
32	0.4	11.0	0.0	12.5	0.2	13.0	0.2	13.5	0.1	14.0	0.2	14.0	0.1	16.0
34	0.2	8.0	0.0	12.5	0.2	12.5			0.1	13.5	0.2	14.0	0.1	14.5
36			0.0	12.0										

DO - Dissolved Oxygen in mg/l
Temp - Temperature in C

Appendix D

Water Quality Characteristics, Lake Catherine and Channel Lake,
1977, 1978, 1979, 1980

Appendix D-1. Water Quality Characteristics, Lake Catherine, 1977

hake Catherine, surface

Date	Trans-parency (inches)	Tur-bldlty (FTP)	pH	Alka-Unity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Am-monla (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Diss	Phosphorus (mg/l) Totail	Diss	Algae (ets/ml)
5/16/77	69	4	9.05	162	224	0.26	0.10	38.8	313	245	0.05	0.02	2610
5/23/77	57	4	8.67	169	214	0.12	0.01	36.7	271	261	0.05	0.03	3090
5/31/77	42	4	8.71	154	272	0.26	0.05	48.4	238	206	0.06	0.02	2190
6/6/77	39	2	8.52	164	265	0.32	0.07	48.5	476	440	0.06	0.02	570
6/13/77	45	3	8.45	182	258	0.13	0.11	47.4	392	370	0.06	0.02	5660
6/20/77	33	4	8.65	169	305	0.14	0.02	48.6	340	304	0.15	0.04	6080
6/27/77	35	6	8.68	169	258	0.11	0.07	52.7	262	201	0.05	0.02	3140
7/5/77	33	7	8.25	167	199	0.10	0.06	56.6	350	302	0.06	0.01	3020
7/11/77	33	6	8.35	169	225	0.11	0.12	53.5	320	320	0.06	0.02	2790
7/18/77	33	4	8.00	169	233	0.11	0.24	53.0	338	282	0.06	0.02	2180
7/26/77	39	4	8.35	156	267	0.14	0.09	54.4	386	316	0.06	0.02	
8/1/77	39	3	8.40	169	300	0.07	0.05	59.2	418	234	0.07	0.03	1180
8/8/77	45	3	8.30	164	327	0.08	0.11	59.8	442	170	0.03	0.02	2590
8/17/77	60	5	8.10	164	293	0.06	0.14	55.2	344	228	0.05	0.02	3520
8/22/77		3	8.20	172	260	0.34	0.07	50.7	276	216	0.04	0.02	4880
8/30/77	51	3	7.90	167	293	0.17	0.04	52.6	416	360	0.04	0.01	610
9/6/77	39	4	8.30	172	267	0.04	0.05	57.6	408	388	0.05	0.01	700

Lake Catherine, mid-depth

Date	Tur-bldlty (FTU)	pH	Alka-Unity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Am-monla (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Diss	Phosphorus (mg/l) Total	Diss	Algae (cts/ml)
5/16/77	2	8.72	174	243	0.17	0.10	40.2	335	294	0.06	0.04	1820
5/23/77	1	8.23	182	224	0.18	0.50	33.4	252	240	0.15	0.13	1160
5/31/77	2	8.16	177	265	0.14	0.21	45.3	256	224	0.08	0.05	1290
5/6/77	2	8.26	172	278	0.26	0.19	43.0	518	458	0.08	0.03	550
6/13/77	3	9.14	177	325	0.12	0.37	46.9	396	364	0.08	0.05	2260
6/20/77	2	8.22	177	331	0.13	0.29	47.4	378	338	0.18	0.15	7390
6/27/77	3	7.87	182	291	0.11	0.37	51.8	282	206	0.10	0.07	2910
7/5/77	5	7.97	164	199	0.16	0.54	50.8	320	310	0.05	0.01	140
7/11/77	3	8.00	167	166	0.12	0.15	52.0	316	300	0.05	0.02	680
7/18/77	2	7.73	177	207	0.09	0.28	48.0	324	278	0.05	0.03	2950
7/26/77	3	7.90	187	113	0.07	0.19	51.0	382	306	0.05	0.01	
8/1/77	4	8.25	169	240	0.08	0.12	59.6	404	228	0.13	0.03	810
8/8/77	3	7.90	164	273	0.07	0.10	59.8	386	238	0.05	0.02	630
8/17/77	3	7.85	172	267	0.06	0.22	50.5	336	260	0.08	0.04	2520
8/22/77	4	8.30	172	260	0.13	0.06	53.4	270	216	0.04	0.01	2520
8/30/77	3	8.10	167	253	0.09	0.04	52.8	404	374	0.04	0.01	210
9/6/77	3	8.20	177	280	0.01	0.07	55.7	412	394	0.05	0.03	130

Appendix D–1. Concluded

Lake Catherine, deep

Date	Tur-bldity (FTU)	pH	Alka-Unity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Am-monia (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Solids (mg/l) Diss	Phosphorus (rag/1) Total	Phosphorus (rag/1) Diss	Algae (cts/ml)
5/15/77	4	7.79	189	243	0.15	0.87	31.1	329	288	0.37	0.34	250
5/23/77	3	7.95	199	293	0.11	1.97	31.3	216	232	0.11	0.40	140
5/31/77	2	7.46	171	331	0.09	2.06	36.7	211	231	0.51	0.44	220
6/6/77	37	7.78	197	298	0.25	1.71	39.2	616	432	0.19	0.35	180
6/13/77	2	7.57	205	298	0.11	2.50	31.6	406	361	0.60	0.52	190
6/20/77	4	8.15	187	298	0.13	0.73	39.2	380	318	0.21	0.21	4410
6/27/77	3	7.15	212	265	0.11	2.59	40.0	298	210	0.61	0.53	2530
7/5/77	4	7.30	210	225	0.08	4.80	40.3	318	306	0.56	0.49	70
7/11/77	13	7.65	207	205	0.11	1.38	41.1	316	316	0.51	0.35	710
7/18/77	18	7.50	220	310	0.11	3.21	43.2	430	301	0.82	0.58	1810
7/26/77	3	7.35	227	210	0.07	2.27	35.6	396	316	0.89	0.72	810
8/1/77	5	8.35	222	313	0.08	1.51	39.2	426	221	0.93	0.79	170
8/8/77	4	7.70	210	300	0.10	4.01	39.8	460	212	1.09	0.87	100
8/17/77	4	7.10	253	313	0.09	4.53	21.5	338	281	1.10	0.93	210
8/22/77	3	7.95	237	280	0.11	1.51	33.8	332	230	0.88	0.67	800
8/30/77	3	7.50	217	320	0.12	4.35	31.6	462	368	1.11	0.88	140
9/6/77	4	7.10	252	333	0.01	4.96	33.3	418	404	1.26	0.85	170

Appendix D-2. Water Quality Characteristics, Channel Lake, 1977

Channel Lake, surface

Date	Trans-parency (inches)	Tur-bldlty (FTU)	pH	Alka-Unity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Am-monia (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Diss	Phosphorus (mg/l) Total	Diss	Algae (cts/ml)
5/16/77	60	1	8.96	177	248	0.32	0.09	18.2	325	321	0.06	0.03	990
5/23/77	15	6	8.87	177	199	0.15	0.08	11.9	295	272	0.08	0.01	2803
5/31/77	33	5	8.81	159	238	0.09	0.01	18.1	262	230	0.10	0.03	3507
6/6/77	27	4	8.51	167	238	0.15	0.25	50.7	661	158	0.09	0.03	770
6/13/77	36	4	6.51	171	238	0.12	0.18	53.0	398	371	0.10	0.03	3310
6/20/77	33	8	8.67	167	311	0.12	0.09	18.9	372	330	0.12	0.03	3690
6/27/77	27	8	8.62	161	205	0.08	0.09	53.1	272	200	0.07	0.03	3590
7/5/77	33	9	8.15	162	199	0.14	0.23	51.8	551	306	0.08	0.02	710
7/11/77	24	6	8.15	161	116	0.12	0.09	55.1	328	320	0.07	0.03	2690
7/18/77	27	6	7.95	162	253	0.11	0.30	57.6	351	306	0.10	0.02	1890
7/26/77	29	5	8.25	167	107	0.11	0.10	59.8	402	300	0.06	0.02	2910
8/1/77	32	6	8.10	161	253	0.08	0.11	59.6	412	261	0.16	0.03	3660
8/8/77	39	4	8.30	167	287	0.08	0.22	61.3	402	190	0.05	0.02	2120
8/17/77	51	6	8.00	172	307	0.06	0.30	57.5	362	256	0.07	0.02	800
8/22/77	18	4	8.20	171	267	0.10	0.12	57.1	300	196	0.07	0.02	5190
8/30/77	36	5	8.50	177	217	0.10	0.10	56.9	116	358	0.08	0.02	820
9/6/77	27	9	8.50	171	267	0.01	0.13	58.0	444	390	0.10	0.02	210

Channel Lake, mid-depth

Date	Tur-bidity (FTU)	pH	Alka-linity (mg/l)	Hard-ness (mg/l)	Nl-trate (mg/l)	Am-monla (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Diss	Phosphorus (mg/l) Total	Diss	Algae (cts/ml)
5/16/77	1	8.21	181	248	0.27	0.11	46.2	317	277	0.09	0.06	720
5/23/77	2	8.33	192	253	0.23	0.30	44.9	271	258	0.08	0.01	550
5/31/77	2	7.97	187	215	0.20	0.37	48.0	262	262	0.10	0.08	970
6/6/77	4	8.13	167	219	0.07	0.13	48.9	181	138	0.09	0.02	660
6/13/77	3	8.15	172	232	0.12	0.18	53.0	108	384	0.08	0.03	2850
6/20/77	6	8.01	151	311	0.13	0.16	47.6	332	312	0.27	0.15	2770
6/27/77	4	7.89	161	205	0.08	0.31	51.8	312	223	0.06	0.03	2010
7/5/77	5	7.90	172	192	0.11	0.18	51.8	333	311	0.06	0.02	110
7/11/77	8	3.05	161	179	0.11	0.13	56.1	298	201	0.07	0.02	900
7/18/77	4	7.75	172	187	0.10	0.15	56.6	338	291	0.06	0.02	2150
7/26/77	3	7.75	171	133	0.10	0.11	56.8	388	306	0.11	0.05	2680
8/1/77	3	7.95	179	217	0.08	0.11	60.1	132	210	0. 10	0.03	1910
8/8/77	3	8.15	167	293	0.09	0.20	56.1	381	256	0.08	0.05	
8/17/77	1	8.00	162	280	0.08	0.23	57.9	321	268	0.07	0.02	610
8/22/77	1	8.20	179	260	0.09	0.09	51.2	288	228	0.08	0.02	3180
8/30/77	5	8.25	171	280	0.13	0.03	56.9	128	368	0.09	0.02	170
9/6/77	5	8.10	171	287	0.01	0.10	58.6	128	378	0.09	0.02	170

Appendix D-2. Concluded

Channel Lake, deep

Date	Tur-bldity (FTU)	pH	Alka-linity (mg/l)	Hard-ness (mg/l)	Ni-trate (mg/l)	Am-monla (mg/l)	Sul-fate (mg/l)	Solids (mg/l) Total	Diss	Phosphorus (mg/l) Total	Diss	Algae (ets/ml)
5/16/77	2	8.21	187	218	0.20	0.35	50.5	332	326	0.13	0.11	H O
5/23/77	3	8.09	197	191	0.11	1.11	12.1	305	281	0.21	0.21	280
5/31/77	22	7.50	199	331	0.09	1.39	11.8	361	286	0.19	0.34	320
6/6/77	3	7.91	191	278	0.23	1.36	18.1	510	168	0.28	0.22	380
6/13/77	16	7.32	197	278	0.12	1.66	17.1	191	388	0.12	0.28	720
6/20/77	10	8.09	235	252	0.12	0.58	50.0	352	328	0.27	0.20	2360
6/27/77	3	7.71	210	215	0.12	1.81	52.9	520	215	0.13	0.36	190
7/5/77	119	7.35	225	238	0.10	8.63	13.1	531	352	0.79	0.69	H O
7/11/77	3	7.50	222	232	0.10	2.03	60.3	342	328	0.61	0.51	3110
7/18/77	7	7.10	217	427	0.12	0.88	51.2	396	382	0.69	0.56	890
7/26/77	3	7.10	231	127	0.07	3.72	15.6	130	330	0.96	0.75	160
8/1/77	1	7.65	215	317	0.08	51.6	15.7	162	272	1.39	1.16	230
8/3/77	3	7.50	212	313	0.10	1.52	38.7	156	272	0.88	0.77	110
8/17/77	35	7.10	172	333	0.08	5.80	29.5	506	120	1.20	1.05	130
3/22/77	3	8.50	212	313	0.08	2.05	13.1	356	211	0.93	0.88	480
8/30/77	3	7.50	270	233	0.13	6.82	38.2	150	106	1.38	0.31	200
9/6/77	37	7.15	232	327	0.09	5.27	19.0	618	106	1.06	0.73	130

Appendix D-3. Water Quality Characteristics, Lake Catherine Station 1, 1978

Lake Catherine station 1, surface

Date	Turbidity (Ftu)	Transparency (inches)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	Total silica (mg/l)
5/10/78	1.5	37	8.6	173	271	0.33	0.20	0.31
5/17/78	1.8	38	8.4	170	232	0.32	0.05	0.54
5/24/78	3.1	99	8.6	168	277	0.32	0.19	1.33
5/31/78	4.0	72	8.7	173	307	0.33	0.02	0.23
6/7/78	3.3	45	9.0	166	330	0.36	0.19	0.72
6/28/78	5.5	42	8.8	156	314	0.14	0.23	0.86
7/13/78	5.1	36	8.5	146	251	0.08	0.07	0.93
7/19/78	5.0	30	8.4	170	261	0.03	0.03	1.39
7/27/78	6.9	45	8.4	161	264	0.13	0.01	3.16
8/9/78	6.5	33	8.6	156	277	0.19	0.02	2.78
8/24/78	2.0	54	8.1	154	264	0.19	0.12	4.12
9/6/78	1.4	57	8.4	160	264	0.11	0.09	2.14
9/19/78	4.0	45	8.2	160	228	0.20	0.29	3.30
10/4/78	0.0	42	8.2	174	290	0.31	0.31	1.83

Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids (mg/l)		Phosphorus (mg/l)	
			Total	Dissolved	Total	Dissolved
0..01	0.20	54.0	373	370	0.07	0.01
0..01	0.03	52.2	372		0.09	0.03
0,.10	0.02	58.0	374	373	0.06	0.03
0..69	0.08	54.3	375	368	0.05	0.03
0..06	0.02	97.7	435	430	0.06	0.03
0..06	0.02	51.4	380	301	0.04	0.01
0..03	0.00	68.1	357	335	0.05	0.02
0 .01	0.04	69.9	379	378	0.06	0.01
0..02	0.13	47.4	331	329	0.04	0.00
0 .07	0.03	43.3	346	330	0.06	0.02
0 .14	0.02	39.6	300	292	0.03	0.03
0 .06	0.01	34.3	357	320	0.05	0.03
0 .06	0.02	36.2	300	293	0.06	0.01
0 .10	0.04	32.3	305	293	0.10	0.06

Lake Catherine station 1, mid-depth

Date	Turbidity (Ftu)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	Total silica (mg/l)
5/10/78	1.1	8.4	170	271	0.33	0.25	0.25
5/17/78	3.4	8.5	168	271	0.52	0.35	0.81
5/24/78	3.1	8.5	173	257	0.26	0.29	0.91
5/31/78	2.0	8.5	173	327	0.36	0.48	0.39
6/7/78	0.0	8.6	170	337	0.42	0.27	0.69
6/28/78	2.5	8.6	156	314	0.14	0.25	1.43
7/13/78	7.5	8.3	161	250	0.08	0.10	1.21
7/19/78	2.0	8.2	163	254	0.05	0.15	1.82
7/27/78	3.1	8.2	161	284	0.14	0.14	2.24
8/9/78	2.1	8.2	172	294	0.15	0.04	2.15
8/24/78	1.0	8.0	154	218	0.16	0.12	3.25
9/6/78	1.4	8.2	158	257	0.12	0.24	1.94
9/19/78	3.3	8.1	164	294	0.18	0.29	3.09
10/4/78	0.0	8.2	170	264	0.13	0.33	2.26

Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids (mg/l)		Phosophorus (mq/l)	
			Total	Dissolved	Total	Dissolved
0.01	0.04	54.0	378	372	0.10	0.02
0.01	0.02	49.9	367	365	0.09	0.02
0.12	0.02	54.9	380	368	0.08	0.02
0.10	0.02	54.9	370	360	0.06	0.05
0.05	0.05	90.9	420	386	0.10	0.05
0.08	0.02	51.2	387	377	0.04	0.02
0.07	0.02	66.6	369	336	0.05	0.02
0.03	0.01	65.4	325	325	0.03	0.01
0.08	0.02	45.3	332	332	0.06	0.00
0.12	0.04	45.8	357	335	0.04	0.04
0.22	0.02	37.2	291	276	0.05	0.04
0.06	0.02	35.7	287	283	0.04	0.03
0.06	0.03	35.3	350	292	0.05	0.03
0.11	0.06	34.1	297	292	0.06	0.06

Appendix D–3. Concluded

Lake Catherine station 1, deep

Date	Turbidity (Ftu)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	Total silica (mg/l)
5/10/78	3.0	8.2	175	271	0.29	0.39	0.56
5/17/78	5.0	8.4	168	279	0.31	0.35	1.03
5/24/78	18.4	8.2	173	271	0.26	0.89	1.37
5/31/78	4.0	8.1	175	304	0.17	1.14	1.41
6/7/78	2.0	8.5	179	317	0.23	1.06	2.44
6/28/78	30.8	8.2	179	347	0.15	1.30	4.82
7/13/78	5.1	7.9	198	281	0.01	2.79	3.31
7/19/78	3.8	7.8	184	280	0.04	2.80	5.12
7/27/78	5.8	7.7	207	277	0.12	2.66	5.22
8/9/78	2.1	7.4	226	290	0.08	8.70	3.52
8/24/78	5.5	7.5	228	320	0.16	3.41	7.08
9/6/78	4.2	7.6	221	317	0.13	5.72	6.78
9/19/78	4.7	7.8	250	347	0.11	7.31	10.97
10/4/78	30.0	8.1	182	290	0.11	0.48	2.68

Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids (mg/l)		Phosphorus (mg/l)	
			Total	Dissolved	Total	Dissolved
0.02	0.17	51.2	369	353	0.14	0.09
0.03	0.10	53.1	391	375	0.11	0.06
0.98	0.23	60.1	490	373	0.25	0.11
0.90	0.03	58.4	374	370	0.23	0.15
0.07	0.20	90.5	413	413	0.30	0.25
2.56	0.26	50.5	631	390	0.54	0.29
0.15	0.28	66.6	398	385	0.62	0.52
0.09	0.32	65.6	484	406	0.60	0.50
0.16	0.33	43.6	363	357	0.64	0.52
0.17	0.45	45.8	393	392	0.83	0.74
0.48	0.56	44.0	387	362	0.92	0.79
0.24	0.74	36.0	431	315	0.80	0.66
0.23	0.76	41.8	378	256	1.36	1.19
0.90	0.10	33.8	346	190	0.13	0.10

Appendix D-A. Water Quality Characteristics, Channel Lake, 1978

Charme I Lake, surface

Date	Turbidity (Ftu)	Transparency (inches)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)
5/10/78	1.6	37	8.5	170	264	0.29	0.06
5/17/78	5.0	38	8.4	166	284	0.23	0.39
5/24/78	2.1	75	8.4	168	263	0.23	0.25
5/31/78	2.0	54	8.6	170	314	0.30	0.27
6/7/78	1.4	36	8.9	170	317	0.36	0.09
6/28/78	5.0	30	8.8	161	314	0.14	0.18
7/13/78	5.1	27	8.6	164	250	0.14	0.21
7/19/78	3.5	30	8.1	166	247	0.09	0.01
7/27/78	6.9	39	8.4	156	277	0.14	0.03
8/9/78	9.4	42	8.4	172	330	0.16	0.01
8/24/78	1.0	46	8.4	164	257	0.26	0.05
9/6/78	4.2	33	8.4	162	271	0.15	0.23
9/19/78	4.7	36	8.0	164	274	0.23	0.28
10/4/78	0.0	39	8.2	168	277	0.13	0.23

Total silica (mg/l)	Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids(mg/l)		Phosphorus(rag/1)	
				Total	Dissolved	Total	Dissolved
0.05	0.01	0.03	53.0	363	340	0.07	0.01
0.2S	0.01	0.02	53.5	375	365	0.10	0.04
1.27	0.13	0.02	56.4	367	360	0.05	0.03
0.33	0.08	0.02	57.2	360	358	0.04	0.04
0.46	0.09	0.04	83.7	403	400	0.08	0.03
1.11	0.08	0.01	51.4	397	374	0.06	0.02
2.14	0.07	0.04	66.6	364	350	0.07	0.03
2.25	0.07	0.03	68.6	406	386	0.07	0.02
1.54	0.13	0.02	47.0	352	342	0.04	0.01
2.70	0.04	0.01	44.6	357	341	0.04	0.03
2.97	0.08	0.02	41.3	302	299	0.04	0.03
3.86	0.09	0.02	37.7	320	298	0.05	0.01
4.82	0.06	0.03	40.5	308	302	0.08	0.01
3.61	0.07	0.02	38.3	286	283	0.06	0.02

Channel Lake, mid-depth

Date	Turbidity (Ftu)	PH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	Total silica (mg/l)
5/10/78	0.8	8.5	166	264	0.28	0.10	
5/17/78	2.0	8.4	168	296	0.34	0.21	0.11
5/24/78	3.1	8.3	163	320	0.26	0.29	0.46
5/31/78	3.0	8.5	167	294	0.32	0.47	0.42
6/7/78	1.4	8.7	170	325	0.38	0.24	0.51
6/28/78	3.5	8.7	163	304	0.12	0.27	0.93
7/13/78	4.7	8.2	214	263	0.10	0.35	1.78
7/19/78	4.5	8.1	212	255	0.10	0.27	1.91
7/27/78	6.9	8.2	161	251	0.13	0.07	1.73
8/9/78	2.9	7.7	189	337	0.18	0.94	2.07
8/24/78	1.5	8.0	164	271	0.22	0.18	2.94
9/6/78	3.5	7.8	168	274	0.15	0.18	4.52
9/19/78	3.3	8.2	164	290	0.20	0.24	4.54
10/4/78	0	8.1	172	290	0.13	0.28	3.09

Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids(mg/l)		Phosphorus (mg/l)	
			Total	Dissolved	Total	Dissolved
0.01	0.03	54.4	356	349	0.12	0.03
0.01	0.02	53.8	375	375	0.12	0.06
0.10	0.02	60.9	374	359	0.07	0.05
0.10	0.01	58.6	355	355	0.07	0.03
0.18	0.04	86.4	403	400	0.13	0.04
0.07	0.03	51.0	391	377	0.06	0.02
0.05	0.19	69.6	387	350	0.08	0.02
0.07	0.23	70.6	409	390	0.08	0.02
0.10	0.09	51.8	347	333	0.04	0.02
0.12	0.23	47.4	362	351	0.17	0.11
0.09	0.19	41.3	321	321	0.05	0.02
0.09	0.10	38.4	329	309	0.05	0.02
0.06	0.03	37.2	338	298	0.05	0.02
0.08	0.04	37.1	285	279	0.10	0.04

Appendix D-4. Concluded

Channel Lake, deep

Date	Turbidity (Ftu)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	Total silica (mg/l)
5/10/78	7.7	8.5	170	267	0.28	0.19	0.07
5/17/78	43.0	8.2	168	281	0.39	0.42	1.41
5/24/78	3.1	8.3	170	281	0.33	0.67	0.99
5/31/78	1.5	8.4	171	304	0.25	0.96	1.37
6/7/78	1.0	8.3	172	302	0.27	0.94	1.24
6/28/78	3.5	8.5	184	330	0.13	1.49	2.32
7/13/78	3.3	8.0	188	273	0.10	1.51	2.25
7/19/78	2.5	8.3	200	285	0.07	3.46	5.33
7/27/78	20.7	7.6	221	323	0.02	2.62	5.27
8/9/78	5.8	7.4	240	304	0.17	5.31	3.61
8/24/78	4.0	7.6	242	330	0.18	3.87	5.89
9/6/78	3.5	7.4	246	314	0.20	10.99	9.10
9/19/78	3.3	7.5	238	337	0.23	0.58	7.91
10/4/78	1.6	7.5	217	317	0.13	5.45	7.20

Total iron (mg/l)	Total manganese (mg/l)	Sulfate (mg/l)	Solids (mg/l)		Phosphorus (mg/l)	
			Total	Dissolved	Total	Dissolved
0.02	0.03	53.0	376	360	0.08	0.01
3.78	0.12	54.4	692	334	0.54	0.08
0.10	0.08	59.8	386	359	0.13	0.08
0.22	0.08	55.5	357	352	0.14	0.13
0.07	0.32	87.7	391	389	0.22	0.19
0.20	0.39	50.9	398	390	0.35	0.33
0.09	0.29	71.1	517	366	0.35	0.31
0.07	0.33	61.6	677	411	0.69	0.65
0.49	0.29	39.0	388	367	0.79	0.75
0.18	0.30	43.7	397	392	0.88	0.75
0.19	0.38	35.5	389	381	0.89	0.85
1.98	0.59	43.4	551	380	1.28	1.06
0.12	0.48	40.9	436	389	1.07	0.94
0.14	0.68	39.8	339	330	0.81	0.68

Appendix D-5. Water Quality Characteristics, Lake Catherine, 1979

Date 1979	Trans. inches	pH	Alka mg/l	Sulfate mg/l	Hardness mg/l	Silica mg/l	Chlorine demand mg/l	Phosphorus Total mg/l	Phosphorus Diss. mg/l	Ammonia-H mg/l	Nitrate-N mg/l	T. Iron mg/l
Lake Catherine, surface												
5/9	33	8.51	169	33.8	230	0.13	4.83	0.06	0.02	0.14	0.43	0.42
5/22	78	8.10	180	36.0	240	0.79	4.90	0.04	0.02	0.19	0.36	0.16
6/5	84	8.22	185	35.0	227	0.39	3.30	0.04	0.03	0.15	0.25	0.06
6/21	36	8.45	183	38.4	227	0.69	5.30	0.08	0.02	0.01	0.18	0.10
7/2	42	8.52	184	30.4	233	1.81	4.34	0.06	0.02	0.01	0.11	0.04
7/17	39	8.47	185	33.2	235	1.04	6.78	0.04	0.01	0.20	0.26	0.06
8/2	36	8.21	178	34.0	224	2.86	5.76	0.07	0.02	0.16	0.20	0.06
8/23	39	8.38	161	30.0	213	2.22	6.78	0.08	0.02	0.20	0.19	0.10
9/5	33	8.67	144	31.6	217	0.92	6.20	0.04	0.01	0.03	0.16	0.07
9/20	30	8.22	173	32.6	247	0.40	4.96	0.07	0.01	0.14	0.17	0.11
10/4	27	8.21	170	30.9	240	1.26	5.72	0.08	0.01	0.21	0.07	0.15
Lake Catherine, mid-depth												
5/9		8.47	168	33.0	227	0.26	4.34	0.05	0.02	0.10	0.55	0.43
5/22		8.13	180	37.8	238	0.77	4.90	0.04	0.03	0.17	0.31	0.10
6/5		8.12	185	35.7	232	0.30	3.90	0.06	0.03	0.23	0.25	0.06
6/21		8.35	185	36.0	233	1.73	4.40	0.04	0.02	0.10	0.16	0.11
7/2		8.33	185	30.7	233	1.86	6.29	0.06	0.02	0.19	0.10	0.12
7/17		8.03	186	31.2	240	1.73	6.91	0.07	0.02	0.33	0.15	0.06
8/2		8.24	177	32.8	227	3.26	5.76	0.07	0.03	0.16	0.18	0.08
8/23		8.39	161	31.9	229	1.92	7.18	0.08	0.03	0.20	0.21	0.11
9/5		8.12	163	33.2	217	1.15	6.56	0.03	0.00	0.25	0.13	0.14
9/20		8.25	171	32.2	229	0.30	4.92	0.05	0.01	0.14	0.17	0.11
10/4		8.16	174	33.2	233	1.22	5.41	0.09	0.02	0.22	0.08	0.11
Lake Catherine, deep												
5/9		7.80	179	31.8	232	0.72	5.54	0.08	0.04	0.56	0.64	0.25
5/22		8.11	178	37.4	233	0.45	6.20	0.05	0.03	0.33	0.42	0.12
6/5		7.79	187	33.8	233	1.20	4.6	0.16	0.15	0.68	0.22	0.08
6/21		7.80	194	34.8	233	1.89	11.0	0.22	0.21	1.85	0.33	0.10
7/2		7.93	192	31.9	237	2.45	14.54	0.19	0.13	0.97	0.14	0.09
7/17		7.81	198	33.6	240	3.89	16.53	0.28	0.27	1.04	0.14	0.53
8/2		8.11	177	34.8	227	3.15	14.00	0.08	0.03	0.20	0.12	0.08
8/23		7.84	157	31.0	213	4.18	12.01	0.20	0.14	0.80	0.16	0.35
9/5		7.62	166	29.8	213	4.30	16.83	0.24	0.21	1.39	0.20	0.21
9/20		8.32	172	32.6	225	0.36	4.83	0.09	0.01	0.20	0.15	0.12
10/4		8.19	172	31.9	223	1.10	5.54	0.09	0.02	0.21	0.08	0.29

Appendix D-6. Water Quality Characteristics, Channel Lake, 1979

Date 1979	Trans. inches	pH	Alka mg/l	Sulfate mg/l	Hardnees mg/l	Silica mg/l	Chlorine demand mg/l	Phosphorus Total mg/l	Phosphorus Diss. mg/l	Ammonia-N mg/l	Nitrate-N mg/l	T. Iron mg/l
Channel Lake,, surface												
5/9	44	8.15	170	32.2	228	0.07	4.65	0.10	0.02	0.12	0.42	0.12
5/22	81	8.17	183	36.2	240	0.60	5.80	0.04	0.03	0.23	0.31	0.09
6/5	75	8.30	186	33.5	227	0.47	3.10	0.04	0.01	0.11	0.25	0.06
6/21	36	8.37	185	37.8	230	0.94	5.60	0.06	0.01	0.10	0.09	0.09
7/2	27	8.79	179	33.0	230	1.99	4.88	0.07	0.03	0.16	0.13	0.12
7/17	24	8.48	175	35.6	223	2.67	6.34	0.06	0.01	0.23	0.28	0.13
8/2	30	8.51	173	32.8	221	3.91	5.18	0.07	0.04	0.06	0.22	0.04
8/23	36	8.71	165	28.0	220	3.84	5.80	0.06	0.03	0.14	0.14	0.03
9/5	27	8.74	160	32.2	211	3.82	9.21	0.05	0.01	0.23	0.16	0.05
9/20	30	8.16	177	31.0	239	4.34	5.45	0.06	0.01	0.19	0.16	0.10
10/4	27	8.14	176	32.5	227	4.55	6.20	0.09	0.03	0.27	0.13	0.12
Channel Lake, mid-depth												
5/9		8.25	170	32.9	232	0.03	4.65	0.04	0.02	0.12	0.54	0.13
5/22		8.16	180	37.8	239	0.51	6.20	0.07	0.04	0.17	0.32	0.17
6/5		7.98	185	35.0	233	0.60	3.80	0.08	0.05	0.28	0.25	0.07
6/21		8.08	181	38.6	233	0.94	5.10	0.06	0.01	0.06	0.09	0.07
7/2		8.38	181	33.8	233	2.05	4.88	0.06	0.02	0.12	0.12	0.09
7/17		8.48	173	34.8	227	2.56	7.76	0.07	0.02	0.05	0.19	0.12
8/2		8.41	172	33.6	227	3.82	5.76	0.07	0.02	0.07	0.13	0.06
8/23		8.17	167	31.6	227	4.22	5.89	0.04	0.03	0.29	0.13	0.02
9/5		7.82	162	30.4	188	4.20	6.20	0.04	0.00	0.00	0.20	0.16
9/20		8.17	174	31.0	227	4.34	5.36	0.07	0.01	0.11	0.15	0.06
10/4		8.21	172	33.6	227	4.61	6.38	0.09	0.01	0.28	0.10	0.21
Channel Lake, deep												
5/9		8.09	188	33.8	228	1.58	4.88	0.19	0.07	0.35	0.44	2.00
5/22		7.98	183	33.0	233	1.11	10.20	0.13	0.09	0.88	0.21	0.15
6/5		7.83	187	33.7	233	1.44	6.00	0.16	0.12	0.82	0.19	0.07
6/21		7.61	198	34.2	234	3.10	18.90	0.29	0.27	2.29	0.16	0.12
7/2		7.80	199	29.6	240	3.72	14.23	0.36	0.26	1.47	0.09	0.10
7/17		8.28	177	36.0	227	2.48	11.35	0.12	0.01	0.28	0.17	0.30
8/2		7.67	230	17.6	220	5.16	24.63	0.52	0.23	3.14	0.12	0.11
8/23		7.85	211	26.2	260	5.41	22.15	0.41	0.32	2.65	0.14	0.18
9/5		7.48	192	26.1	233	5.52	16.30	0.26	0.25	2.35	0.16	0.10
9/20		7.46	196	30.7	252	5.67	6.25	0.27	0.21	2.19	0.20	0.08
10/4		8.20	182	32.5	230	4.73	8.85	0.13	0.04	0.29	0.12	0.67

Appendix D-7. Water Quality Characteristics, Lake Catherine, 1980

Date 1980	BOD mg/l	Chlorine demand mg/l	Trans in	Turbid NTU	pH	Alka mg/l	Hard mg/l	Nitrate mg/l	Amm. mg/l	Phosphorus mg/l Total	Phosphorus mg/l Diss.	Total iron mg/l	Sulfate mg/l	Chloride mg/l	Silica mg/l	Solids mg/l Total	Solids mg/l Susp.
Lake Catherine, surface																	
5/12	—	2.88	58.0	—	7.7	199	246	0.13	0.07	<0.05	<0.05	<0.10	30	—	0.20	—	—
5/27	—	3.10	40.0	—	8.2	201	248	0.12	0.08	0.08	0.07	<0.10	34	—	0.25	—	—
6/17	4.53	5.81	36.0	12	8.3	181	236	<0.05	0.04	0.03	<0.05	0.12	28	32.22	0.74	323	6.0
7/6	3.42	5.25	32.0	20	8.3	184	220	0.10	0.13	<0.05	<0.05	0.08	31	32.85	1.20	300	6.4
7/23	2.20	5.60	137.0	12	8.2	186	228	0.08	0.19	0.05	<0.05	0.06	35	33.90	1.75	310	6.4
8/12	—	8.18	111.0	10	8.1	190	230	0.11	0.12	<0.05	<0.05	0.08	20	33.50	1.50	275	0.0
9/5	—	7.90	102.0	16	8.0	192	226	0.07	0.05	<0.05	<0.05	0.07	17	33.00	3.75	333	2.4
9/30	—	5.77	50.0	10	8.0	196	228	<0.05	<0.05	<0.05	<0.05	0.08	14	34.00	1.00	253	5.6
Lake Catherine, mid-depth																	
5/12	—	3.44	—	—	7.7	194	248	0.13	0.16	<0.05	<0.05	<0.10	30	—	0.15	—	—
5/27	—	3.44	—	—	7.9	199	268	0.16	0.21	0.09	0.09	<0.10	34	—	0.25	—	—
6/17	2.62	8.56	—	10	8.3	186	232	<0.05	0.06	0.02	<0.05	0.12	24	32.75	0.85	315	3.6
7/6	2.57	4.54	—	20	8.2	179	228	0.10	0.05	0.06	<0.05	0.06	31	32.32	1.16	306	8.8
7/23	1.82	5.25	—	10	8.1	168	236	0.05	0.14	0.05	<0.05	0.05	34	33.90	1.75	312	1.2
8/12	—	7.12	—	10	8.1	173	224	0.12	0.09	<0.05	<0.05	<0.05	17	34.00	1.25	268	0.0
9/5	—	8.00	—	10	8.4	180	224	0.05	<0.05	<0.05	<0.05	0.05	18	33.50	3.00	338	2.0
9/30	—	5.06	—	10	8.2	192	228	<0.05	<0.05	<0.05	<0.05	0.08	14	33.50	1.00	266	5.6
Lake Catherine, deep																	
5/12	—	3.47	—	—	7.1	196	252	0.12	1.50	<0.15	<0.05	<0.10	30	—	0.58	—	—
5/27	—	2.75	—	—	7.4	202	256	0.10	2.20	0.15	0.12	<0.10	30	—	1.59	—	--
6/17	6.11	11.65	—	10	7.5	207	244	0.10	3.20	0.40	0.28	0.16	24	31.16	3.00	349	12.0
7/6	7.60	9.86	—	18	7.9	213	228	0.08	3.10	0.45	0.38	0.12	28	26.49	3.50	342	8.4
7/23	2.31	9.86	—	20	7.5	189	236	<0.05	3.60	0.40	0.38	0.10	35	33.11	2.25	359	1.8
8/12	—	23.45	—	70	7.2	254	262	0.11	5.00	1.00	0.90	0.20	16	23.50	7.50	351	4.8
9/5	—	12.92	—	10	7.7	230	230	<0.05	3.65	0.70	0.70	0.10	15	36.50	5.50	361	5.2
9/30	—	5.06	—	15	8.1	192	230	<0.05	<0.05	<0.05	0.05	0.10	14	33.00	1.00	272	3.6

Appendix D-8. Water Quality Characteristics, Channel Lake, 1980

Date 1980	BOD mg/l	Chlorine Demand mg/l	Trans in	Turbid NTU	pH	Alka mg/l	Hard mg/l	Nitrate mg/l	Amm mg/l	Phosphorus mg/l Total	Phosphorus mg/l Diss.	Total iron mg/l	Sulfate mg/l	Chloride mg/l	Silica mg/l	Solids mg/l Total	Solids mg/l Susp.
Channel Lake, surface																	
5/12	—	2.75	—	—	7.7	202	244	0.12	0.39	<0.05	<0.05	<0.10	30	—	0.15	—	—
5/27	—	1.72	41.0	—	8.4	198	252	0.10	0.07	0.08	0.08	<0.10	36	—	0.24	—	—
6/17	4.29	5.14	36.0	16	8.5	181	232	0.12	0.02	0.03	<0.05	0.12	28	35.75	1.26	334	9.6
7/6	3.19	5.60	32.0	28	8.3	176	220	0.08	0.04	0.07	<0.05	0.05	36	32.85	1.70	305	16.0
7/23	3.56	4.90	36.0	16	8.5	173	232	0.05	0.04	<0.05	<0.05	0.11	37	34.70	2.90	333	2.4
8/12	—	7.83	53.0	10	8.4	188	224	0.10	0.07	<0.05	<0.05	0.05	17	34.00	3.50	309	3.6
9/5	—	8.68	52.0	16	8.3	190	226	0.07	0.05	<0.05	<0.05	0.10	18	32.00	5.50	292	6.0
9/30	—	6.48	32.0	20	8.2	192	224	<0.05	<0.05	<0.05	<0.05	0.12	14	33.50	3.00	270	11.6
Channel Lake, mid-depth																	
5/12	—	3.44	—	—	7.7	199	246	0.12	0.18	<0.05	<0.05	<0.10	30	—	0.15	—	—
5/27	—	0.69	—	—	8.1	200	252	0.16	0.02	0.06	0.06	0.10	32	—	0.25	—	—
6/17	2.70	5.81	—	12	8.0	186	240	0.08	0.42	0.05	<0.05	0.11	26	32.22	1.88	334	7.2
7/6	3.25	5.25	—	38	8.4	179	220	0.08	0.04	<0.05	<0.05	0.05	34	32.32	1.60	321	24.8
7/23	2.84	9.15	—	16	7.6	186	236	0.04	1.10	<0.05	<0.05	0.08	33	32.84	2.50	333	2.8
8/12	—	8.89	—	20	8.2	190	232	0.10	0.18	<0.05	<0.05	0.12	17	34.50	3.50	309	3.6
9/5	—	9.06	—	16	8.0	283	278	<0.05	0.03	<0.05	<0.05	0.07	17	34.50	6.00	290	6.0
9/30	—	6.48	—	15	8.0	187	224	<0.05	0.01	<0.05	<0.05	0.12	12	30.50	3.00	279	11.6
Channel Lake, deep																	
5/12	—	5.50	—	—	7.4	203	248	0.05	0.59	<0.05	<0.05	<0.10	30	—	1.00	—	—
5/27	—	2.75	—	—	7.5	204	256	0.08	2.35	0.20	0.20	0.12	32	—	1.28	—	—
6/17	4.83	20.60	—	14	7.5	206	248	0.13	4.10	0.45	0.38	0.16	25	31.16	3.00	351	8.0
7/6	2.25	12.52	—	30	7.9	213	240	0.08	1.48	0.06	0.05	0.06	31	30.73	2.25	274	10.0
7/23	5.70	19.78	—	38	7.3	218	236	0.05	3.60	0.35	0.28	0.11	32	29.67	3.75	356	3.6
8/12	—	27.00	—	70	7.3	269	270	0.12	4.90	0.70	0.68	0.22	20	14.50	5.00	330	2.0
9/5	—	21.98	—	20	8.2	180	228	0.12	5.18	0.84	0.84	0.12	16	33.00	6.00	345	5.2
9/30	—	16.40	—	18	7.4	212	238	<0.05	1.20	0.20	0.08	0.05	11	31.00	4.25	283	12.8