AN ASSESSMENT OF THE ECOLOGY OF FOX CHAIN OF LAKES AND THE APPLICABILITY OF IN-LAKE RESTORATION TECHNIQUES

Veerasamy Kothandaraman and Ralph L. Evans[1)]

Water Quality Section
Illinois State Water Survey
P.O. Box 717
Peoria, Illinois 61601

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 interconnected bodies of water with a surface area of 6,850 acres, natural shorelines, picturesque beauty, and proximity to the city of Chicago combine to make the Chain a popular area for recreation and resort development.

The Chain of Lakes, in an advanced stage of eutrophication, 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 picturesque beauty of the region, and the aesthetic and recreational enjoyment of the Chain's waters.

A detailed 18-month investigation of the Fox Chain of Lakes was conducted by the Illinois State Water Survey (Kothandaraman, et al., 1977). The lakes develop distinct summer stratification and become totally anoxic below the thermoclines. Marked increases of ammonia, phosphorus, silica, and other end products of anaerobic decomposition of bottom sediments occur. Algal densities of 10,000 counts per milliliter or more are not uncommon in each of the lakes, and blue-green algae are the dominant species in the lakes.

A detailed nutrient budget developed for the lake system indicated that the total phosphorus and total nitrogen loading rates are, respectively, 10.3 and 86.0 $g/m^2/yr$, which are far in excess of the rates likely to be assimilated without giving rise to nuisance algal blooms. The nutrients released from the lake bottom sediments under anaerobic conditions in the deeper lakes during periods of summer stagnation are also sufficient to sustain algal growths of bloom proportions in the lakes.

Limiting the nutrient influx to the lakes is an essental 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 in removal of phosphorus from municipal waste discharges and 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.

PILOT LAKE RESTORATION SCHEMES

Figure 1 also shows the sites and the pilot lake restoration schemes investigated in the Chain of Lakes. Chemical treatment, using copper sulfate in the Mineola Bay of Fox Lake, resulted in significant decreases in algal counts after each treatment. However, the algal densities tended to

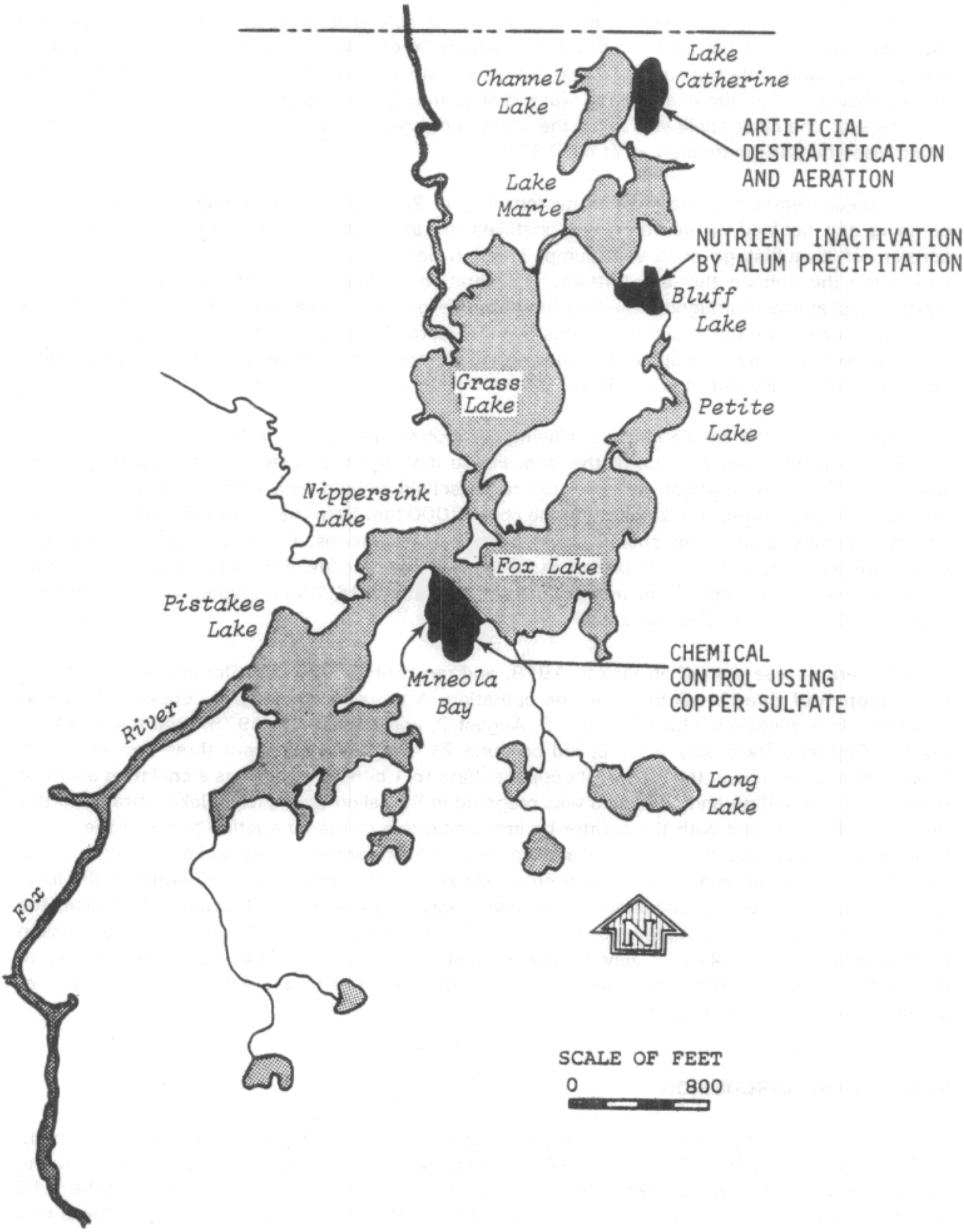

Figure 1. Fox Chain of Lakes in Illinois

increase within a week after chemical application. Nutrient inactivation using aluminum sulfate to precipitate phosphorus from the water column was investigated in Bluff Lake (92 acres). The immediate effect of the alum treatment was a dramatic improvement in lake transparency and a decrease in algal density. A marked drop in total and dissolved phosphorus levels was observed in the deeper portion of the lake. However, the beneficial effects of nutrient inactivation by alum precipitation were only transitory, lasting not more than a week. Consequently, this technique is not a viable consideration in an overall water quality management plan for the Chain. The method and rates of chemical applications for the aforementioned in-lake treatment techniques can be found elsewhere (Kothandaraman et al., 1978).

A unique aeration-destratification system (Figure 2), which is a combination of mechanical pumping and bubbled air aeration, was installed in Lake Catherine (150 acres). The system consists of a multistage deep well pump, aeration device, air hoses, and a mounting skid for supporting the unit on the lake bottom. The aeration system is also capable of applying and dispersing chemicals throughout the lake from a single location. The details of the installation of the aerator, reasons for the selection of this type of aerator, principles of its operation, and the hydrodynamic mixing of the upwelled hypolimnetic waters with epilimnetic waters are discussed in detail by Kothandaraman et al., (1979).

Installation of the device involved placing the unit on the bottom in 28 feet of water, about 750 feet from the southern end of the lake. Figure 3 shows the location of the aerator in Lake Catherine. *In-situ* observations for temperature, dissolved oxygen, and secchi disc readings were made at sampling station 1 in Lake Catherine about 2000 feet from the aerator. Samples were also collected at this location for chemical and biological evaluations. For purposes of comparison, similar observations and sample collections for analyses were made in the adjoining Channel Lake. Lake Catherine has maximum and mean depths of 39 feet and 16.7 feet, respectively,as compared to 35 and 13.7 feet for Channel Lake.

The aerator was started on May 9, 1979, and ran continuously until October 4, 1979, with the exception of three breakdowns in the operation. A thousand pounds of copper sulfate was applied on four occasions (June 21, July 5, August 2, and August 23, 1979) with the aid of the aerator. Copper sulfate only was applied on June 21. For the subsequent three copper sulfate applications, citric acid in the ratio of 2 copper sulfate to 1 citric 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 completing the chemical applications, water samples were collected from seven locations in Lake Catherine (figure 3) in order to examine the distribution of copper in the lake. Water samples were also collected the following day at these seven locations. Following the copper sulfate-citric acid applications on July 5 and August 2, 220 pounds of potassium permanganate were applied on July 11 and August 7, respectively. This was done primarily to oxidize the decaying algae after copper sulfate application and to avoid possible depression of dissolved oxygen concentration in the lake.

RESULTS AND DISCUSSION

Temperature. The pre-aeration investigations of the Fox Chain of Lakes (Kothandaraman et al., 1977, 1978) indicate that Catherine and Channel Lakes exhibit comparable stratification features. However, the water strata of Lake Catherine are colder than those of Channel Lake at depths of 15 feet below the water surface. During 1975 and 1977, surface water temperatures in these two lakes attained a maximum of about 27.5°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.

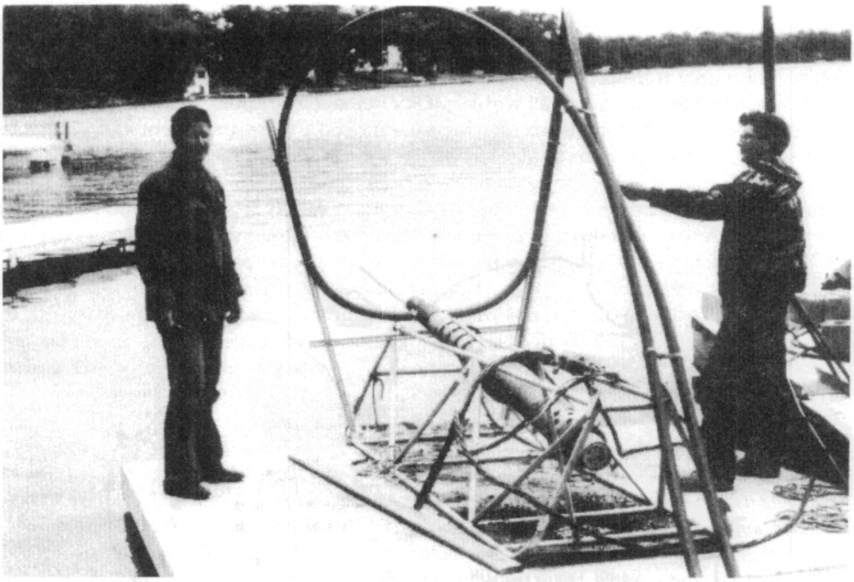

Figure 2. Aerator used in Lake Catherine

The isothermal plots for Lake Catherine at station 1, and for Channel Lake are shown, respectively, in figures 4 and 5. The periods of aerator shutdown either because of power failure, control panel malfunctioning, or vandalism are marked in figure 4.

The 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 shutdown (July 14 to July 26, 1979) of the aerator, Lake Catherine exhibited a tendency to stratify again. However, when the aerator was restarted, the lake destratified soon after. The temperature data show that the aerator destratified the lake completely. Water temperatures in Lake Catherine at 35 feet depth were 5 to 7°C higher than the temperatures for Channel Lake. Maximum observed surface water temperatures were also about 2°C cooler in Lake Catherine.

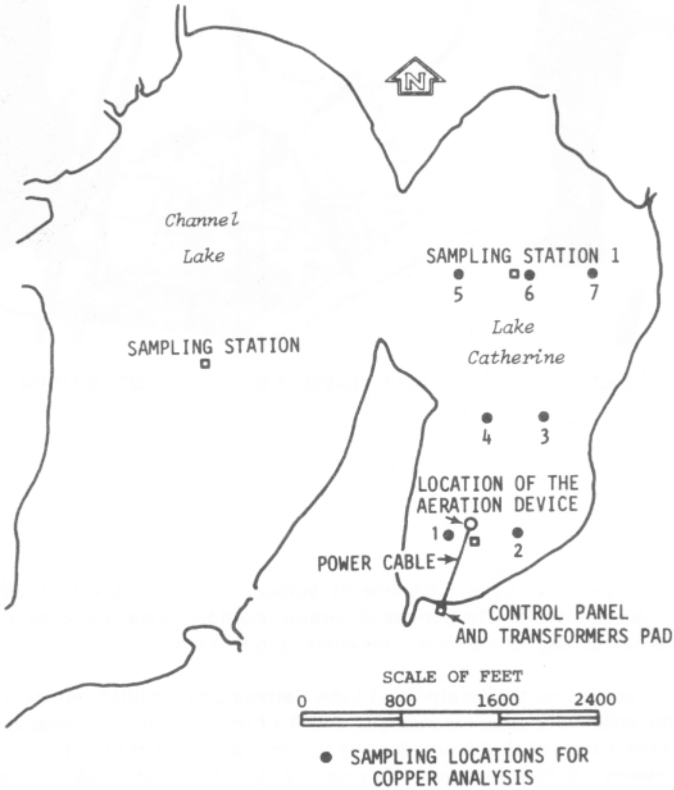

Figure 3. Location of the aeration device in Lake Catherine and sampling stations

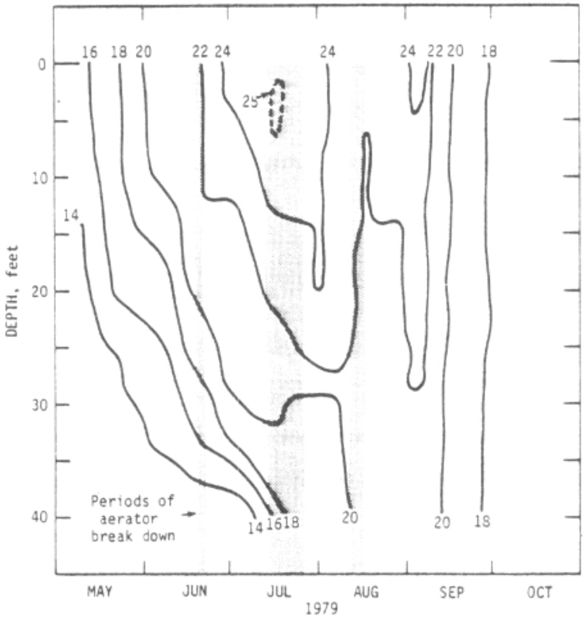

Figure 4. Isothermal plots in °C for Lake Catherine station 1

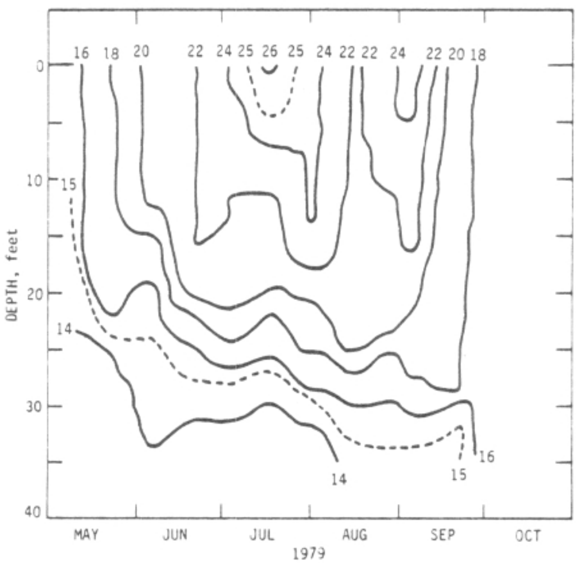

Figure 5. Isothermal plots in °C for Channel Lake

Dissolved Oxygen. Observations in 1975 and 1977 (Kothandaraman et al. 1977, 1978) of Lake Catherine and Channel Lake showed that the volume of the water column below the 15-foot depth was devoid of oxygen during summer stratification. July was the most critical month. Decomposition of algal silt in the profundal regions of these deep lakes and the subsequent oxygen demand of the products of decomposition are major causes of oxygen depletion in the hypolimnion. *In-situ* sediment oxygen demand determinations carried out in 1975 (Kothandaraman et al., 1977) indicated that a demand rate of about 16.5 g/m^2/day prevailed in these two lakes.

The effects of artificial destratification and aeration on the oxygen resources of Lake Catherine are shown in figure 6. Even though the aerator was started on May 10, 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 gradully 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 7).

Because of the extended period of shutdown of the aerator during the latter half of July, the anoxic zone extended to about 14 feet from the surface. Oxygen levels increased in the deeper waters with the resumption of aerator operation. The upward mobility of the anoxic zone in Channel Lake during 1979 was abrupt and occurred in May.

Secchi Disc Transparency. The temporal variations in secchi disc observations in these two lakes for the year 1979 are shown in figure 8. The days of chemical treatment in Lake Catherine to control algae are also noted on the figure. Secchi disc observations in Lake Catherine appear to increase after each copper sulfate application. These improvements in clarity could not be sustained for long because of the probable ingress of wind-swept algae from Channel Lake.

Phytoplankton. The temporal variations in the total algal densities in Lake Catherine and Channel Lake are shown in figure 9. Algal densities at the surface and mid-depth in Lake Catherine are generally less than in Channel Lake. The data presented clearly indicate a reduction in total algal counts in Lake Catherine. This is not just due to 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 of decreasing trends in the algal densities in Lake Catherine very closely follow the trends in Channel Lake. These trends in Lake Catherine sometimes go counter to the anticipated effects of copper sulfate application. Thus it can be concluded that the algal blooms in Channel Lake overwhelm the beneficial effects of aeration and chemical treatment in Lake Catherine. Nevertheless, there is a discernible trend in the decrease of algal count. Also, it is seen from figure 10 that there is a concomitant decrease in the dominance of blue-green algae in Lake Catherine. The ratio of blue-green to total algae is less in Lake Catherine than in Channel Lake, particularly during August and September after the prolonged break down of the aerator in July.

Benthic Macroinvertebrates. A more diversified benthic population was observed in Lake Catherine than in Channel Lake. The benthic population in Lake Catherine was composed of 58 percent *Chaoborus,* 37 percent Chironomidae, 4 percent *Hyalella,* and 1 percent Ceratopogonidae. in Channel Lake the benthos consisted of 94 percent ***Chaoiborus*** and 6 percent Chironomidae. *Hyalella* and Ceratopogonidae were found only in Lake Catherine.

Chemical Characteristics. The chemical quality characteristics of the surface and mid-depth water samples collected from these lakes had comparable values. However, the deep water samples collected close to the lake bottom were distinctly different as evidenced by table 1. Products of decomposition like alkalinity, silica, ammonia-N, and total and dissolved phosphorus were much lower in Lake Catherine than in Channel Lake. By the same token, chemical constituents of higher oxidative status like sulfate and nitrate were higher in Lake Catherine. The

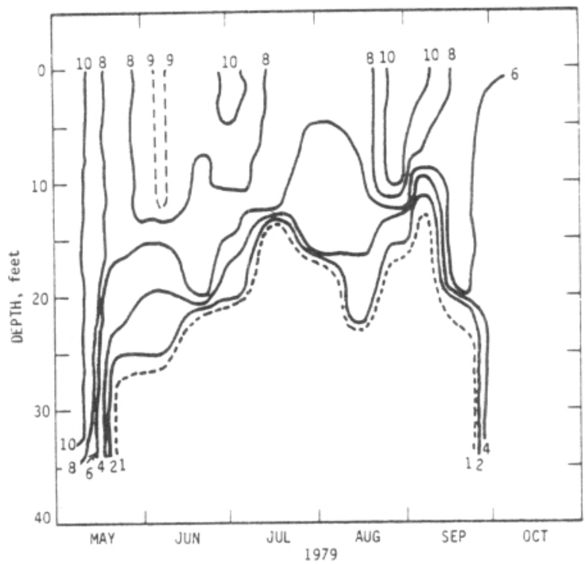

Figure 7. Isopleths of dissolved oxygen in mg/l for Channel Lake

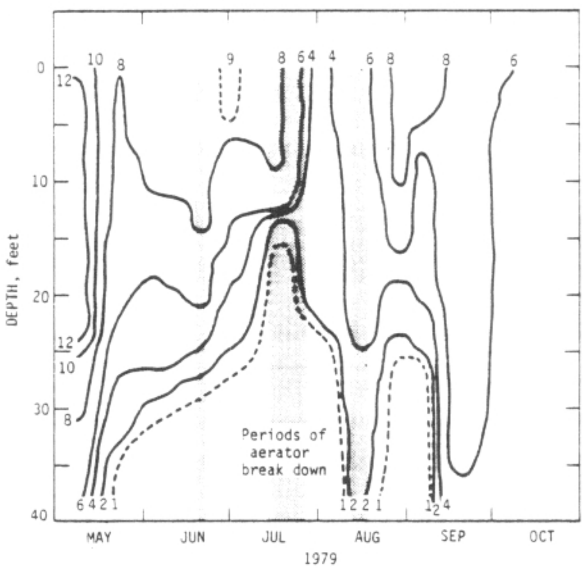

Figure 6. Isopleths of dissolved oxygen in mg/l for Lake Catherine station 1

Table 1. Summary of Chemical Quality Characteristics for August-September 1979 at Deep Locations of Catherine and Channel Lakes

Parameters	Catherine		Channel	
	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
Amonia-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

Table 2. Copper Concentrations in Lake Catherine
(Concentrations in milligram per liter)

Locations	6/21/79*	6/22/79	7/5/79*	7/6/79	7/11/79
1A	0.08	0.03	0.82	0.11	0.03
1B	0.23	0.08	0.07	0.15	0.07
2A	0.08	0.02	0.02	0.13	0.03
2B	0.29	0.03	0.11	0.15	0.05
3A	0.00	0.02	0.28	0.10	0.02
3B	0.25	0.03	0.07	0.19	0.02
4A	0.00	0.03	0.04	0.02	0.02
4B	0.02	0.02	0.12	0.15	0.05
5A	0.00	0.00	0.02	0.07	0.02
5B	0.10	0.02	0.07	0.07	0.02
6A	0.02	0.02	0.06	0.03	0.00
6B	0.04	0.02	0.07	0.07	0.06
7A	0.00	0.00	0.09	0.15	0.02
7B	0.04	0.02	0.09	0.10	0.05

Note: 1A = surface sample at sation 1
1B = sample at 5 feet depth in station 1 and so on
* = date of copper sulfate application

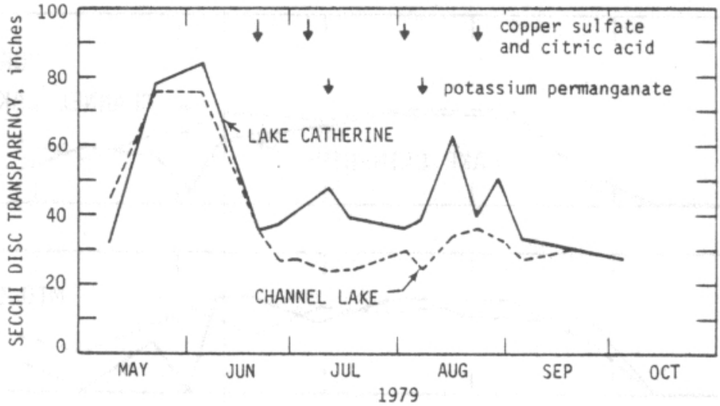

Figure 8. Transparencies in Lake Catherine and Channel Lake

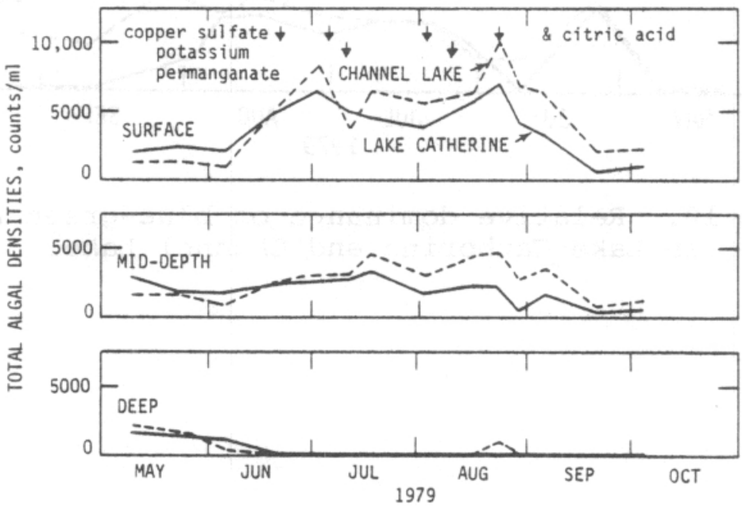

Figure 9. Total algal densities in Lake Catherine station 1 and Channel Lake

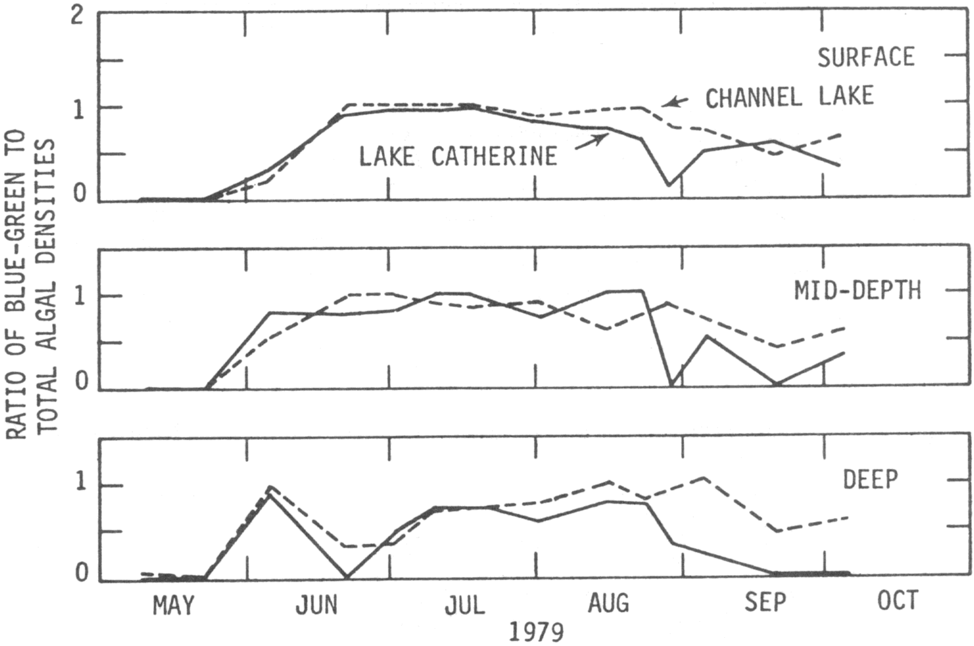

Figure 10. Relative dominance of blue-green algae in Lake Catherine and Channel Lake.

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, had also been significantly reduced in Lake Catherine due to aeration.

Chemical Treatment. Copper sulfate was applied to Lake Catherine on four occasions during June through August 1979. The first lake chemical treatment on June 21 was only with copper sulfate, whereas for the remaining three applications, copper sulfate was chelated with citric acid prior to lake application. Results of copper analyses for the first two applications are shown in table 2. 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. Potassium permanganate was applied on July 11 and August 7, a few days after the application of copper sulfate in each case. Since potassium permanganate is a strong oxidant, it oxidizes decaying algal cells, thus relieving the potential demands on the oxygen resources of the lake.

SUMMARY

A unique aeration-destratification system which is a combination of mechanical aeration and bubbled air aeration was installed in Lake Catherine. The aerator is capable of applying chemicals from a single location and dispersing the chemicals throughout the lake. Consequently, the efficacy of artificial lake destratification in combination with chemical treatment (chemicals used; copper sulfate, citric acid, and potassium permanganate) as a lake management technique was investigated.

The aerator destratified the thermal regime of the lake, and oxygen concentrations of 2 mg/1 or more were maintained to a depth of about 28 feet from the surface. The data gathered during the summer and fall of 1979 indicate that the combination of aeration and chemical treatments has several beneficial impacts on the lake; *viz*, decrease in algal abundance, shift in algal species make up to the more desirable greens and diatoms, improved lake transparencies, and a significant decrease in the release of products of anaerobic decomposition—ammonia, phosphorus, silica, etc.—from the lake bottom sediments. A more detailed account of the sampling procedures, procedures for chemical analyses, algae identification and enumeration, chemical applications in the lake, etc. is given by Kothandaraman et al. (1980).

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