GUIDELINES FOR APPLYING COPPER SULFATE AS AN ALGICIDE: LAKE LOAMI FIELD STUDY

ENR

Illinois Department of Energy and Natural Resources

James R. Thompson, Governor
Karen A. Witter, Director

GUIDELINES FOR APPLYING COPPER SULFATE AS AN ALGICIDE:
LAKE LOAMI FIELD STUDY

Final Report

Prepared by:

Illinois State Water Survey
Water Quality Section
P.O. Box 697
Peoria, IL 61820

Principal Investigators:

Raman K. Raman
Billy C. Cook

Prepared for:

Illinois Department of
Energy and Natural Resources
Office of Research and Planning
325 W. Adams, Room 300
Springfield, IL 62704-1892

James R. Thompson, Governor
State of Illinois

Karen A. Witter, Director
Illinois Department of
Energy and Natural Resources

CONTENTS

GUIDELINES FOR APPLYING COPPER SULFATE AS AN ALGICIDE:
LAKE LOAMI FIELD STUDY

by Raman K. Raman and Billy C. Cook

INTRODUCTION

Excessive enrichment of lakes by plant nutrients is a widepread problem, particularly for lakes that serve as sources of municipal water supplies. Increased nutrient loading (input) as a result of human activity has come to be known as "cultural eutrophication." The high levels of nutrients commonly associated with cultural eutrophication can quickly lead to undesirable growth of algae and other aquatic plants and to many related water quality problems.

Most impoundments in Illinois are formed in fertile floodplains draining croplands, are relatively shallow, and have low capacity-inflow ratios (hydraulic retention time). Since these impoundments generally inundate rich bottomlands and fertile topsoils, they normally begin their lives with high biological productivity (Kothandaraman and Evans, 1983a, 1983b). This is because mineral nutrients and organic materials are leached from these soils into the overlying waters. Consequently, a large number of these lakes show symptoms of eutrophy right from their nascency, including hypolimnetic oxygen depletion, high concentrations of phosphorus and nitrogen, and varying degrees of growths of phytoplankton and macrophytes. These problems become more and more severe as time progresses, ultimately leading to increased water treatment costs and in some instances even to abandonment of the lake as a water supply source (Kothandaraman and Evans, 1982).

Because of the eutrophic conditions in the impoundments, taste and odor problems are encountered in most water supply systems using impoundments as their source. In a recent survey sponsored by the American Water Works Association (AWWA) Taste and Odor Control Committee, "decaying organic matter and viable algae" were overwhelmingly (92%) cited as the main "odor cause" in raw water supplies, as quoted by Ficek (1983). In addition to color, taste, and odor problems, other problems such as reduced filter runs, increased costs of treatment chemicals, and corrosion of concrete and of metals are attributed to planktonic growths in surface water impoundments (Palmer, 1962).

Through their photosynthetic processes, algae utilize carbon dioxide, converting it into organic matter and oxygen. They are an essential part of the lake and reservoir ecosystem and constitute the basic foundation of the aquatic food chain. Generally, problems develop only when excessive algal growths occur.

Copper sulfate is routinely employed to control algal blooms in about 70 of the nearly 100 water supply impoundments in Illinois. Until 1986, copper sulfate was the only algicide approved by the Illinois Pollution Control Board (1982) for use in public water supply impoundments. In April 1986, potassium permanganate was approved as an additional algicide that could be used in water supply impoundments. However, the rules and regulations are not specific about the quantities of algicides to be applied or the frequency of application.

Copper sulfate is currently being used without due regard for: 1) the chemistry of the lake waters, or 2) the need for and frequency of application. For example, copper sulfate application rates in water supply impoundments in Illinois during 1982 ranged from 5 to 100 pounds per acre with a mean rate of 21.9 lbs/acre. The frequency of application ranged from 1 to 10 times per year. The recommended rate found in the literature for copper sulfate application is 5.4 lbs/acre for high-alkalinity waters (Fair et al., 1971; Muchmore,.1973), which are found in much of Illinois. Kothandaraman and Evans (1982, 1983a, 1983b) reported that for Lake Eureka in central Illinois, one to four applications of copper sulfate were adequate for controlling problem-causing blue-green algae. Thus it is obvious that the chemical is generally being misused and misapplied in Illinois. This is not only uneconomical but is also ecologically undesirable. This investigation was undertaken to critically examine the algicide application practices in Lake Loami, Loami, Illinois, and to determine whether the rates and frequencies of copper sulfate applications in that lake are justified.

Most Illinois water supply impoundments and treatment systems are owned and operated by municipalities that lack the resources or technical know-how needed to critically assess the taste and odor problems caused by algal blooms and to adopt remedial measures. As the impoundments form an important segment of the water resources in Illinois, this resource must be managed wisely. It is hoped that the results of this study will assist water supply impoundment managers in the judicious use of copper sulfate as an algicide.

Objectives and Scope

The primary objective of this investigation was to conduct field-scale studies and use the results to develop guidelines for the proper use of copper sulfate in water supply impoundments, with respect to both the rate and frequency of application. The field study was designed to provide answers to the following questions:

- Is an application rate of copper sulfate greater than 5.4 pounds/acre warranted in high-alkalinity waters?

- Can the chelating agent, citric acid, enhance the algicidal effect of copper in high-alkalinity waters and, if so, what are the relative economics of algae control with and without a chelating agent?

- What are the concentrations of copper ions in the water column on a daily basis after the algicide is applied?

- How do the phytoplankton respond on a daily basis after the algicide application?

- What are the possibilities that the chelating agent in copper sulfate applications increases the solubility of heavy metals such as barium, cadmium, lead, and zinc, causing them to pass through the subsequent water treatment processes?

Detailed limnological studies of Lake Loami were carried out on a periodic basis during 1987 to delineate the physical, chemical, and biological characteristics of the lake waters that impact the finished water quality. Limno-corral (enclosure) studies were conducted simultaneously with lake application of copper sulfate to control algae in order to elicit answers to the aforementioned questions. The details of the limnological and limno-corral studies are discussed in the "Materials and Methods" section.

BACKGROUND

Chemistry of Copper

Although copper is distributed widely in both biotic and abiotic components of ecosystems, many aquatic organisms are sensitive to small increases in copper concentrations in the water. The response to increased copper levels differs with species and with the physicochemical form of copper in the water.

The distribution and final fate of copper released into ecosystems, and its availability to biota, depend on how the copper is partitioned among the

compartments in the ecosystem. The major processes that control the chemical speciation of copper in natural waters are precipitation, formation of complexes with inorganic or organic ligands, adsorption by particulate material, and biological concentration. These processes can be affected by the concentration of copper, pH, alkalinity, and concentration of copper-binding sites associated with dissolved organic materials and suspended particulates. In general, precipitation of copper as tenorite (CuO), malachite ($Cu_2(OH)_2CO_3$), or azurite ($Cu_3(OH)_2(CO_3)_2$) and formation of inorganic complexes ($CuOH^+$, $Cu(OH)_2^{2+}$, $CuCO_3$, $Cu(CO_3)_2^{2-}$, etc.) will be important with increasing pH, alkalinity, and copper concentration (McKnight et al., 1983).

On the basis of investigations in synthetic fresh water, Sylva (1976) postulates that in most aquatic systems complexation, adsorption, and precipitation processes are capable of reducing free copper concentrations to very low values even in the presence of high levels of total copper. Figure 1 shows the speciation of copper in typical fresh waters as a function of pH. The most rapid changes in copper chemistry occur in the pH range 6.5 - 8.0 such that less than 10% of the copper present at pH 8.0 is in the form of cupric ions. Hydrolysis and precipitation products dominate the chemistry of copper at this and higher pH levels.

Note: $A=Cu^{2+}$; $B=Cu_2(OH)_2^{2+}$; $C=CuOH^+$; $D=CuCO_3$; $E=HCO_3^-$; $F=H_2CO_3$; G=pH at which $Cu(OH)_2$ will precipitate; H=pH at which $Cu_3(OH)_2(CO_3)_2$ will precipitate; and I=pH at which $Cu_2(OH)_2CO_3$ will precipitate (from Sylva, 1976)
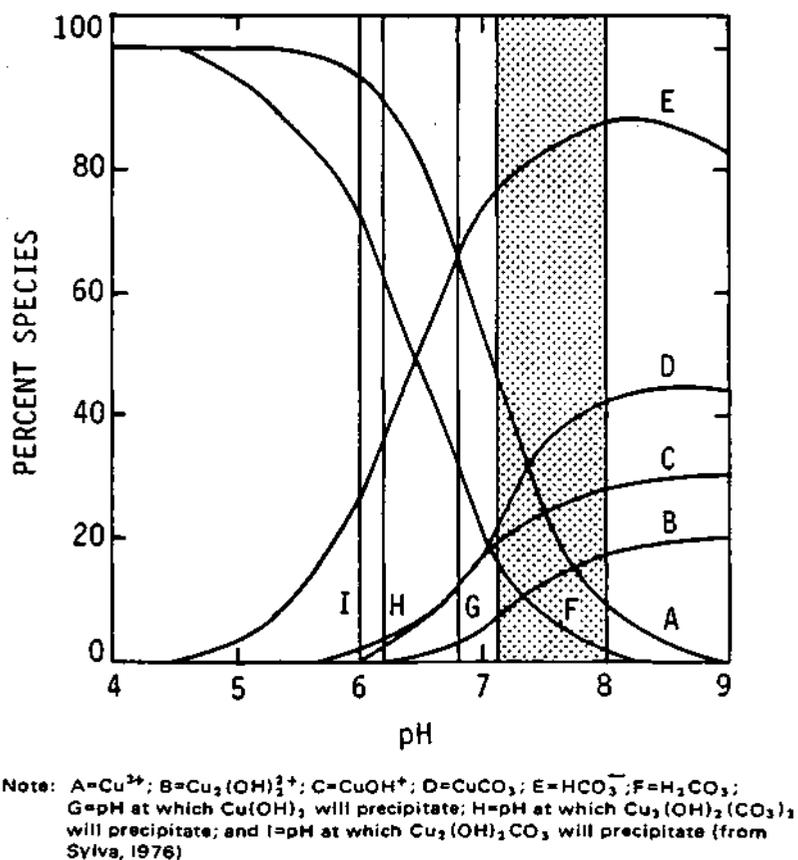
Figure 1. Speciation of copper (II) (total concentration 2 ppm) and carbonate as a function of pH

McGuire et al. (1984) provide a vivid description of visual observations of the results of copper sulfate application to the water supply reservoir of the Metropolitan Water District of Southern California. Shoreline treatment with medium-size chunks of copper sulfate at 200 pounds/acre to control attached blue-green algae was employed. Scuba divers observed the reservoir bottom as the application boat passed overhead spreading the copper sulfate chunks. The chunks settled rapidly to the bottom and began to dissolve immediately. Instead of a blue color, the water in the immediate vicinity of the copper sulfate chunks became <u>milky white</u>. It appeared that copper carbonate precipitate was immediately formed and eventually settled to the bottom. The authors indicate that the formation of copper carbonate was expected since the total alkalinity of the water is usually around 120 milligrams per liter (mg/L) as $CaCO_3$ and the pH is 8.3.

It is clear that the chemical conditions of most aquatic systems are such that even if relatively large levels of total copper are present, the processes of hydrolysis, precipitation, and adsorption will very often be able to reduce the free Cu^{2+} concentrations to extremely low values.

Adsorption of copper onto suspended solids is considerable above pH 6.5 (James and Healy, 1972) and plays a significant role in the reduction of total dissolved copper. Studies by Wagemann and Barica (1979) indicated that the rate of disappearance of copper was always slower in filtered than in unfiltered samples. Results by Stiff (1971) also point to the presence of suspended solids as having a profound effect on the physical state of copper in aquatic environments.

Symmes's (1975) investigation into copper cycling in Indiana Lake, Massachusetts (a soft-water lake treated annually with copper sulfate) showed that copper sulfate application to the lake was followed by rapid conversion of soluble copper to particulate forms which were deposited on the lake bottom. Conversion and deposition was approximately 90% completed by the 10th day following treatment, and most of it occurred within the first 5 days.

Data collected in Canadian lakes (Spear and Pierce, 1979) showed that dissolved copper concentrations reached background levels within 5 days following single copper sulfate applications. Also, Whitaker et al. (1978), who investigated the efficacy of copper sulfate in controlling *Aphanizomenon flos-aquae* (a blue-green alga) in several Canadian prairie lakes, reported that low concentrations in the range of 25 to 40 micrograms per liter (µg/L) as Cu^{2+} on a whole-lake volume basis were effective and that copper concentrations in the water returned to background levels after 8 to 10 days.

Demayo and Taylor (1981) reported that investigations in lakes in southwestern Manitoba showed that 78% to 98% of the dissolved copper (0.45 micrometers, or µm) was in the form of $Cu(OH)_2$ and was complexed with dissolved organic matter. The free Cu^{2+} ion concentrations ranged from <0.02% to 0.37% of the dissolved copper. The pH of the lakes ranged from 8.0 to 9.4'. When copper was added to the lakes (as $CuSO_4 \cdot 5H_2O$), its dissolved concentration decreased according to first-order kinetics. The half-times for the disappearance of dissolved copper from the water column ranged from 1 to 2 days in most of the lakes, and a steady state was reached in approximately 10 days after the addition of copper sulfate.

Toxicity of Copper to Algae

The relatively low toxicity of copper to humans is reflected in finished water quality standards, which set the maximum allowable concentrations of copper at 5.0 mg/L (Illinois Pollution Control Board, 1982). According to Water Quality and Treatment (American Water Works Association, 1950), copper may be beneficial or even essential for the growth of living organisms. The U.S. Environmental Protection Agency has proposed an RMCL (i.e., Recommended Maximum Contaminant Level) for copper of 1.3 mg/L in drinking water. The average daily human intake of copper from water and food is generally between about 2 and 5 milligrams. Richey and Roseboom (1978) have demonstrated that for bluegill and channel catfish native to Illinois, the 14-day TL-50 (i.e., the concentration at which 50% mortality occurs within 14 days in an acute toxicity flow-through test) ranged from 1.2 mg/L to 37 mg/L (as $CuSO_4 \cdot 5H_2O$), depending upon the weight and species of the fish. These concentrations are more than an order of magnitude higher than accepted algicidal levels.

On the basis of laboratory bioassay tests using two California lake water samples, Elder and Horne (1978) reported that 5-10 µg/L of Cu^{2+} suppressed photosynthesis, chlorophyll-a levels, and nitrogen fixation by blue-green algae *(Aphanizomenon* and *Anabaena).* Likewise, Gibson (1972), experimenting with a pure culture of *Anabaena flos-aquae* in a synthetic medium containing 0.05, 0.1, 0.25, 0.75, and 1.0 ppm of copper, found that a concentration of 0.25 mg/L was algicidal and the lower concentrations were algistatic. Also Fitzgerald (1963) reported on tests in which three typical bloom-forming blue-green algae exposed to 0.056 to 0.1 mg/L ($CUSO_4 \cdot 5H_2O$) failed to grow after a reasonable incubation period. Whitaker et al. (1978) found that concentrations of 25 to 40 µg/L as Cu^{++} for the whole-lake volume proved to be effective in controlling *Aphanizomenon flos-aquae* in several Manitoba lakes.

Several investigators (McKnight, 1981; Demayo and Taylor, 1981; Elder and Home, 1978; Harrison and Bishop, 1984; and others) maintain that the toxicity of copper is determined by cupric ion activity and not by the total copper concentration. Wagemann and Barica (1979) introduced their "total toxic copper" concept, which, in the absence of chelating agents, included Cu^{2+}, $Cu(OH)_2$, and $CuOH^+$. Elder and Home (1978) state:

> Complexation of copper is generally assumed to reduce the availability of the metal for biological uptake, although not necessarily by removing it from solution (Home and Goldman, 1974). On the other hand, Gachter and others (1974) and Sylva (1976) correctly pointed out that this assumption has not been experimentally verified and it is entirely possible that some or all natural copper complexes are actually available.

Some studies have indicated that precipitated copper salts and copper-citric acid complexes are no less effective as toxic agents when tested with different blue-green algae for which required concentrations for toxicity varied from 0.05 to 0.1 ppm $CuSO_4 \cdot 5H_2O$ (Fitzgerald, 1963). McGuire et al. (1984) found that precipitated copper was effective in controlling attached blue-green algae on the lake bottom. It should be pointed out that the study conducted by Fitzgerald (1963) indicated that the toxicity of copper to

bluntnose minnow and several sunfishes was reduced in the presence of citric acid without its algicidal properties being affected. Stern et al. (1978), Guy and Kean (1979), and Kothandaraman et al. (1980) have similarly verified that citric acid enhanced the algicidal properties of copper sulfate.

On the other hand, copper toxicity is known to be partly or completely counteracted by strong chelants such as nitrilotriacetic acid (NTA), ethylenediamine tetra acetic acid (EDTA), and tripolyphosphate (TPP) (Home and Goldman, 1974; Gachter et al., 1978), and by exocellular polypeptides produced by algae (Fitzgerald, 1963). This would indicate that a delicate balance must be sought between the effectiveness of an added ligand, such as citric acid, triethanolamine, etc., and its interference in biological uptake. Citric acid appears to lie on the razor's edge. It should be noted that commercial formulations of copper-triethanolamine complexes are marketed as algicide agents, but the Illinois Pollution Control Board (Environmental Register, November 7, 1985) ruled that copper-triethanolamine complexes were not suitable as public water supply algicides.

The mechanisms by which copper affects algae are not well defined. Interference with photosynthesis, respiration, and cell division by the action of copper on cell membranes (Gibson, 1972), nitrogen fixation by blue-green algae (Horne and Goldman, 1974), and iron uptake (Demayo and Taylor, 1981) have all been suggested as possible mechanisms.

Several factors alter the toxicity of metals to aquatic organisms. They include pH, the presence of inorganic carbon, and the presence of other metals or toxicants (antagonistic, additive, and synergistic effects). Factors affecting the physiological responses of organisms include temperature, dissolved oxygen, pH, and light. Also important is the condition of the organism (size, activity, growth phase) and any previous exposure to copper or other metals that has resulted in acclimation or adaption.

Copper toxicity is also affected by the rate at which copper is absorbed by the organisms. Gibson (1972) reported that *Anabaena flos-aquae* removed larger amounts of copper from the test medium than did *Scenedesmus quadricauda* and that young cultures of the blue-green algae were more susceptible to copper than old ones. Several investigators have concluded that blue-green algae in general are more sensitive to copper than greens and diatoms (Demayo and Taylor, 1981; Fitzgerald, 1963; Home and Goldman, 1974; Meadows, 1984).

Lake Application Dosage Rates

The determination of correct copper sulfate dosage for a given lake or reservoir is a key factor in insuring success in controlling undesirable algae. Should the initial treatment dosage be inadequate to control the problem algae, an additional heavier application will then be required. This is tantamount to initial wasted effort and needless copper addition to the aquatic environment. On the other hand, excess copper sulfate additions are wasteful and run the risk of resulting in fish kills.

In a report prepared for the Illinois Institute for Environmental Quality (a predecessor of the Illinois Department of Energy and Natural

Resources), Muchmore (1973) summarized the prevalent dosage rates applicable for water supply impoundments:

Gratteau (1970) stated that copper sulfate concentrations of 0.4 ppm prevent the growth of algae. McKinney (1962) points out the value of adding copper sulfate before maximum algae growth is observed to permit minimum dosage as low as 0.1 ppm. Wilbur (1969) recommends daily application to 1 ppm copper sulfate over a 2-3 day period. A U.S. Government Printing Office document (1968) states that 0.5 ppm $CuSO_4$ kills a high percentage of algae and Kott (1969) reports that 10 mg/l $CuSO_4$ for 4 days kills all algae. deBussey, et al. (1969) found that $CuSO_4$ applications of 0.2 to 0.4 ppm controlled algae growth. In a recent article Mackenthun (1970) states that the dosage rate of the commercial chemical ($CuSO_4 \bullet 5H_2O$) is usually 1 mg/l and sometimes 2 mg/l.

The importance of alkalinity in determining required copper sulfate dosage is stressed by Mackenthun (1969). He recommends a $CuSO_4 \bullet H_2O$ rate of 1 ppm for lakes having a total methyl orange alkalinity of 40 mg/l or greater. Alkalinities below this require only 0.3 ppm. He states these levels will not harm fish. Fair et al., (1971) recommend raising copper sulfate dosages by as much as 5% for each 10 mg/l of alkalinity (as $CaCO_3$). In the absence of normal amounts of CO_2, an additional 5% is recommended. A 20% increase in dosage is recommended for each 10 mg/l of organic material present, and temperature corrections they say may be based on a Q_{10} of 1.3. Q_{10} is the reaction rate change due to a 10°C temperature increase.

Kothandaraman et al. (1980) reported using a copper sulfate application rate of 5.4 pounds/acre. This is equivalent to a dosage rate of 1 mg/L as $CuSO_4 \bullet 5H_2O$ for the top two feet of the lake surface. The presumption here is that active algal photosynthesis is limited to the top two feet of the photic zone. This dosage rate is equivalent to 0.25 mg/L as Cu^{2+} for the top two feet of the lake surface. They also reported that the algicidal effectiveness of copper sulfate applied to the lake was enhanced significantly when copper sulfate was mixed with citric acid as a chelant in the weight ratio of 2 to 1 (two copper sulfate pentahydrate to one citric acid monohydrate).

Application rates (mg/L, μg/L, etc.) suggested in the literature (other than the pounds/acre basis) do not specify whether the rates are expressed as Cu^{2+} or $CUSO_4 \bullet 5H_2O$ and do not indicate whether the amount of algicide applied is based on total lake volume or is limited to the volume of the lake for the top two feet of the lake surface.

Currently, no specific guidelines exist in Illinois for the amount or frequency of chemical application to water supply impoundments. Effler et al. (1980) state: "Due to the complexity and system-specific dependence of copper chemistry, empirically derived loadings of $CuSO_4 \bullet 5H_2O$ have been adopted by regulatory agencies in the U.S. In New York State, the dosage limit is 0.3 mg/l $CuSO_4$ in the upper 2 m of the treated systems." This dosage rate limitation is equivalent to 5.3 pounds/acre of lake surface.

Ecological Impact

Repeated algicide applications to a single system can lead to a heavy accumulation of copper compounds in the sediments that might inhibit or adversely affect many benthic organisms. It has also been demonstrated that algae develop resistance to copper so that eventually the amount required for effective control can become prohibitive from an economic and ecological standpoint.

Also the mechanisms of copper loss < from the aquatic environment discussed earlier make it difficult at best to maintain the desirable concentration levels of dissolved copper needed for algicidal action. To maintain these levels, algicide applicators have simply increased frequency and dosages in order to "overpower" the effects of precipitation, complexation, and adsorption.

Hanson and Stefan (1984), reporting on the effects of 58 years of copper sulfate treatment of the Fairmont Lakes in Minnesota, state:

> The shallow Fairmont Lakes in southern Minnesota have been treated with copper sulfate for 58 years to reduce excessive algal growth. Copper sulfate was applied to five lakes at a cumulative rate of up to 1647 kg/ha (1470 lb/acre) totalling 1.5 million kilograms. Data collected since treatment of the Fairmont Lakes began in 1921 provide alarming insights into the lake response to sustained chemical treatment with copper sulfate. Short-term and long term effects have occurred. Short-term effects include: a) the intended temporary killing of algae, b) dissolved oxygen depletion by decomposition of dead algae, c) accelerated phosphorus recycling from the lake bed and recovery of the algal population within 7 to 21 days, and d) occasional fish kills due to oxygen depletion or copper toxicity or both. Long-term effects are shown to include: a) copper accumulation in the sediments, b) tolerance adjustments of certain species of algae to higher copper sulfate dosages, c) shift of species from green to blue-green algae and from game fish to rough fish, d) disappearance of macrophytes, and e) reductions in benthic macroinvertebrates. The conclusion is that while copper sulfate treatments enjoy great popularity because they kill and remove algae almost instantaneously, other immediate or cumulative side effects can be harmful to many other aquatic organisms.

Muchmore (1973) cites the work of Mackenthun and Cooley (1952), which indicates that in a group of Wisconsin lakes, copper concentrations in bottom muds of reservoirs that had been routinely treated with copper sulfate were considerably lower than the 9000 ppm (dry basis) they found necessary to affect bottom-dwelling organisms in their laboratory studies. In their study of many Wisconsin lakes, no difference in the diversity of benthal populations could be attributed to the presence of copper.

Several investigators (Elder and Home, 1978; Symmes, 1975; Effler et al., 1980; Whitaker et al., 1978; McKnight, 1981) observed that the application of copper sulfate to control target algae (particularly blue-green

algae) in lakes resulted in the significant reduction of the target species, but they also noted that post-treatment blooms of other species reached very high levels of biomass. Another significant impact reported by these investigators is a sharp reduction in dissolved oxygen levels in the water column within two days after the algicide application. This phenomenon is postulated as resulting from a decrease in the algal photosynthetic oxygen addition and from the oxygen demand exerted by the decaying algal cells. This phenomenon has also been observed in Illinois lakes (Kothandarman et al., 1980; Raman et al., 1986).

STUDY AREA

Lake Loami, located 12 miles southwest of Springfield, Illinois, serves as a water supply source to the village of Loami with a population of about 800 people. It is a side-channel impoundment. Water level in the impoundment is maintained by pumping water from a channel impoundment on Lick Creek, running approximately 0.25 mile to the south. Figure 2 is a location map showing the lake, Lick Creek, and the village.

The reservoir was originally constructed in 1957 as a levied storage basin to serve primarily as a water supply source. This original lake had a surface area of 4.5 acres and a capacity of 9.5 million gallons. In figure 3, which shows the bathymetric details of the lake, the original lake is designated as "East Basin." In 1976, a part of the levee on the west side of the original basin was breached by the burrowing of muskrats. The sudden water emergency caused by the draining of the village's water supply by the "muskrat ramble" drew national attention with a visit by an NBC crew on February 4, 1977. As an alternative to rebuilding the damaged levee, a new impounding dam was built in 1978, enclosing a small unnamed creek running adjacent to the reservoir. The new larger reservoir that was created was at a slightly higher spillway elevation than the former reservoir and was about 2.5 times as large in both area and volume. Morphometric details for the east and west basins and the total lake are given in table 1. The depth-area-volume relationships for the two basins and the whole lake, determined in a 1987 sedimentation survey, can be found in Bogner (1987).

From 1957 to 1978, the natural drainage to Lake Loami was limited to direct precipitation and the limited drainage from the levee banks. The watershed of the reservoir was extended by pumping to include all of Lick Creek above the pump intake. In 1978, when the dam was constructed across the valley of the unnamed creek adjoining the east basin, the total natural drainage area (figure 2) of the expanded lake became 53 acres, including the water surface area.

Details of the sedimentation survey, including rate of capacity loss and sediment depths in the lake, can be found in Bogner (1987). Sediment yield from the lake's watershed has been found to be 3.8 tons/acre.
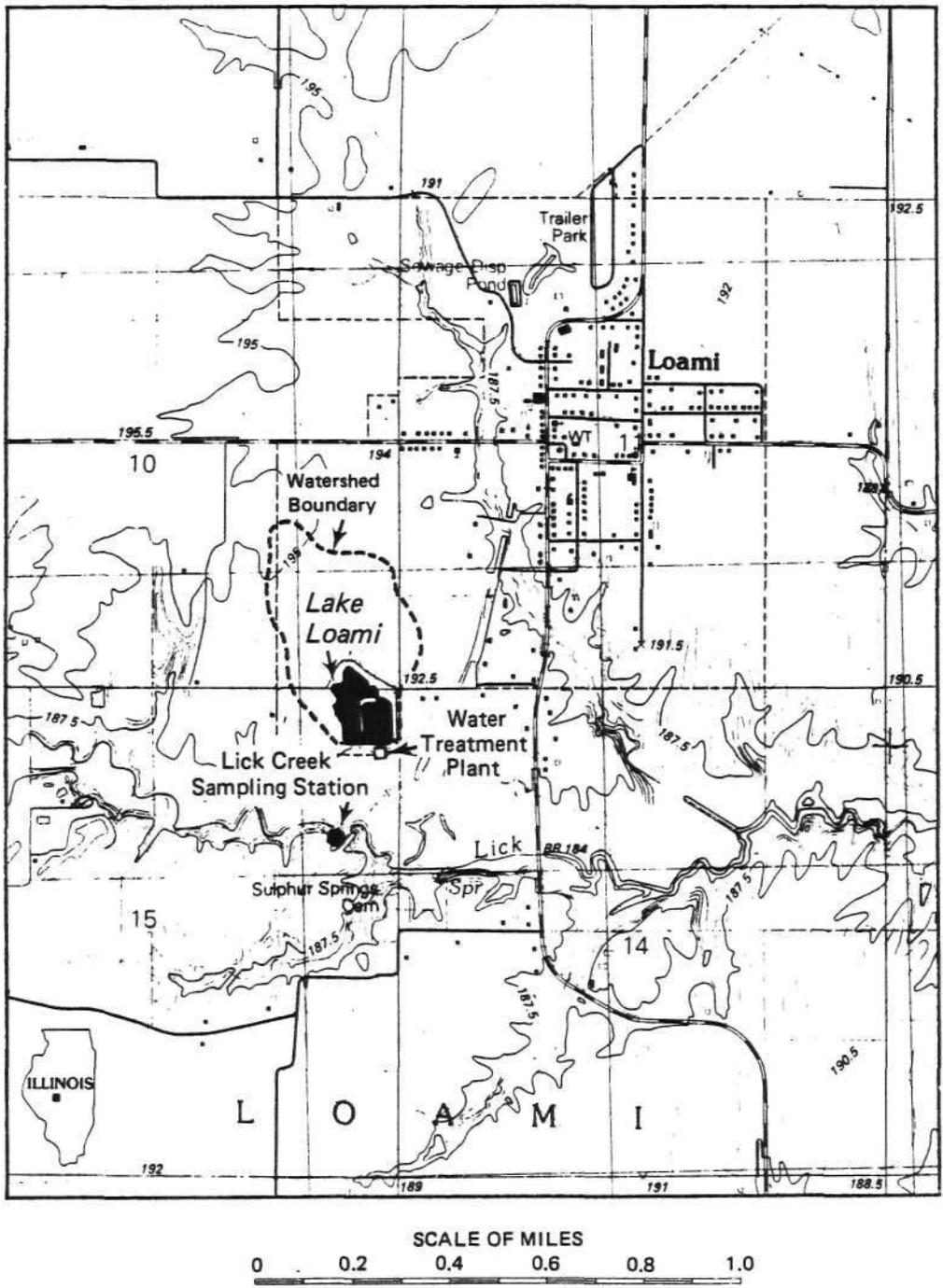
Figure 2. Location and watershed boundary of Lake Loami

Creek Inflow

LAKE LOAMI
Sangamon County

Water Depth below
Spillway Level
(feet)

▲ Monument
→ Range end
(no monument)

▲ NW

NS2

4

N

NS1

NE ▲

6

8

EW4

Dividing Levee

West Basin

4

Enclosures

8

East Basin

EW3

12

EW2

16

EW1

SW

SE

SCALE OF FEET
0   50   100

Spillway

Lake Sampling Station
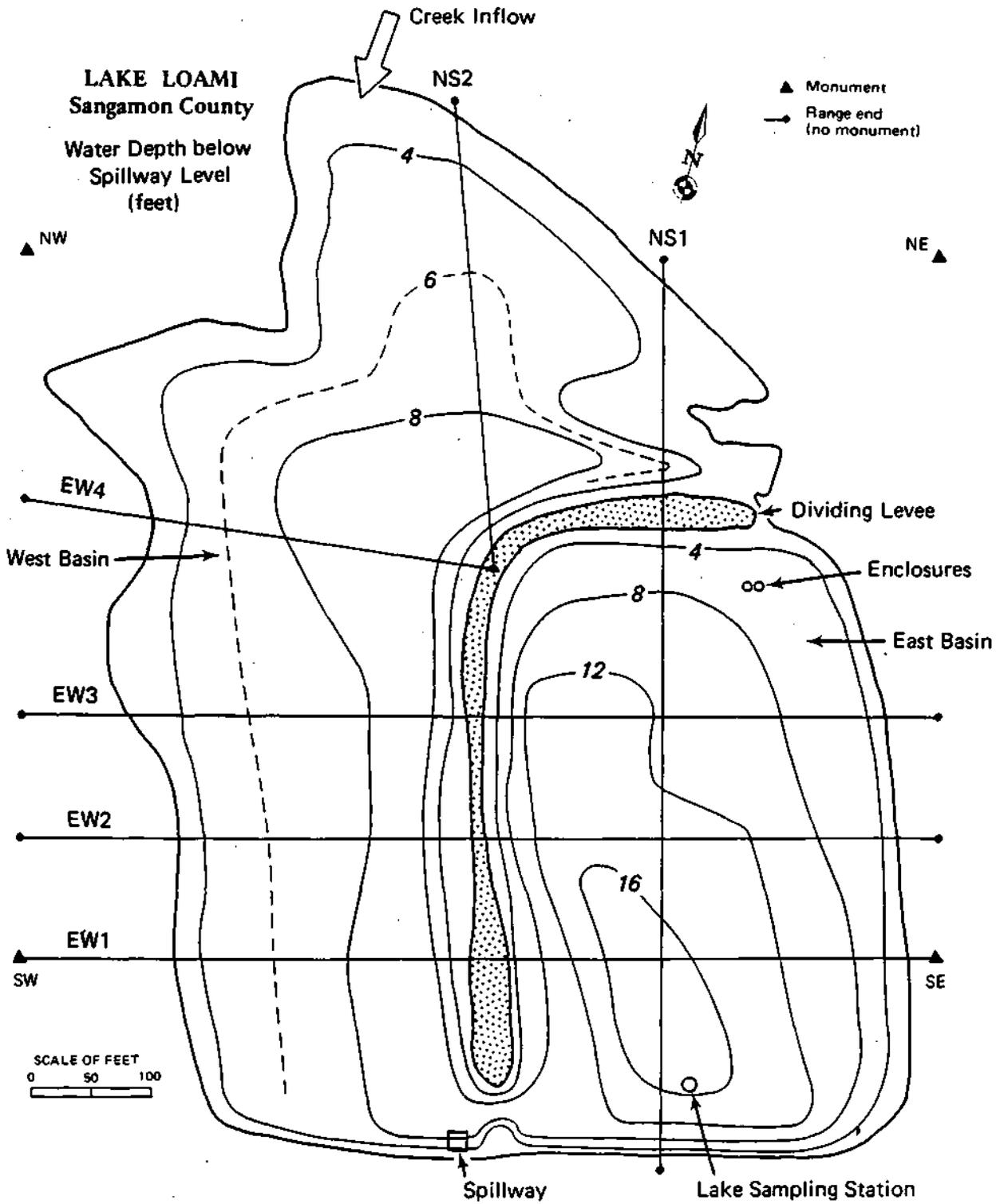
Figure 3. Bathymetric map of Lake Loami

Table 1. Morphometric Details, Lake Loami

	East Basin	West Basin	Whole Lake
Surface area, acres	3.93	6.15	10.08
Volume, acre-feet	37.6	33.5	71.1
Mean depth, feet	10.4	5.4	7.1
Maximum depth, feet	16.0	8.0	16.0
Total original capacity loss, percent	11.7	11.25	11.5
Annual capacity loss, percent	0.39	1.25	0.78
Watershed area, acres			53.0

Loami Water Supply System

The public water supply system for the "village of Loami was constructed in 1957-1958 and consists of a channel dam and pumping facilities on Lick Creek, a side-channel reservoir, a water treatment plant, an underground clear well, a hydropneumatic storage tank, and a water distribution system. The channel dam on Lick Creek impounds a drainage area of runoff from 29 square miles. Water is pumped into the side-channel reservoir by a 1,000 gallon-per-minute (gpm) low-lift centrifugal pump.

Treatment includes prechlorination, clarification in a "contraflo" solids contact upflow clarifier (General Filter Company, Ames, IA), filtration in a rapid rate gravity anthracite filter, and fluoridation. Treatment capacity is 100 gpm, and clear well storage is 23,000 gallons. Pumpage to the distribution network is through a master meter and an 18,850-gallon hydropneumatic storage tank to a 60,000 gallon elevated tank, using a 200 gpm high service pump. A flow diagram for the water treatment process is shown in figure 4.

The "contraflo" clarifier comprises a flash mixing zone, a flocculation zone, an upward sludge filtration zone, and a sludge concentrator. Alum and lime are used for coagulation and pH adjustments, respectively. Powdered activated carbon is used occasionally for taste and odor control. The filter media consist of anthracite coal, with effective size 0.6 to 0.8 mm and a uniformity coefficient not greater than 1.75. The filter media depth is 30 inches supported on 16 inches of graded gravel bed.

Raw water intake into the plant is through a 6-inch pivoted pipe (figure 5) that can be raised and lowered by a hoist mechanism on the pier. The pivoted portion of the intake pipe is perforated, and the lakeside end of the pipe is open for water withdrawal. During 1987, the average daily production of the treatment plant was 55,000 gallons.
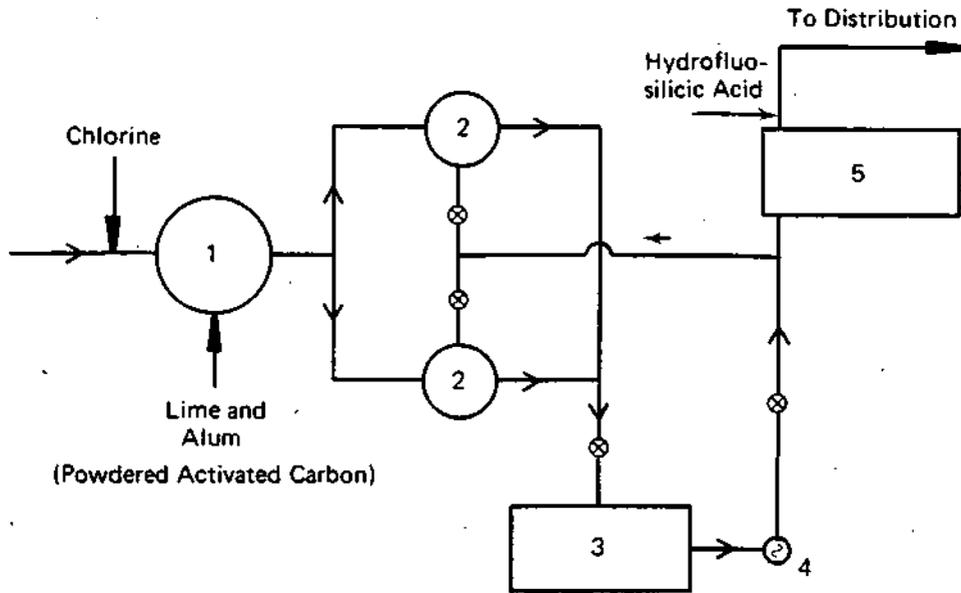
EXPLANATION

1. "Contraflo" solids contact upflow clarifier
   (General Filter Company)
2. Anthracite filters
3. Underground clear well
4. High head pump
5. Above ground steel hydropneumatic tank

Figure 4. Flow diagram for Loami water treatment plant

INTAKE STRUCTURE
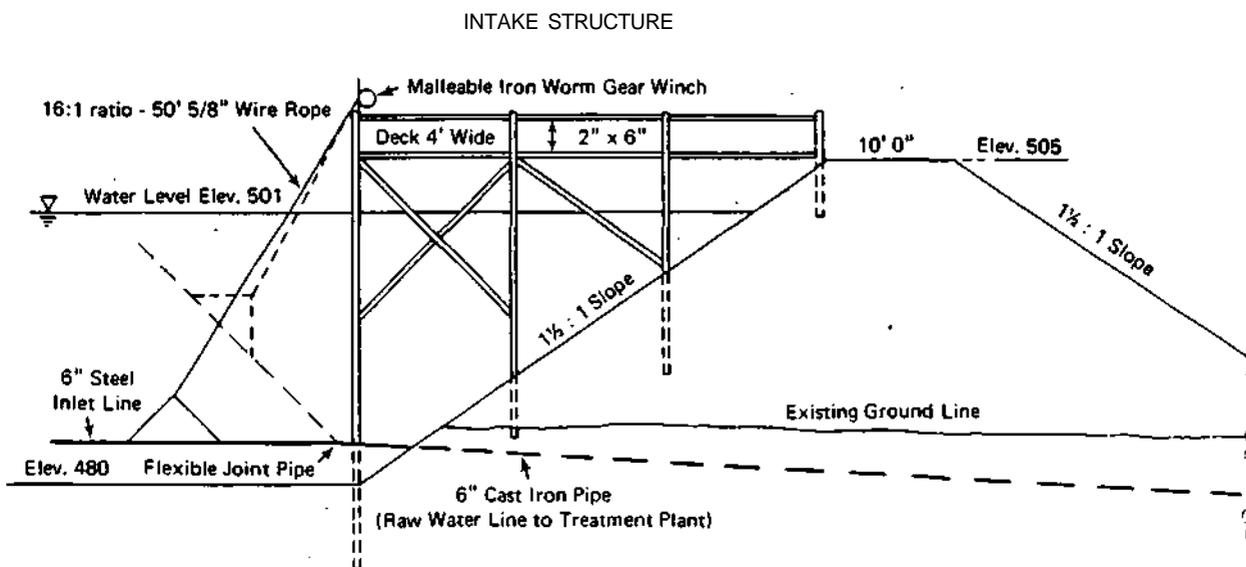
Figure 5. Intake facility for Loami water treatment plant

MATERIALS AND METHODS

General Lake Limnology

     To assess the current conditions of the lake and to evaluate the need for controlling algal blooms in the lake to prevent or minimize taste and odor problems in the finished potable water supply, certain physical, chemical, and biological characteristics of the lake were monitored during calendar year 1987. The lake was monitored once a month from January through April and again from October through December, and it was visited biweekly during the intervening summer months. During the year, a total of 18 visits were made for the routine monitoring of the lake. Water samples were also collected from Lick Creek at the channel dam site for chemical and biological characterization. The locations of the tributary and lake monitoring stations are shown in figures 2 and 3, respectively.

     In-situ observations for temperature, dissolved oxygen (DO), and secchi disc readings were made at the deepest part of the lake off of the dock shown in figures 5 and 6. 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. (1985). Temperature and dissolved oxygen measurements were obtained in the water column at 2-foot intervals commencing from the surface of the lake.

     For measuring secchi disc transparencies, an 8-inch-diameter secchi disc with black and white quadrant markings, which was 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 as the secchi disc reading.

     Water samples for chemical analyses and algal identification and enumeration were obtained from the lake with a Kemmerer sampler 1 foot below the surface, at mid-depth, and 1 foot from the bottom.

     Water samples for determinations of cyanide, metals, hardness, ammonia-N, Kjeldahl-N, total phosphate, and nitrate-N were collected in 1-liter round glass bottles. Samples for determinations of metals and hardness were preserved with 5 mL of concentrated reagent grade nitric acid, and the cyanide samples were preserved with 5 mL of 6N sodium hydroxide. Samples for analyses of phosphate and various forms of nitrogen were preserved with 5 mL of concentrated sulfuric acid. Samples for determining total dissolved solids, suspended solids, volatile suspended solids, dissolved phosphate, sulfate, chloride, and chlorophyll-a, were collected in plastic bottles, transported to the laboratory in an ice chest, and refrigerated until the analyses were performed.

     Determinations for pH and alkalinity were made at the lake site soon after sample collections. Chlorophyll-a analyses were made on the same day of the arrival of the samples in the laboratory. *Standard Methods* (APHA et al.,
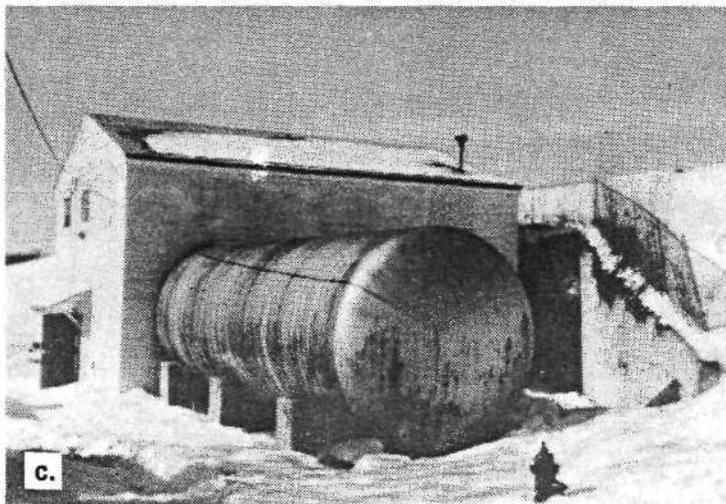
Figure 6. Views of a) the dock, b) sampling from the dock, and c) the exterior of the treatment plant

1985) procedures were used except where noted. The methods and procedures for the chemical analyses are given in table 2. Metal analyses for routine lake samples were limited to the determination of total copper, iron, and manganese.

Water samples in a volume of 380 mL were collected for algal identification and enumeration, preserved with 20 mL of formalin at the time of collection, and stored at room temperature until examined.

For algal identification and enumeration, the sample was thoroughly mixed and a 1-mL aliquot was pipetted into a Sedgwick Rafter Cell. A differential interference contrast microscope equipped with a 10X or 20X eyepiece, a 20X or 100X objective, and a Whipple disc was used for identifying and counting purposes. Five short strips were counted. The algae were identified as to species and were classified into five main groups: blue-greens , greens, diatoms, flagellates, and others. 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 connections. For flagellates, a colony of *Dinobryon* or a single cell of *Ceratium* was recorded as a unit.

Figure 6 shows . the dock from which lake water samples were collected. Note the steel rope over the lower deck which is used to raise or lower the intake pipe. Also shown in the figure is an external view of the treatment plant, which is located immediately on the south side of the dock and the embankment. The steel pressure storage tank which is a part of the distribution system can also be seen.

Algicide Applications and Enclosure Studies
_____

From 1979 to 1983, Lake Loami received excessive treatments of copper sulfate: four treatments during the summer months with 750 pounds of copper sulfate used for each application. After consultation with the State Water Survey, this was reduced to a four-time treatment schedule of 100 pounds of copper sulfate along with 50 pounds of citric acid for each treatment during the summers of 1984 to 1986.

One of the initial objectives of this study was to investigate the efficacy of different rates of copper sulfate application in the whole lake with and without the chelating agent citric acid in order to determine the optimal dosage for controlling the problem-causing blue-green algae. The plan was for limno-corral (enclosure) studies to be carried out concomitantly with whole-lake treatment and monitoring.

In recent years enclosures have frequently been used for documenting the responses of an isolated water column to experimental treatments (McQueen and Lean, 1983; McQueen and Story, 1986; Lewis, 1986; Solomon et al., 1986). Rigid enclosures made of plywood and flexible plastic columns suitable for in-situ bioassay work have been used in the past. One of the drawbacks of flexible plastic film for enclosures is that, although relatively inexpensive and easy to work with, it deteriorates rapidly under prolonged exposure to

Table 2. Analytical Procedures

pH	Glass electrode method with portable Metrohm Herisau meter (model E588).
Alkalinity-	Potentiometric method; titration with standard sulfuric acid solution to an end point of 4.5.
Conductivity	YSI model 33 conductivity meter.
Hardness	EDTA titrimetric method.
Chlorophyll-a*	Filtration through 0.45 μm filter, acetone extraction and colorimetric determination.
Cyanide	Distillation and determination by colorimetric method.
Total ammonia	Steam distillation, phenate method.
Dissolved nitrate	Chromotropic method after sample filtration through 0.45 μm filter paper.
Total phosphorus	Sample is digested with sulfuric-nitric acid mixture and determined by ascorbic acid method.
Total dissolved phosphorus	Sample is first filtered through a 0.45 μm filter paper, digested with sulfuric-nitric acid mixture, and determined by ascorbic acid method.
Total suspended solids	Dry weight of solids retained on gooch crucible with fiber glass filter.
Metals: Ag, Ba, etc.(total)	Flame atomic absorption.

* (Jones and Lee, 1982)

ultraviolet (UV) radiation.   Evidences of such breakdown have been reported to occur within 30 days' exposure (Landers, 1979).   Landers (ibid) discussed the advantages and construction details of a durable, reusable enclosure system that compensates for changing water levels.   Figure 7 shows details of this type of low-cost enclosure, which is made of UV-resistant, cross-laminated polyolefin sheeting reinforced with a grid of twisted polyester filaments with a depth-compensating capacity of about 1.5 feet to 6.5 feet.   Landers (1979) reported that field testing of six such enclosures for 126 days showed this type of enclosure to be convenient and durable.   The diameter of the two enclosures used in Lake Loami was 8 feet, and the enclosures were located in the northeast corner of the lake, where the depths of the water column fluctuate from 4 to 6 feet (figure 3).

During 1987, Lake Loami was first treated with copper sulfate pentahydrate to control algal blooms on June 17.   The copper sulfate pentahydrate was applied at the rate of 10.8 pounds/acre (109 pounds) along with 5.4 pounds/acre of citric acid (55 pounds) as a chelating agent.   The chemicals were applied to the lake by the bag-dragging method. Simultaneously, enclosure B was treated at the same rate as the main lake by adding the required amounts of the chemicals and mixing the contents with a boat paddle.   Enclosure A was untreated and served as a control.   On the third day after copper sulfate was applied, the lake and enclosure B were treated with potassium permanganate at the rate of 2 pounds per acre.

Observations for DO, temperature, and secchi disc readings at the lake and the enclosures were made prior to the chemical treatments.   Samples were also obtained for determining pH, alkalinity, conductivity, and chlorophyll-a;
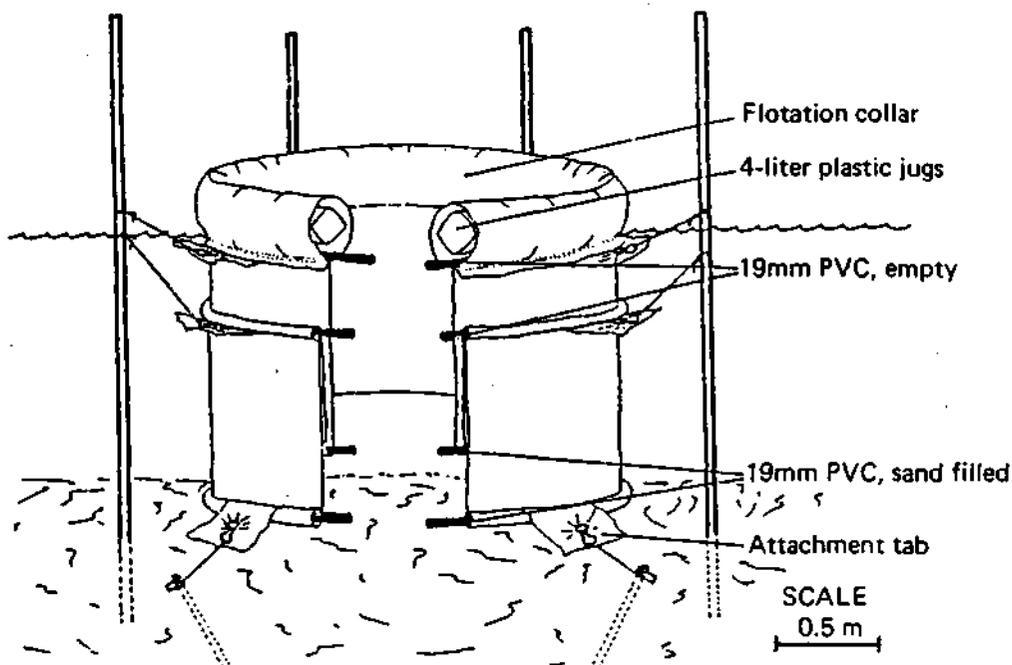
Figure 7. Schematic of the enclosure used in Lake Laomi
(After Landers, 1979)

for algal identification and enumeration; and for analyses of the metals silver, barium, calcium, cadmium, chromium, copper, iron, magnesium, manganese, nickel, lead, and zinc. The same protocol of sample collections and sample preservations as was described for routine monitoring was used for the intensive monitoring.

Surface, mid-depth, and deep samples were obtained at the deepest part of the lake. The deepest part of the lake happened to be at the end of the do.ck near the water intake (figures 3 and 5). The enclosures were monitored from a boat. Samples from the enclosures were obtained at the surface and near the bottom. A 1-gallon plastic jug attached to a 10-foot metal rod and weighted at the bottom was used to collect water samples from the centers of the enclosures. For the collection of near-bottom samples, the sample bottle was kept stoppered until the bottle was positioned near the center and a few inches above the bottom of the enclosures. The stopper was then pulled out with a string, allowing sample collection. The intensive monitoring of the lake and the enclosures was conducted 0, 1, 3, 5, 7, and 10 days after $CUSO_4$ application.

It was initially presumed that the lake would be treated for algal control at least four times as in the past. However, it became apparent that there was no need to treat the lake more than once. There were no filter clogging or taste and odor problems due to algal growths in the lake. This was somewhat surprising since the mean air temperatures for June, July, and August 1987 for this area were respectively 75.4, 78.8, and 75.3°F, which were higher than the long-term averages of 73.1, 76.5, and 74.2°F for the corresponding months. The warmer conditions were extremely conducive for algal blooms compared to conditions in years past.

The intensive monitoring initiated on June 17, 1987 and carried through June 27, 1987 was the only effort in which concomitant monitoring of the enclosures and the whole lake was conducted after an algicide application. On August 17, 1987, during the absence of the senior researcher on vacation, the treatment plant operator applied 100 pounds of copper sulfate to the lake, along with 25 pounds of citric acid. This was not followed by potassium permanganate treatment, and no enclosure study was carried out at this time. The lake did not receive any further chemical treatment during the remainder of the calendar year.

A second enclosure study with intensive monitoring was conducted on August 4-14, 1987, and a third was conducted on September 23 - October 3, 1987. The purpose of these studies was to delineate the efficacy of using different copper sulfate application rates along with different copper sulfate-chelant ratios. The details regarding the copper sulfate application rates for all the intensive monitoring studies are tabulated in table 3. Views of the enclosures in Lake Loami are shown in figure 8.

Table 3. Details of Chemical Treatment for the Intensive Monitoring Studies

Period	Whole Lake	Enclosure A	Enclosure B
6/17/87 to 6/27/87	Copper sulfate 10.8 lbs/acre	(Control)	Copper sulfate 10.8 lbs/acre
	Citric acid 5.4 lbs/acre		Citric acid 5.4 lbs/acre
8/4/87 to 8/14/87	-	Copper sulfate 5.4 lbs/acre	Copper sulfate 5.4 lbs/acre
		No citric acid	Citric acid 2.7 lbs/acre
9/23/87 to 10/3/87	-	Copper sulfate 10.8 lbs/acre	Copper sulfate 5.4 lbs/acre
		No citric acid	Citric acid 16.2 lbs/acre
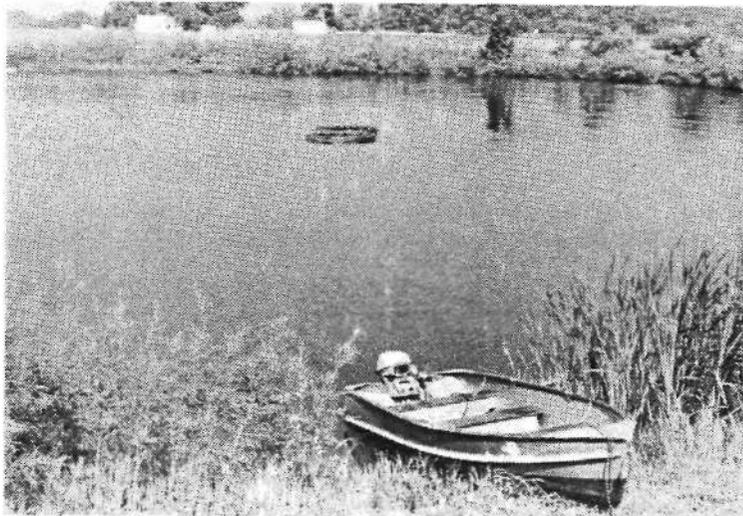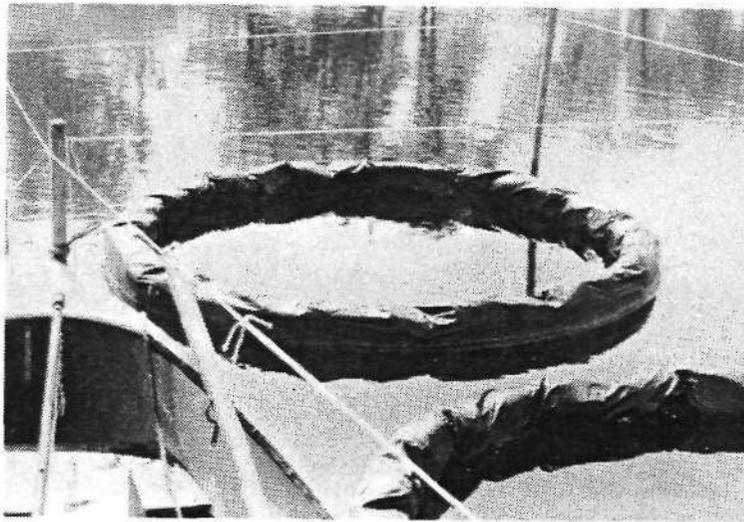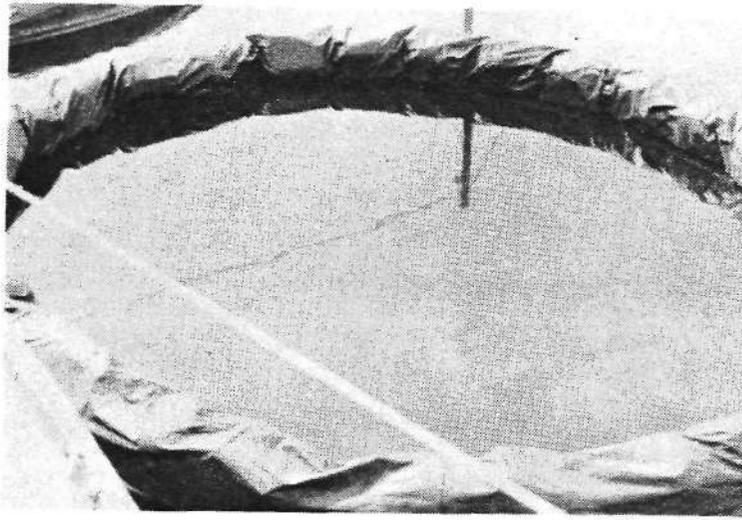
Figure 8. Views of the enclosures in the lake

Water Quality Characteristics

Physical Characteristics

Temperature and Dissolved Oxygen. Lakes in the temperate zone generally undergo seasonal variations in temperature through the water column. These variations, with their accompanying phenomena, are perhaps the most influential controlling factors within the lakes.

The temperature of a deep lake in the temperate zone is about 4°C during early spring. As the air temperature rises, the upper layers of water warm up and mix with the lower layers by wind action. By late spring, the differences in thermal resistance cause the mixing to cease, and the lake approaches the thermal stratification of the summer season. Closely following the temperature variation in water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. These two interrelated forces are capable of creating strata of water of vastly differing characteristics within the lake.

During thermal stratification the upper layer (the epilimnion) is isolated from the lower layer of water (the hypolimnion) by a temperature gradient (the thermocline). Temperatures in the epilimnion and hypolimnion are essentially uniform. The thermocline will typically have a sharp temperature drop per unit depth from the upper to the lower margin. When the thermal stratification is established, the lake enters the summer stagnation period, so-named because the hypolimnion becomes stagnated.

With lower air temperatures during the fall season, the temperature of the epilimnion decreases. This decrease in temperature continues until the epilimnion is the same temperature as the upper margin of the thermocline. Successive cooling through the thermocline to the hypolimnion results in a uniform temperature through the water column. The lake then enters the fall circulation period (fall turnover) and is again subjected to a complete mixing by the wind.

Declining air temperature and the formation of an ice cover during the winter produce a slight inverse thermal stratification. The water column is essentially uniform in temperature at about 3 to 4°C, but slightly colder temperatures of 0 to 2°C prevail just below the ice. With the advent of spring and gradually rising air temperatures, the ice begins to disappear, and the temperature of the surface water rises. The lake again becomes uniform in temperature, and the spring circulation occurs.

The most important phase of the thermal regime from the standpoint of eutrophication is the summer stagnation period. The hypolimnion, by virtue of its stagnation, traps sediment materials such as decaying plant and animal matter, thus decreasing the availability of nutrients during the critical growing season. In a eutrophic lake, the hypolimnion becomes anaerobic or devoid of oxygen because of the increased content of highly oxidizable material and because of its isolation from the atmosphere. In the absence of

oxygen, the conditions for chemical reduction become favorable and more nutrients are released from the bottom sediments to the overlying waters.

However, during the fall circulation period, the lake water becomes mixed, and the nutrient-rich hypolimnetic waters are redistributed. The nutrients which remained trapped during the stagnation period become available during the following growing season. Therefore, a continual supply of plant nutrients from the drainage basin is not mandatory for sustained plant production. Fruh (1967) and Fillos and Swanson (1975) state that after an initial stimulus, the recycling of nutrients within a lake might be sufficient to sustain highly productive conditions for several years.

Isothermal plots for Lake Loami near the water intake are shown in figure 9. The vertical temperature profiles for the deep station on selected dates are shown in figure 10. From figure 9 it is seen that the summer stratification begins to set in during the middle of May and intensifies progressively during the summer months. The maximum water temperature of 31.1°C was observed on July 28. The lake experienced the maximum temperature differential of 9.4°C between the surface and bottom waters on the same date. Thereafter, the intensity of stratification began to decrease. The lake was found to be uniform in temperature after the fall turnover on September 23, 1987. The vertical temperature profiles shown in figure 10 clearly show the temperature gradients which persist in the lower strata of the lake during summer months. Because the lake is relatively shallow, it does not exhibit the three classic zones of stratification.

It is common knowledge that the impoundment of water alters its physical, chemical, and biological characteristics. The literature is replete with detailed reports on the effects of impoundments on various water quality
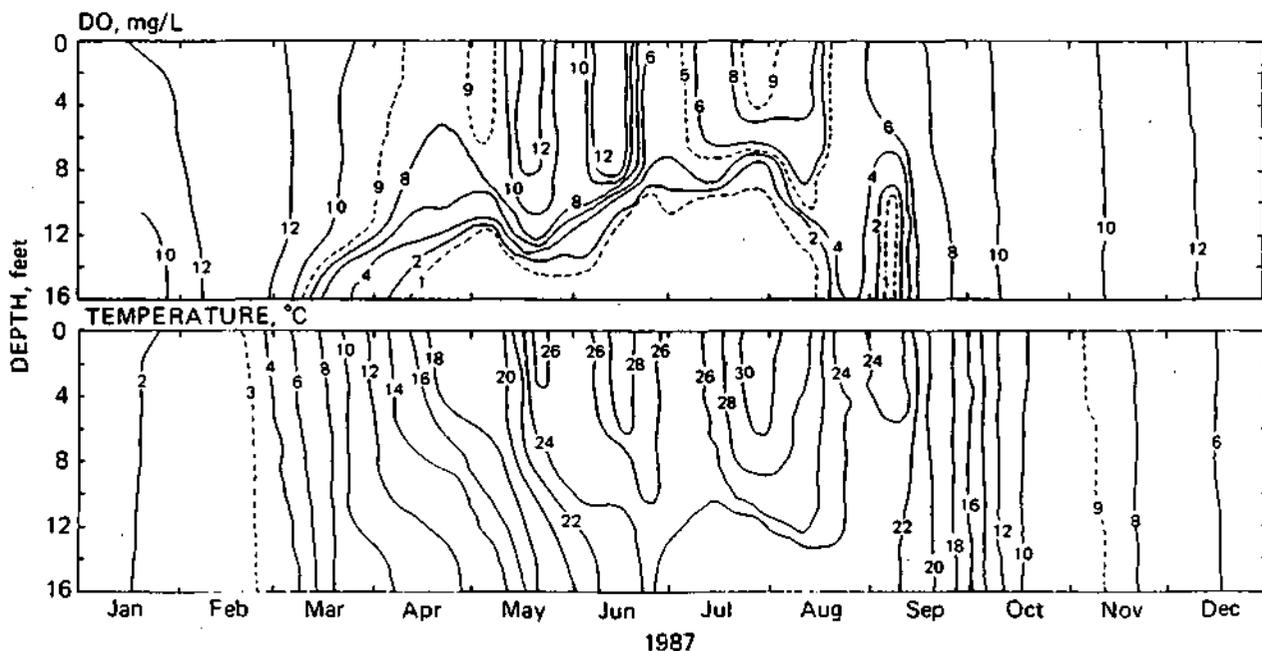
Figure 9. Isothermal and isodissolved oxygen plots for Lake Loami
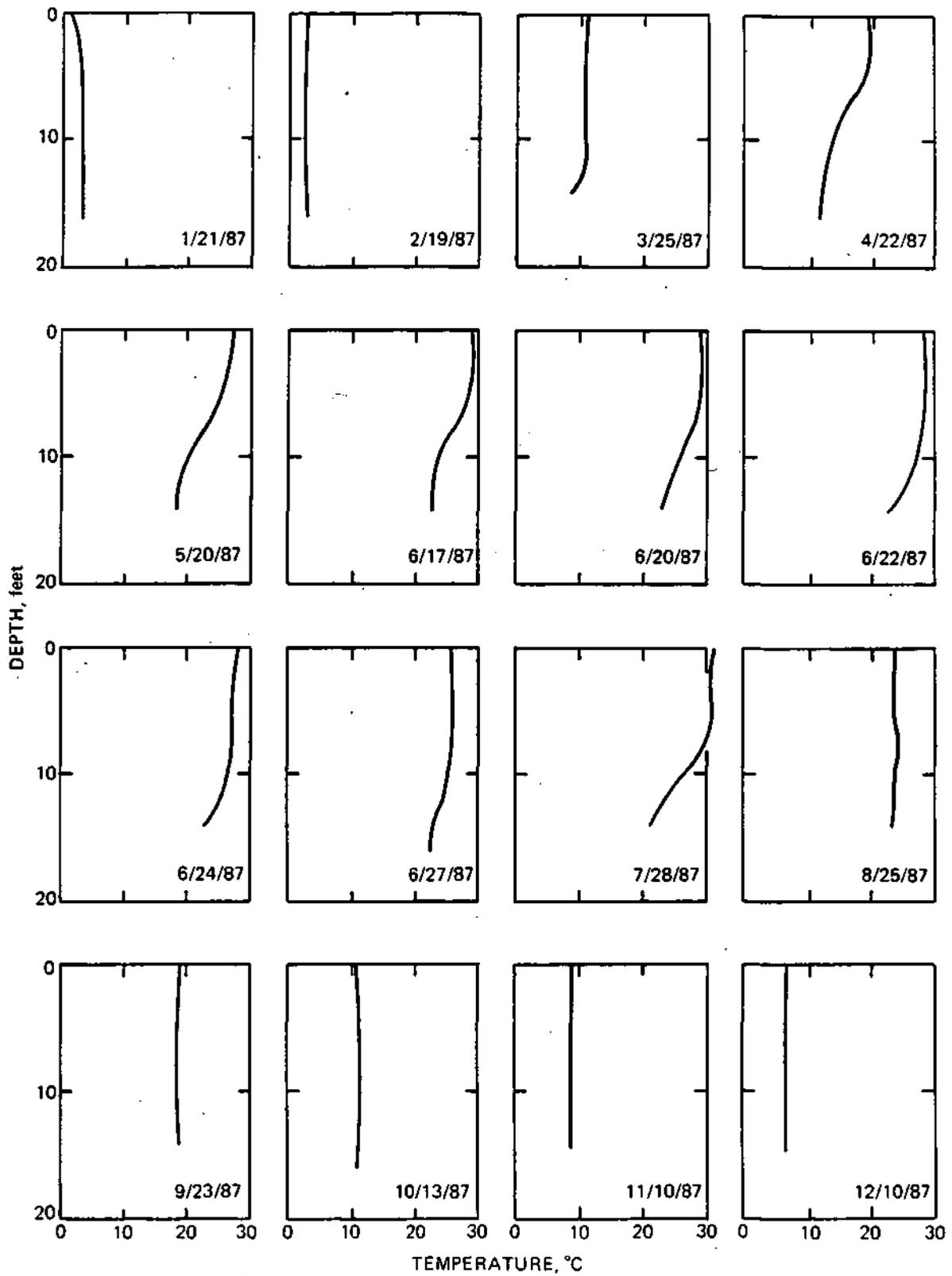
Figure 10. Temperature profiles on selected dates

parameters. The physical changes in the configuration of the water mass following impoundment reduce reaeration rates to a small fraction of those of free-flowing streams. Where the depth of impoundment is considerable, the thermal stratification acts as an effective barrier to wind-induced mixing of the hypolimnetic zone. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanism.

During the period of summer stagnation and increasing water temperatures, the bacterial decomposition of the bottom organic sediments exerts a high rate of oxygen demand on the overlying waters. When this rate of oxygen demand exceeds the oxygen replenishment by molecular diffusion, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom. Hypolimnetic zones of man-made impoundments have been found to be anaerobic within a year of their formation (Kothandaraman and Evans, 1975).

The isopleths of dissolved oxygen (DO) for Lake Loami are shown in figure 9. Selected vertical DO profiles for the deep station are shown in figure 11. Dissolved oxygen depletion began to occur during late April. As the summer thermal stagnation intensified, the anoxic zone of hypolimnetic waters increased progressively, reaching a maximum during mid-July. The extent of this anaerobic zone started diminishing thereafter, and the DO concentration became uniform in the water column in late August. As is apparent from figure 9, the progression of this anoxic zone coincided with the progression of the thermal stratification in the lake.

During the period of peak stratification, July 28, 1987, the lake was totally anoxic at depths 8 feet from the surface and below. About 10.9 acre-feet, or approximately 29% of the water column in the part of the lake (east basin) containing the water intake structure, was anoxic, severely impairing the quality of raw water for the water treatment plant. During summer months, adequate oxygen levels did not generally exist at depths below 10 feet from the surface. The depth-area-volume relationships for Lake Loami and for the two basins (east basin and west basin) can be found elsewhere (Bogner, 1987).

As indicated earlier, the lake was treated with algicide on June 17, 1987 to control algal blooms in the lake. Prior to the chemical treatment, the oxygen concentrations in the water column up to 8 feet from the surface were at supersaturated levels, with a mean value of 13.5 mg/L (figure 11). However, these mean values were 11.2, 6.6, 3.8, and 3.2 mg/L on days 1, 3, 5, and 7 after chemical treatment. This was in spite of the application of potassium permanganate on day 3 to oxidize the decaying algal cells to minimize undue demand on the dissolved oxygen resources. The oxygen values recovered to adequate levels on the 10th day (June 27, 1987). Some of the fish kills reported in the literature as occurring after copper sulfate treatment in lakes may have been due to severe oxygen depletions in addition to possible acute toxicity.

The dissolved oxygen and temperature data collected for the lake during this investigation are included in Appendix A. Table 4 shows the percent saturation values for the lake near the water intake. It should be noted that there was an algal bloom developing in the lake from late May, which probably reached a peak on June 17, 1987 when the DO concentration at the surface was 166% saturation. The saturation levels at the surface decreased steadily to a
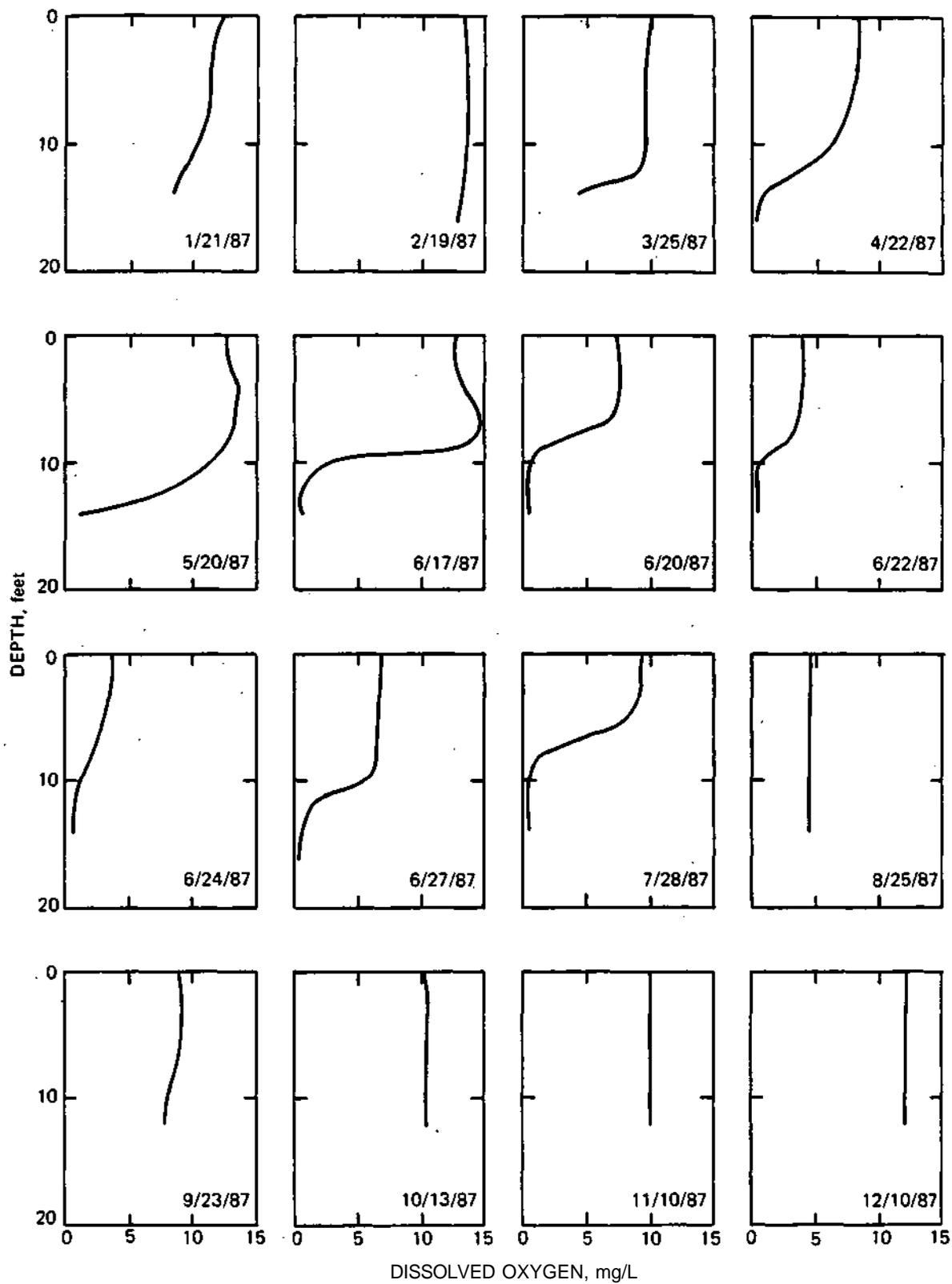
Figure 11. Dissolved oxygen profiles on selected dates

Table 4.   Percent Dissolved Oxygen Saturation near Lake Loami Water Intake

Depth (feet)	1/21/87	2/19/87	3/25/87	4/22/87	5/6/87	5/20/87	6/3/87	6/17/87*	6/18/87	6/20/87	6/22/87	6/24/87
0	88	99	90	93	100	160	110	166	157	97	52	49
2	86	98	89	92	102	158	109	169	156	97	52	46
4	84	97	89	92	100	170	109	177	150	97	51	44
6	83	97	89	74	100	162	109	189	151	95	51	37
8	82	97	88	70	92	156	108	175	123	44	44	28
10	79	97	88	64	49	129	107	28	18	6	6	14
12	72	96	87	38	6	99	60	4	4	5	5	5
14	66	97	38	7	2	16	20	4	3	5	5	5
16		93		4	2							

Depth (feet)	6/27/87	7/1/87	7/14/87	7/28/87	8/11/87	8/25/87	9/8/87	9/23/87	10/13/87	11/10/87	12/10/87
0	82	56	84	128	112	56	93	97	94	86	98
2	82	55	84	125	112	56	93	96	93	86	98
4	81	55	84	124	111	56	93	96	93	85	98
6	81	55	82	90	109	56	71	96	92	86	97
8	81	45	53	24	97	56	28	93	92	85	97
10	80	18	10	6	68	51	8	86	93	85	97
12	16	5	6	6	17	51	5	85	93	86	96
14	6	5	6	6	5				93		
16	5	5									

* Copper sulfate was applied on 6/17/87 after DO temperature observations were made.
   Potassium permanganate was applied on 6/20/87.

value of 49% on June 25, 1987. before recovering to about 82% on June 27, 1987. Strictly from an oxygen resources viewpoint, there seems to be a need for caution in applying algicides to impoundments.

Secchi Disc Transparencies. Secchi disc visibility is a measure of the lake water transparency or its ability to allow light transmission. Even though the secchi disc transparency is not an actual quantitative indication of light transmission, it serves as an index and a means of comparing similar bodies of water or the same body of water at different times. Since changes in water color and turbidity in a deep lake are generally caused by aquatic flora and fauna, transparency is often related to these entities.

The mean and range of values observed for secchi disc readings near the water intake are given in table 5 along with summaries of observations for other physical and chemical water quality parameters for the lake and Lick Creek. The temporal variations in secchi disc observations are shown in figure 12. The mean secchi disc reading was 47 inches. A maximum value of 86 inches was observed in early June prior to the onset of algal bloom in mid-June. The minimum value of 25 inches occurred during March monitoring. Application of algicide to control the algal bloom in June did not generally improve the clarity of the lake. The secchi disc reading was 65 inches on June 17, 1987 when the algicide was applied. It increased to 86 inches on day 1 and then steadily decreased to 27 inches on June 27, 1987, when the intensive monitoring of the lake was terminated.

Chemical Characteristics

In Lake Loami, even though there was no well-defined thermocline during summer stratification, there were two distinct zones of vastly differing water quality characteristics. Table 5 shows the mean and range of values of various chemical parameters observed for near-surface, mid-depth, and near-bottom waters of Lake Loami and also for Lick Creek. Values for cyanide were not included in this table because it was never detected in any of the lake samples. These waters are typical of northern and central Illinois surface waters: high in alkalinity and hardness. The temporal variations in the chemical parameters for near-surface, mid-depth, and near-bottom waters and Lick Creek are shown respectively in figures 12, 13, 14, and 15.

The mean, maximum, and minimum values of chemical characteristics of the lake's surface and mid-depth waters are very nearly the same. However, the values for the near-bottom waters are distinctly different. The mean values for alkalinity, hardness, conductivity, phosphate-phosphorus, ammonia-nitrogen, iron and manganese were significantly higher for the near-bottom waters than for the surface or mid-depth waters. In most of the cases, the maximum and minimum values of these chemical parameters for near-bottom waters were higher than those for the surface or mid-depth waters.

Temporal variations in pH, alkalinity, and conductivity of the surface waters follow the typical pattern of high photosynthesis during summer months: pH values remaining above 8.0 and reaching a maximum value of 9.98 during the summer months (June to August), with concomitant decreases in alkalinity and conductivity (figure 12). Phosphorus, ammonia-nitrogen, and manganese

Table 5. Lake Loami and Lick Creek Water Quality Characteristics

Parameter	Near Surface		Mid-Depth		Near Bottom		Lick Creek	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Secchi disc, inches	47	86-25						
Chlorophyll-a, μg/l	12.0	36.7-1.6	12.9	34.3-2.6	24.5	135.0-3.6	7.2	32.5-1.7
pH (units)		7.81-9.98		7.60-10.00		7.25-9.22		7.69-8.29
Alkalinity (as CaCO$_3$)	134	182-100	135	184-106	152	202-118	261	317-136
Hardness	163	216-126	164	218-129	184	249-139	329	365-261
Conductivity (umho/cm)	344	461-276	340	439-279	368	485-296	617	684-505
Suspended solids	11	21-4	11	19-4	23	81-7	38	86-6
Total phosphate-P	0.06	0.13-0.02.	0.07	0.15-0.02	0.19	0.8-0.05	0.23	1.06-0.04
Dissolved phosphate-P	0.02	0.06-0.01	0.02	0.06-0.01	0.08	0.7-0.01	0.13	0.81-0.02
Total ammonia-N	0.10	0.25-0.0	0.12	0.42-0.01	0.63	4.32-0.03	0.16	0.53-0.03
Nitrate-N	0.73	5.12-0.00	0.53	2.41-0.00	0.74	4.13-0.02	6.5	11.6-0.14
Total copper	0.03	0.07-0.01	0.03	0.05-0.01	0.05	0.20-0.00	0.01	0.02-0.00
Total iron	0.29	0.57-0.09	0.30	0.74-0.08	1.35	5.64-0.16	1.54	4.07-0.22
Total manganese	0.08	0.40-0.01	0.09	0.41-0.01	0.45	1.53-0.04	0.13	0.26-0.04

Note: Values in mg/L unless otherwise indicated.
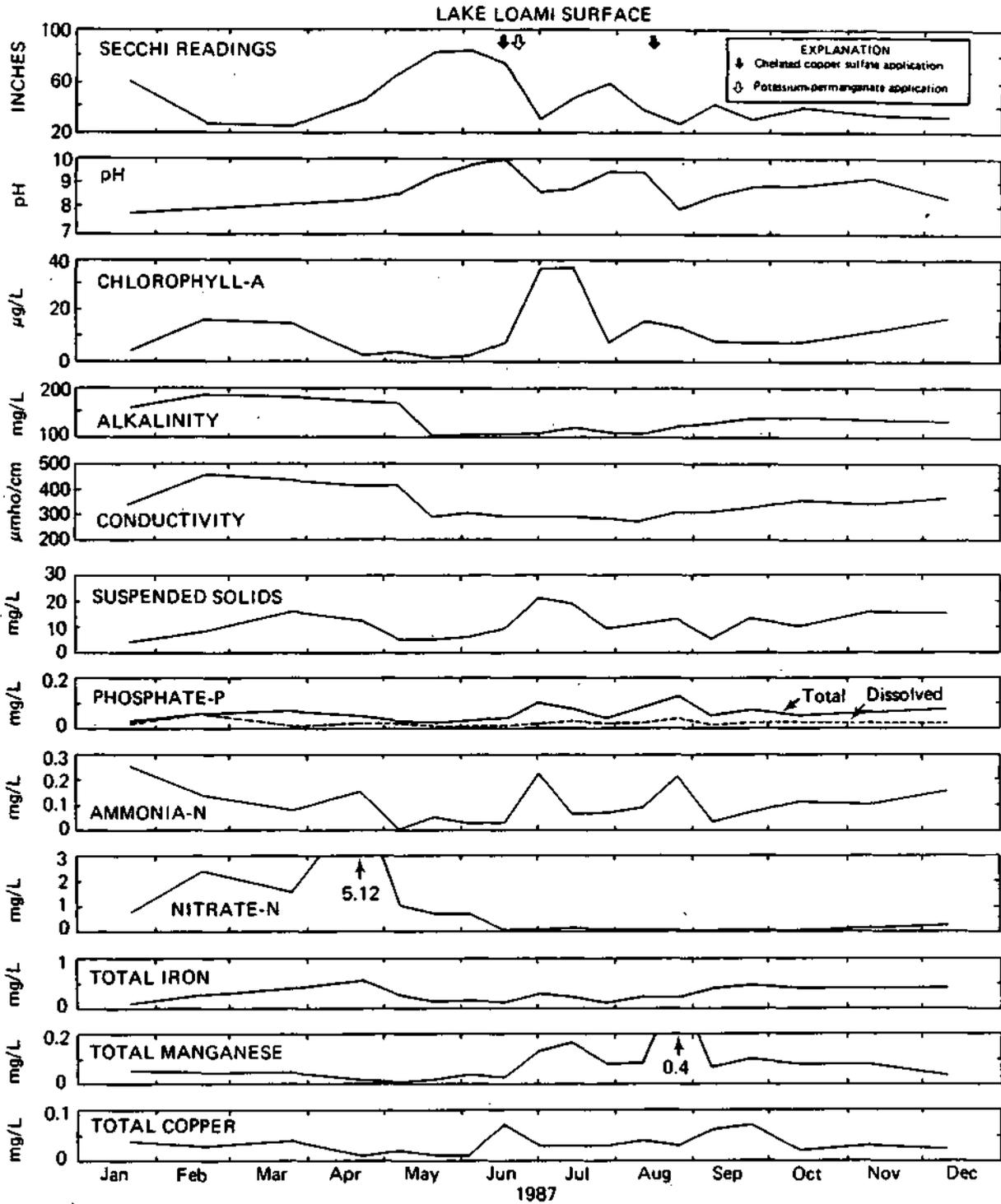
Figure 12. Temporal variations in surface water quality characteristics
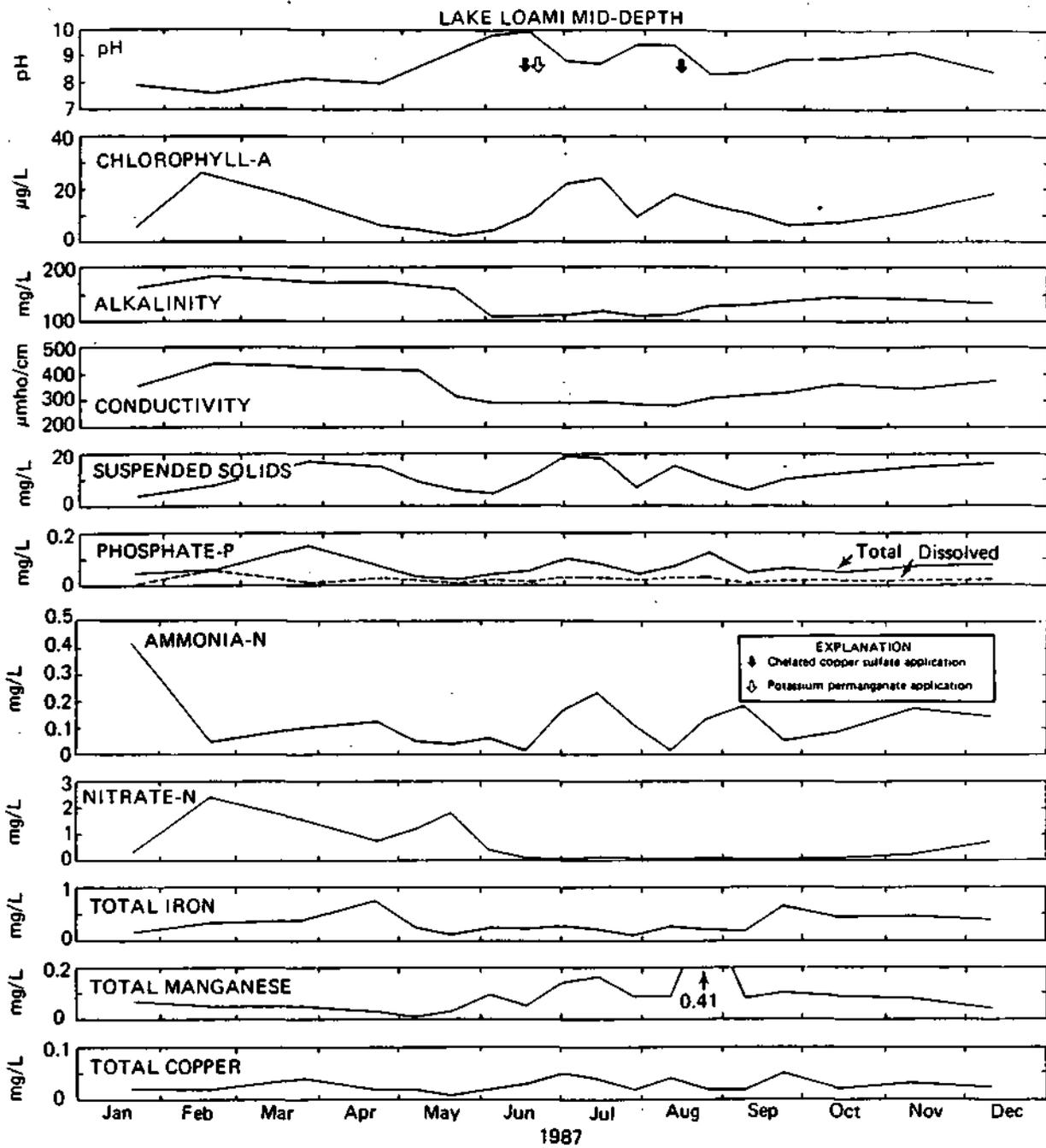
Figure 13. Temporal variations in mid-depth water quality characteristics
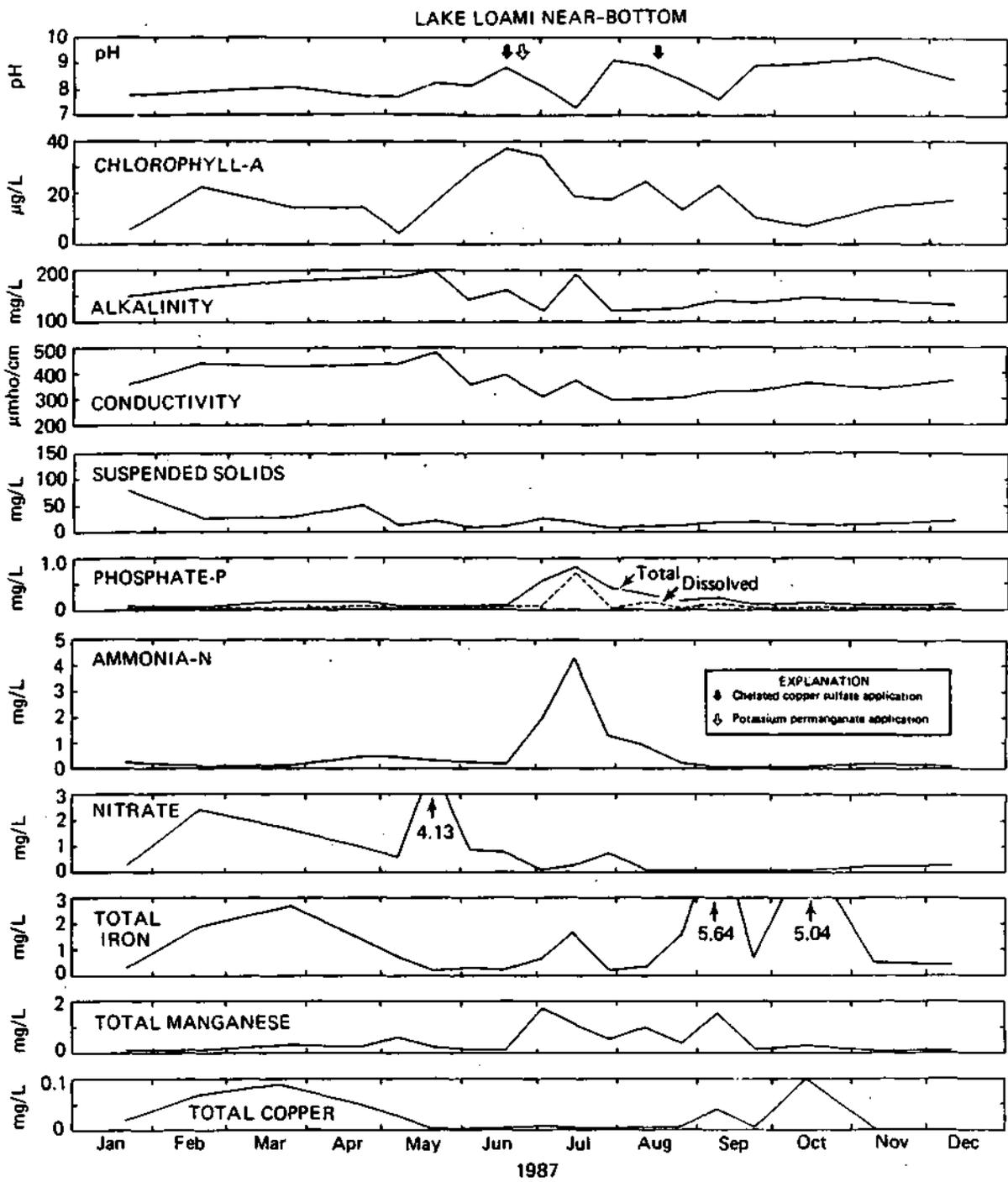
Figure 14. Temporal variations in near-bottom water quality characteristics

33
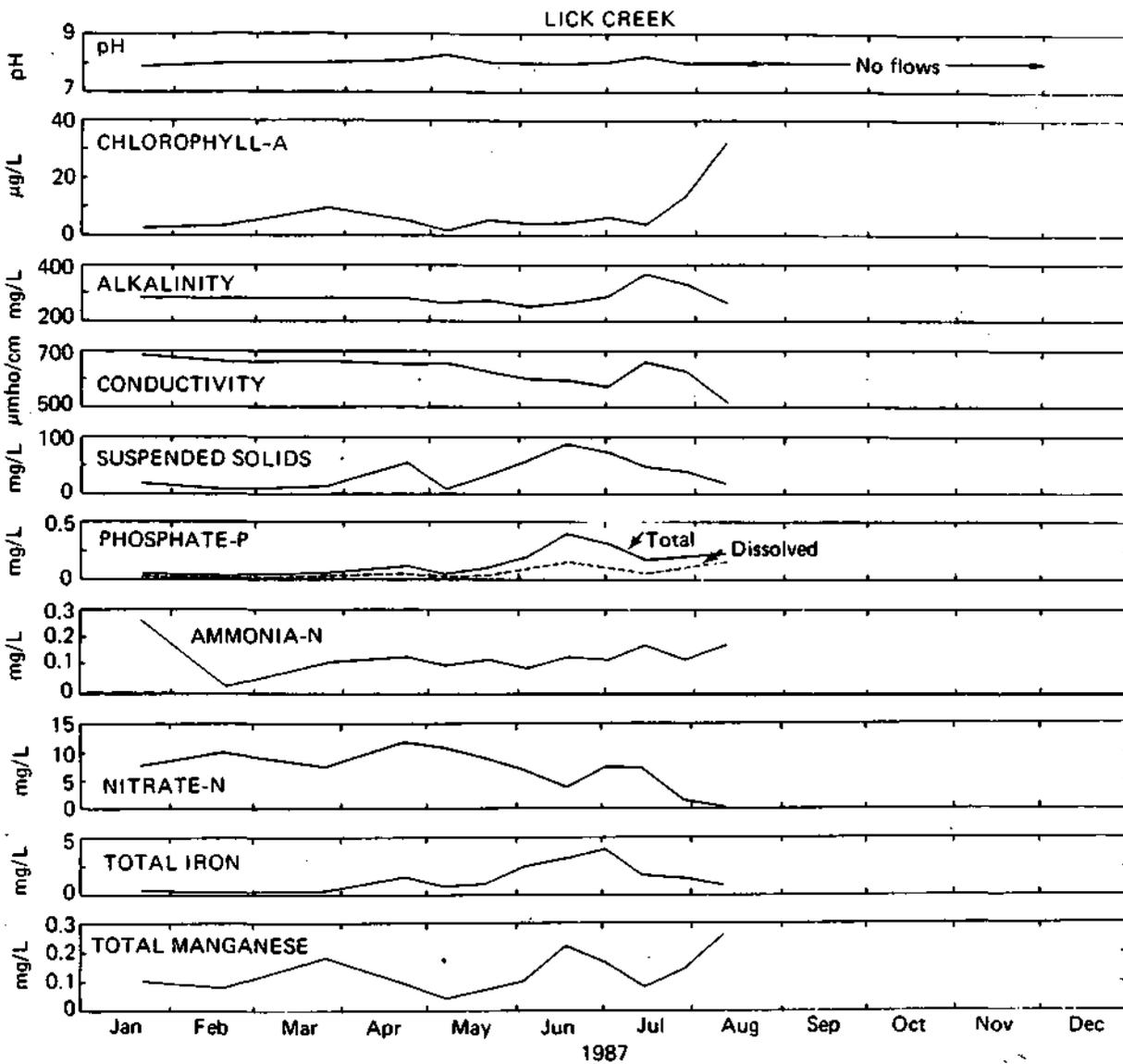
LICK CREEK

*Figure 15. Temporal variations in water quality characteristics
of Lick Creek at Loami*

34

concentrations were much higher in the bottom waters during summer months (figure 14) because of the mineralization of organic matter in the bottom sediments under anaerobic conditions. Iron concentrations in the bottom waters showed elevated values in September and October. The higher mean concentration of copper in the bottom waters than in the surface waters is probably due to the past copper sulfate application practices and the consequent accumulation of copper in the sediments. The very high value of chlorophyll-a in Lick Creek during August (figure 15) is due to the ponding behind the channel dam resulting from a lack of adequate flow in the creek.

The mean total phosphorus concentration observed in Lake Loami for the months of November to March was 80 µg/L (0.08 mg/L), which is nearly three times the upper limit value for eutrophic lakes suggested by the USEPA (1980), shown in table 6. The mean summer secchi disc transparency in the lake was 4.1 feet or 1.25 meters. This is less than the lower limit suggested in table 6. The average summer chlorophyll-a concentration in the lake was found to be 17.7 µg/L. which again was higher than the value indicated for eutrophic lakes. On the basis of the aforementioned three water quality parameters, Lake Loami was determined to be eutrophic. As with many central and northern Illinois lakes, internal recycling of phosphorus from lake bottom sediments during summer months under anoxic conditions is one of the major sources of nutrient input to the lake, and this internal recycling of phosphorus is probably adequate to sustain algal blooms. The data on the lake chemical characteristics are included in Appendix B.

Unfortunately no records were maintained in the past at the water treatment plant regarding the nature and frequency of consumer complaints about taste and odor in the finished water. During calendar year 1987, when the authors maintained close contact with the water treatment plant operator and the village board water commissioners, there were no cases of taste and odor complaints. Taste and odor problems in the treated water were avoided during 1987 by manipulating the water intake so that most of the withdrawal occurred at depths 3 to 4 feet below the water surface, where adequate oxygen was present in the raw water. In their investigations for delineating the relationships between odor and water quality characteristics in water supplies using impoundments as their raw water supply sources, Lin and Evans (1981) found a high degree of correlation between the threshold odor numbers and the concentrations of iron, manganese, and ammonia in the raw water sources. They also found that most of the odor complaints occurred during summer months when the lakes thermally stratify. Also, Raman (1985) reported that improving the

Table 6. Quantitative Definition of Lake Trophic State
(USEPA, 1980)

Characteristics	Oligotrophy	Eutrophv
Total phosphorus (winter), µg/l	10-15	20-30
Chlorophyll-a (summer), µg/l	2-4	6-10
Secchi disc depth (summer), meters	3-5	1.5-2

oxygen conditions in the hypolimnetic zone of Lake Eureka by mechanical destratification caused significant reductions in iron, manganese, and ammonia concentrations during summer months. These reductions in turn improved the raw water quality characteristics in Lake Eureka, resulting in the source control of taste and odor problems. Consequently, every effort was taken at Lake Loami to withdraw well-oxygenated lake water by manipulating the intake structure. This strategy appeared to work well, as seen by the lack of taste and odor complaints and the fact that copper sulfate usage in the lake was drastically reduced during 1987.

Biological Characteristics

The total algal counts and the species distribution of algae found at the surface, mid-depth, and near-bottom waters of Lake Loami are shown in tables 7, 8, and 9 respectively. The data for Lick Creek are given in table 10. It is obvious from these tables that blue-green algae, the algae that cause the most problems in water supply and recreational impoundments and lakes, are not a factor in Lake Loami. During 1987, these algae were found only one or two times at each of the three depths monitored in the lake, and they were of insignificant numbers.

Green algae were the dominant algae in terms of both total numbers and number of occurrences during this investigation. *Oocystis borgei* was the alga most often observed in the surface waters (14 times) followed by *Chlorella ellipsoidea* (10 times). The highest observed algal count in the lake was 338,400/mL on June 27, 1987, and these algae essentially consisted of *Chlorella ellipsoidea.* The maximum number of algal species found in the surface water samples was 9 on August 25, 1987. A total of 32 algal species were identified in the surface water samples. Similar trends were observed in the mid-depth and deep water samples. It must be pointed out that the algal blooms which occurred during the summer months did not cause either filter clogging or taste and odor problems in the water treatment plant operation.

At the time of copper sulfate application to the lake on June 17, 1987, the total algal count at the surface of the lake was 3,100/mL (table 7), consisting of the green algae *Chrysocapsa planctonica* and *Oocystis borgei*. The algal density was of bloom proportion and was significantly higher than the observed values in the immediate past. The intensive monitoring of the lake immediately following the copper sulfate application (June 17 to June 27, 1987) brings home the futility of trying to control (kill?) algae indiscriminately in the lake. Soon after the algicide application, these two algae decreased in number and were never dominant again after June 22, 1987. However, within 7 days *Chlorella ellipsoidea* took over as the dominant species, reaching an extremely high density of 338,000 counts/mL on June 27, 1987. Within four days of this episode, on July 1, 1987, the algal population returned to a more balanced composition and near-normal levels. It is once again re-emphasized that the extraordinarily high algal count in the lake on June 27, 1987 did not cause any treatment plant operation problems.

As indicated earlier, the lake received a second algicide treatment on August 17, 1987. No initial data were collected prior to the lake treatment, nor was the lake intensively monitored following the treatment as was done

Table 7. Algal Types and Densities at the Surface of Lake Loami

Algal Species	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	6/18	6/20	6/22	6/24	6/27	7/1	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10	Number of times found
BG: *Anabaena spiroides*																				42				1
Aphanizomenon flos-aquae																		95						1
G: *Ankistrodesmus sp.*	97																							1
Chlorella ellipsoidea												138.000	338,000	740	233	155		229,500		2110	260	53	57	10
Chrysocapsa plancconlca							42	1200	130		230			84	132	69								7
Coelastrum microporum					59	90									11				19		17	25		6
Crucigenia rectangularls														42										1
Oocystls borgel					99	170		1900	840	760	1480	400	310	13		126		32		63	17	53		14
Scenedesmus dimorphus					11									21						32				2
Scenedestnus carlnatus													63											2
Surlrella robusta		15																						1
Surireiia *brlghtwellll*		6																						1
Spirogyra communis																						8		1
D: *Ascerionella formosa*		17			50																			2
Calonels amphlsbaena																		21						1
Cyclotella tneneghinlana			55															84	120					3
Gyrosigma kutzlngil				40	8		21																	3
heloslra granulate																		137	168	200		42		4
Navicula cuspidata				23																				1
Synedra ecus			50		23																			2
Synedra ulna																	21							1
Synedra vaucherlae																	25							1
F: *Ceratlum hlrundlnella*															29									1
Dinybryon sertalari							8																	1
Euglena virldls					55												55		32					3
Euglena oxyuris						84											120							2
Euglena gracilis																		53						1
Phacus pleuronectes																	382							1
Tabellarla fenestrate		1							150	60	5			11										4
Tracheloioonos crebea					11	15											124	74				34		5
De: *Glenodinium sp.*														4										1
Glenodinlum margoritatum																	179	95						2
Total	97	38	105	63	314	359	71	3100	1120	820	1715	138,400	338,400	915	405	350	905	230,100	340	2447	328	181	57	
Number of species	1	3	2	2	S	4	3	2	3	2	3	2	3	7	4	3	7	9	4	5	4	5	1	

Note: Density in counts per nllllllter; BG – Blue-Greens; G – Greens; D – Diatoms; F – Flagellates; and De – Desmlds.

Table 8. Algal Types and Densities at the Mid-Depth of Lake Loami

Algal Species	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	6/18	6/20	6/22	6/24	6/27	7/1	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10	Number of times found
BG: *Anabaena splroides*																	17							1
Aphanlzomenon flos-aquae																			67					1
G: *Ankistrodesmus sp.*	55																							1
Chlorella elllpsoidea												68,250	204,750	462		82		157,600		726	128			7
Chrysocapsa plancconies							21	1220	550	74	133			34	36	92	212					42	34	11
Coelastrum microporum						32																42		2
Oocyst is borgel					57	46	27	880	221	582	965	231	21			69	55	42				50	25	14
Pediastrum duplex			13																88	42	17			4
Ulothrix variabilis						17																		1
D: *Asterionella formosa*		27			40	*11*																		3
DiaComa vulgara							6																	1
Fragilaria sp.																	19							1
Gomphonema angustatum		15																						1
Gyrosigma kutzingli																	4		19	19				3
Melosira granulata																	92		122	345	36		25	5
Navicula ambigua	25																							1
S. cuspldata							17																	1
N. gastrum																	4							1
N. radiosa				6																				1
N. ventralis																	6							1
Surlrella robust a																		2						1
Synadra acus				53																				1
Synadra ulna				55																				1
Tabellarla fenestrata														38										1
F: *Ceratium hirundlnella*									8					2	163									3
Euglena oxyuris						11																		1
Euglena virldis				25															23					2
Phacus pleuronectes																	4	84						2
Trachelomonas crebea		8		15				11						11		11	19		13	111	34	11		10
De: *Cosmarium margoritatum*																	139	116						2
Staurastrum cornutum																	15							1
Total	*80*	50	13	114	137	122	71	2110	779	660	1100	68,500	204,800	547	140	254	588	158,000	330	1220	215	145	84	
Number of species	2	3	1	3	4	5	4	3	3	2	2	2	2	5	2	4	13	4	6	5	4	4	3	

Note: Density In counts per milliliter; BG – Blue-Greens; G – Greens; D – Diatoms; F – Flagellates; and De – Desnids.

Table 9. Algal Types and Densities Near the Bottom of Lake Loami

Algal Species	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	6/18	6/20	6/22	6/24	6/27	7/1	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10	Nunber of times found
BG: *Osclllatoria sp.*		44																						1
G: *Chlorella ellipsoidea*												81,400	S5.300	2S0							140			4
Chrysocapsa planctonica								490	254	61	130			53		21	565	119,800				44	55	10
Coelascrum microsporum													32							8		15		3
Oocyscls borgel					25	15	11	1020	164	347	361	190				13	105			27			21	12
Pedlascrum duplex																13								1
P. simplex																			40					1
Scenedesmus dimorphus	13																							1
Ulotrix zonata																							27	1
D: *Asterlonella formosa*		88			15																			2
CycloCella meneghiniana																				166				1
Cymatopleara solea		17		2	6																			3
Diatoma vulgara																			50					1
Gyroslgma kutzingil	13			19	57		11																	4
G. macrum		25																						1
Helosira granulata		25	19																113	88				4
Navlcula baclllum				8																				1
N. cryptocephala		122																						1
N. cuspldata		105		4			23															4		4
N. exlgua													10											1
N. radiosa																			21					1
Nitzschia elllptica		38																						1
Pinnularla sp.		4																						1
Plnnularla cardlnalls					46														11					2
Surirella ovata											50													1
Surirella robusta			6																					1
F: *Ceratlum hirundinella*									69				21		40									3
Euglena oxyuris									6															1
Phacus pleuronecces											6	32	42						55	17				3
Trachelomonas crebea					13		42					74	42				8		97			11	11	9
De: *Cosmarium margoritaCum*																7S		147						2
Glenodlum sp.											25													1
Staurostrum cornutum																		95						1
Total	25	470	25	33	141	36	45	1550	490	410	570	81,700	85.400	333	40	47	760	120,000	387	306	140	74	114	
Number of species	2	9	2	4	4	3	3	3	4	2	5	4	5	2	1	3	4	3	7	5	1	4	4	

Note: Density In counts per milliliter; BG - Blue-Greens; G - Greens; D - Diatoms; F - Flagellates; and De - Desmlds.

39

Table 10. Algal Types and Densities in Lick Creek

Algal Species	1/2	2/19	3/25	4/22	5/6	5/20	6/3	6/17	7/1	7/14	7/28	8/11	8/25	9/8	12/10	Number of times found
BG: *Aphanizomenon flos-aquae*		55											29V	65		3
C: *Actinastrum hantzschll*													431	53		2
Ankistrodesmus falsacus													189			1
Chlorella elllpsoidea											122					1
Chrysocapsa planctonica												615				1
Coelastrum microporum													63		34	2
Crucigenla rectangularis													210	61		2
Oocystls borgei												349	95	11	42	4
Pediastrum simplex									11				189			2
Scenedesmus carlnatus													42			1
5. dimorphus					23									40		2
Ulotrix zonata														48		1
D: *Cyclotella meneghiniana*													179	76		2
Cymatopleura solea						4	29									2
Fragllarla sp.					13											1
Gyroslgma kutzlngli	34							4	19			13		32		5
G. scalproider				44	8											2
Melosira granulata									6	46		99	231			4
Navicula cuspidata							46									1
Navicula gastrum						34								11		2
Navicula viridula	8															1
Nitzschia parvula				21												1
N. slgmoidea	74	67	25	15	17	19										6
N. linearia				8	25											2
SCephanodiscus niagarae													273			1
Surirella ovata	27	21	55			19	71									5
Synedra actlnascroldes			21		21											2
S. ulna			172		23			27								3
S. acus						11					8					2
F: *Ceratium hirundlnella*										21		4				2
Dinobryon sertularia					36											1
Euglena gracldis											63				11	2
Euglena vlrldls										13			126	25		3
Glenodinium sp.							200									1
Phacus plearonecter													63	15		2
Trachelomonas crebea											15	11			25	3
De: *Cosmarlum nargorltatum*												185			4	2
Total	143	143	252	88	166	87	346	31	36	80	208	1276	2385	437	116	
Number of species	4	3	4	4	8	5	4	2	3	3	4	7	13	11	5	

Note: Density in counts per milliliter; BG – Blue-Greens; G – Greens; D – Diatoms; F – Flagellates; and De – Desmids.

during the period June 17 to June 27, 1987. However, during the routine sampling on August 25, 1987 *Chlorella ellipsoidea* was observed to be the most dominant species, with a very high count of 229,500 cells/mL. It is surprising to note that on this date the maximum number of algal species was observed in the surface waters (table 7).

Enclosure Studies

Laboratory toxicity estimates for single species of phytoplankton, as well as for various invertebrate and fish species, are often used in aquatic safety assessments of chemicals. Because of their ecological importance, phytoplanktons have been used in various toxicity studies of a wide variety of chemicals. Since these studies typically have been conducted in the laboratory with single phytoplankton species, the ecological relevance of the results has been questioned. As a result, more relevant multispecies tests have been encouraged (Lewis, 1986). One technique has been to enclose a portion of a natural plankton community and expose it in-situ to the chemical. In these studies, enclosures of various types and sizes have been used to contain the plankton, after which community properties such as species diversity and similarity have been monitored in tests ranging in duration from a few days to several months (ibid).

McQueen and Lean (1983) discussed hypolimnetic aeration and dissolved gas concentrations in deep lakes, determined on the basis of enclosure experiments. McQueen and Story (1986) investigated the impact of hypolimnetic aeration on zooplankton and phytoplankton populations by using paired enclosures in Lake St. George, Canada. The authors are not aware of any in-situ enclosure studies reported to delineate the effects of copper sulfate on standing algal crops in water bodies in this country. Enclosure studies carried out during this investigation are unique for Illinois.

Results of algal identification and enumeration for the three enclosure studies during June 17 to June 27, August 4 to August 14, and September 23 to October 3, 1987 are shown respectively in tables 11, 12, and 13. The chemical dosage rates employed in these intensive monitoring investigations can be found in table 3. As indicated earlier, concomitant observations in the whole lake and the enclosures were made only during the first intensive monitoring period.

The results for the first intensive monitoring indicate that on June 17, 1987 the two dominant algae in the deep part of the lake and the enclosures (tables 7 and 11) were *Chrysocapsa planctonica* and *Oocystis borgei,* and their densities were comparable. In enclosure A, which served as a control and received no algicidal treatment, these two algal species persisted till the end of the study, but the *Chlorella ellipsoidea* appeared on the 7th day and reached a maximum average density of 73,400 counts/mL on the 10th day. This suggests a natural succession of algal dominance. In enclosure B, *C. planctonica* almost disappeared after the second day, but *O. borgei* persisted throughout in smaller numbers as in enclosure A. However, *C. ellipsoidea.* proliferated on the 7th and 10th days, reaching a very high density of 284,800 counts/mL. A similar trend was noted for the whole lake.

41

The maximum number of algal species observed in the untreated enclosure during the first intensive study was 5. The maximum numbers of algal species observed in the treated enclosure and at the lake surface were 5 and 3, respectively. Table 14 shows the diversity index values for phytoplankton communities in the lake and the enclosures during the intensive studies. The diversity index was computed by using the formula:

$$D = - \sum_{i=1}^{m} P_i \log_2 P_i$$

where D is the diversity index, P_i - N_i/N_s and is the probability of the occurrence of the ith genera, N_i is the density of the ith genera, N_s is the total algal density of the sample, and m is the number of species per sample. The index, D, has a minimum value of zero when m equals 1 and a maximum value when m - N_s. The diversity values for the surfaces of the lake and enclosure B were comparable and decreased steadily after copper sulfate treatment. The values for the control remained higher.

The dissolved oxygen, temperature, and secchi disc values for the three intensive studies are shown in tables 15, 16, and 17. The calculated percent dissolved oxygen saturation values are presented in table 18.

It is seen from table 15 that there was practically no difference between the temperature profiles in the two enclosures. The DO in the treated enclosure B decreased drastically on the 5th day (June 22), reaching values of 3.2 mg/L at the surface and 0.6 mg/L at 6 feet from the surface before recovering to normal levels on the 10th day (June 27). The percent saturation values on the 5th day (table 18) ranged from 42 at the surface to 8 at the bottom. The corresponding values for the control were 79 at the surface and 66 at the bottom. The maximum difference in the secchi disc values between the two enclosures during the first intensive monitoring (table 15) was 26 inches on the second day, with the lake bottom of enclosure B clearly visible. The chemical treatment caused an increase in visibility. However, the visibility deteriorated to .29 inches on the 10th day in enclosure B, with the significant algal bloom that occurred after chemical treatment. It is interesting to note that a similar phenomenon also occurred in the whole lake. The secchi disc value increased from 65 inches to 86 inches on the first day of algicide application and then gradually decreased, reaching a low value of 27 inches on the 10th day (figure 12).

The chemical characteristics for enclosures A and B during the first intensive monitoring are shown in tables 19 and 20. The pH values were above 8.0, indicating algal blooms. No trends were detectable with regard to pH, alkalinity, conductivity values, or chlorophyll in either enclosure A, which was a control, or enclosure B, which was treated with 10.8 lbs/acre of copper sulfate and 5.4 lbs/acre of citric acid.

Table 20 for enclosure B shows that there were practically no changes in the concentrations of silver, barium, calcium, cadmium, chromium, iron, magnesium, manganese, nickel, lead, or zinc with time. The chelating agent citric acid used in enclosure B did not cause or enhance the solubilization of other heavy metals from the organic-rich bottom sediments. The concentrations

of heavy metals such as barium, cadmium, chromium, nickel, lead, and zinc were comparable in enclosures A and B and for the whole lake during the first intensive monitoring (tables 19, 20, and 21). Iron and manganese were significantly higher in the near-bottom samples because of the prevailing anoxic conditions in the deep zone of the lake during the summer.

The changes in copper concentrations and algal populations in the lake and the two enclosures during the first intensive monitoring are shown in figures 16a, b, and c. Copper concentrations in the lake surface water samples reached a maximum of 180 µg/L (0.18 mg/L) as Cu^{2+} on day 1 after chemical treatment and gradually diminished to 50 µg/L (0.05 mg/L) on the 10th day. A concentration of 50 µg/L (0.05 mg/L) of copper has been reported to be effective in controlling blue-green algae (Elder and Horne, 1978; Effler et al., 1980; McKnight, 1981; Whitaker et al., 1978). Also, the senior author has observed the effectiveness of copper sulfate chelated with citric acid in controlling blue-green algae in an eutrophic lake at a copper level ranging from 50 to 150 µg/L (0.05 to 0.15 mg/L) (Kothandaraman et al., 1980). Concentrations of copper in the surface waters of the lake were maintained above the background level of about 20 µg/L (0.02 mg/L) for 10 days after copper sulfate was applied. The tremendous increase in algal density in the lake 7 days after treatment is clearly brought out in figure 16a.

Although enclosure A was a control and did not receive any chemical treatment, water samples from this enclosure showed higher levels of copper than background levels. This was probably because of contamination of the sampling equipment by a copper sulfate spill (which was not apparent at the time) in the boat used for applying the chemical to the lake prior to the monitoring of the enclosures. The contamination became apparent only after the copper analyses were completed. Copper concentrations in enclosure B reached a high value of 250 µg/L (0.25 mg/L) before declining to 40 µg/L (0.04 mg/L) on the 10th day. Algal population dynamics pertaining to the first intensive monitoring have already been presented.

The results of the second and third intensive monitorings are presented in tables 22 to 25 and figures 16d through 16g.

During the second intensive monitoring, the copper concentration in enclosure A, which received only 5.4 lbs/acre of copper sulfate (table 22 and figure 16d), was 70 µg/L (0.07 mg/L) on day 1 and quickly declined to background level on the 5th day. However, in enclosure B, which also received 2.7 lbs/acre of citric acid as a chelating agent (table 23 and figure 16e), the maximum copper concentration was 70 µg/L (0.07 mg/L), but the background level was not reached until the 10th day. The impact on the algal population was negligible since the algal densities during the second intensive monitoring were below bloom proportions (table 12).

During the third intensive monitoring, enclosure A received 10.8 lbs/acre of copper sulfate (table 24 and figure 16f), and enclosure B received 5.4 lbs/acre of copper sulfate and 16.2 lbs/acre of citric acid as a chelating agent (table 25 and figure 16g). Stern et al. (1978) reported that a citrate : copper sulfate mixture in a ratio of 8:1 (citric acid at 8 times the weight of copper sulfate pentahydrate at a copper concentration of 500 µg/L, or 0.5 mg/L) was inhibitory to *Microcystis* growth in a laboratory study over a

14-day period, whereas the addition of 500 µg copper/liter (0.5 mg/L) alone was not. Also, Raman and Cook (1986) found in a laboratory study that enhancement of copper solubility occurred up to a copper sulfate : citric acid ratio of 1:5 (w-w). For these reasons, a copper sulfate : citric acid weight ratio of 1:3 was tried in enclosure B.

The copper concentration in enclosure A was 190 µg/L (0.19 mg/L) on day 1 but was below 50 µg/L (0.05 mg/L) on the 5th day, whereas in enclosure B, the copper concentration was 230 µg/L (0.23 mg/L) on day 1 and dropped below 50 µg/L (0.05 mg/L) on the 7th day. A comparison of these results with those from the enclosure studies of the second intensive monitoring (tables 22 and 23 and figures 16d and e) shows that the use of citric acid as a chelating agent resulted in the copper remaining in solution for a longer period than when no chelating agent was used, and that an application rate of 5.4 lbs/acre of copper sulfate with 2.7 lbs/acre of citric acid caused sufficient copper to remain in solution to be effective against blue-green algae. Though the chemicals' weight ratio of 1:3 (copper sulfate to citric acid) resulted in higher concentrations of copper in solution for up to 3 days, there were no differences in concentration levels from the 5th to the 10th days between treatments with weight ratios of 1:0.5 and 1:3 (tables 23 and 25 and figures 16e and g). The senior author has found the weight ratio of 1:0.5 to be effective in controlling blue-green algae in Illinois lakes (Kothandaraman et al., 1980; Kothandaraman and Evans, 1982).

The DO and temperature data presented in tables 16 and 17 and the percent saturation values shown in table 18 for the second and third intensive monitorings indicate that the DO values did not decrease drastically, as they did during the first intensive monitoring (tables 15 and 18). The algal species *Chlorella ellipsoidea,* which gained dominance in the lake system after the first copper sulfate application to the lake, was found in every sample and on every day during the third intensive monitoring (table 13). The density in enclosure A decreased from 20,000 to 6,300 counts/mL after treatment. Similarly, it decreased from 17,000 to 1,900 counts/mL in enclosure B. This indicates that this particular alga is susceptible to copper toxicity but has a tendency to dominate when competition is eliminated and when the effect of copper wears out, as was found during the first intensive monitoring in both the lake and the enclosures.

Table 11. Algal Types and Densities Observed during Enclosure Study of June 17 - June 27, 1987

Algal Species	EA1 6/17	18	20	22	24	27	EA2 6/17	18	20	22	24	27	EB1 6/17	18	20	22	24	27	EB2 6/17	18	20	22	24	27	Number of times found
G: *Chlorella ellipsoldea*					36800	53800					45900	94300					93200	284800				42	73500	194200	9
Chrysocapsa planctonlca	2850	3230	3640	1790	1150		2230	2330	1450	1260	490		3670	640					2160	530	42				15
Coelastrum microporum					32																				1
Crucigenia rectangularis												120			70							59			3
Oocystls borgei	810	950	460	490	330	270	1700		250	730	330		2030	630	470	490	390	180	1230	360	570	390	310	230	22
Ulothrix variabilis																57									1
D: *Calonels amphisbaena*				5																					1
Gyroslgma kutzlngll																							53	21	2
Navlcula cuspidate						42										11		32	84						4
Tabellaria fenestrate	74			21			42										32								4
F: *Ceratium hirundinella*							55												63						2
Euglena virldis																							32		1
Phacus pleuronectes																								11	1
Trachelomonas crebea				27							32														2
De.Glenodinium sp.											84													63	2
ToCal	3730	4180	4100	2330	38300	54700	4050	2330	1700	1990	46800	94400	5700	1270	450	560	93620	285000	3540	890	610	490	73900	1945001	
Number of species	3	2	2	5	4	3	4	1	2	2	5	2	2	2	2	3	3	3	4	2	2	3	4	5	

Note: EA1 - Enclosure A surface; EA2 - Enclosure A near bottom, etc.; Density in counts per Milliliter; BG - Blue-Greens; G - Greens; D - Diatoms; F - Flagellates; and De - Desmlds.

Table 12. Algal Types and Densities Observed during Enclosure Study of August 4 - August 14, 1987

Algal Species	EA1 8/4	EA1 8/5	EA1 8/7	EA1 8/9	EA1 8/11	EA1 8/14	EA2 8/4	EA2 8/5	EA2 8/7	EA2 8/9	EA2 8/11	EA2 8/14	EB1 8/4	EB1 8/5	EB1 8/7	EB1 8/9	EB1 8/11	EB1 8/14	EB2 8/4	EB2 8/5	EB2 8/7	EB2 8/9	EB2 8/11	EB2 8/14	Number of times found
BG: *Anabaena spiroides*				32		40				61	36	55						21	23						7
Osclllatorla sp.					23					38															2
C: *Ankistrodesmes sp.*																					140				1
Chrysocapsa planctonica	172	118	46	71			151	44	48	94		48	155	40	59				151	44	29	32			16
Coelastrum microporum	8								17						49								4		4
Oocyscis borgei	38	27	27		17		13		21					34	25		85	15	34	36	27		27	21	15
Pediastrum simplex							8																		1
O: *Cyroslgma kutzingil*				6					11	15					11		16								5
Meloslra granulate						50				99	80	107													4
Navlcula.cuspldata				8		23						6						32							4
Navicula ventralis												11													1
Rhopalodla gibba	4		8											11											3
Tabellarla fenestrata									6																1
F: *Chrysococeus rufescens*																			4						1
Euglena vlrldls	11									6															2
Trachelomonas crebea			4	32	8	23		15	4	19	25		15			25	53	59		11	17	17	6	58	17
De: *Cosmarium margoritatum*					134	63				116		11			139	1640	160					151	491	721	10
Scaurastrum cornutum		11		11					8					6	17						13	2			7
Total	233	156	85	160	182	200	172	59	115	326	263	238	176	85	144	181	1794	287	212	104	215	200	528	800	
Number of species	5	3	4	6	4	5	3	2	7	6	5	6	3	3	4	3	4	5	4	4	5	3	4	3	

Note: EAl - Enclosure A surface; EA2 - Enclosure A near bottom, etc.; Density in counts per milliliter; BG - Blue-Greens; G - Greens;
      D - Diatoms; F - Flagellates; and De - Desmlds.

46

Table 13. Algal Types and Densities Observed during Enclosure Study of September 23 - October 3, 1987

Aleal SDecles	EA1 9/23	9/24	9/26	9/28	9/30	10/3	EA2 9/23	9/24	9/26	9/28	9/30	10/3	EB1 9/23	9/24	9/26	9/28	9/30	10/3	EB2 9/23	9/24	9/26	9/28	9/30	10/3	Number of times found
G: *Actinastrum sp.*								74																	1
Chlorella elllpsoidea	20900	16200	22200	8430	11800	3270	19150	15770	17250	13680	5890	3010	16840	10820	19020	6560	9210	2240	17450	30190	8410	5370	3180	1440	24
Chrysocapsa planetonica																								69	1
Coelastrum microporum										11		32	32		53					74					5
Oocyst is borgel	32		126	95				42		42	74	84					95	37	32	42					11
Pedlastrum duplex			8					32	95	21												11		21	6
Pediastrum simplex		21																				32		21	3
Scenedesmus dimorphus		21																							1
Vlotrix zanata											32														1
D: *Caloneis amphisbaena*									32									16							2
Cymbella cistula																			32						1
Meloslra granulate	221	116	53	168	63	74	126	105	116	95	95	21	74	84	32	84		127	140	140		53	32	16	22
Navicula cuspidata					21																				1
Navicula ventralis		21	74	32			32	11	42	53		21		11			32					32	74		12
Navicula zanoni				42																					1
Navicula gastrum							21																11		2
Synedta acus																						21			1
Tabellaria fenestrate								74																	1
F: *Ceratium hirundlnella*																		11							1
Euglena gracilis																						42			1
Trachelomonas crebea	74	32	63	53	42	21		21	74			42	21	32	21	32	42	48		63			53	32	18
De: *Clenodinium sp.*			32																						1
Cosmarium margoritatum					11																				1
Staurastrum cornutum						32			21									11				21			4
Total	21200	16400	22556	8820	11937	3397	19230	16129	17630	13900	6090	3210	16988	10988	19073	6676	9390	2479	17622	30510	8440	5582	3350	1599	
Number of species	4	6	7	6	5	4	4	7	7	6	4	6	5	4	3	3	4	6	3	5	2	8	5	6	

Note: EAl - Enclosure A surface; EA2 - Enclosure A near bottom, etc.; Density in counts per milliliter; BC - Blue-Greens; G - Greens; D - Diatoms;
F - Flagellates; and De - Desmids.

Table 14. Diversity Index Values for Phytoplankton Communities in Lake Loami Study

Date	Surface	Lake Mid-depch	Near bottom	Enclosure A Surface	Near bottom	Enclosure B Surface	Near bottom	Remarks
6/17/88	0.67	0.70	0.74	0.62	0.83	0.65	0.83	Lake treatment:
6/18	0.73	0.65	1.03	0.54	0.01	0.69	0.67	C.S. - 10.8 lbs/acre
6/20	0.26	0.36	0.42	0.35	0.41	0.39	0.25	C.A. - 5.4 lbs/acre
6/22	0.41	0.37	1.02	0.64	0.66	0.34	0.65	Enclosure A:
6/24	0.02	0.02	0.03	0.19	0.12	0.03	0.04	Control
6/27	0.01	0.00	0.01	0.05	0.01	0.01	0.01	Enclosure B:
								Same as for lake
8/4				0.85	0.45	0.44	0.85	Enclosure A:
8/5				0.70	0.57	0.99	1.23	C.S. - 5.4 lbs/acre
8/7				1.06	1.64	1.23	1.05	C.A. - none
8/9				1.46	1.60	0.70	0.71	Enclosure B:
8/11				0.85	1.31	0.37	0.31	C.S. - 5.4 lbs/acre
8/14				1.53	1.40	1.05	0.38	C.A. - 2.7 lbs/acre
9/23				0.09	0.55	0.06	0.06	Enclosure A:
9/24				0.08	0.12	0.10	0 07	C.S. - 10.8 lbs/acre
9/26				0.11	0.13	0.20	0.02	C.A. - none
9/28				0.24	0.73	0.10	0.23	Enclosure B:
9/30				0.08	0.18	0.12	0.26	C.S. - 5.4 lbs/acre
10/3				0.20	0.32	0.44	0.47	C.A. - 16.2 lbs/acre

Note: C.S. - copper sulfate pentahydrate; C.A. - citric acid monohydrate.

Table 15. Dissolved Oxygen (DO), Temperature, and Secchi Disc Values for First Intensive Monitoring

Enclosure A

Depth, feet	6/17 DO	Temp.	6/18 DO	Temp.	6/20 DO	Temp.	6/22 DO	Temp.	6/24 DO	Temp.	6/27 DO	Temp.
0	13.5	29.2	12.3	29.9	8.6	28.6	6.1	28.5	5.0	27.9	.5.8	25.9
1	13.5	29.2	12.3	29.9	8.7	28.6	6.1	28.5	5.0	27.8	5.8	25.9
2	13.5	29.1	12.6	29.7	8.7	28.6	6.3	28.4	4.9	27.7	5.8	25.9
3	13.1	29.0	12.7	29.5	8.7	28.6	6.2	28.4	4.7	27.6	5.8	25.9
4	12.5	28.8	12.6	29.4	8.6	28.5	5.9	28.4	4.5	27.6	5.5	25.9
5	11.3	28.5	12.4	29.3	8.5	28.5	5.1	28,2	4.3	27.5	5.4	25.8
6			11.5	29.2					4.2	27.5	5.4	25.8
Secchi Disc, (in.)	48		47		60		57		42		48	

Enclosure B

Depth, feet	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	13.3	29.3	11.4	29.7	6.1	28.5	3.2	28.6	4.2	27.9	7.3	25.7
1	13.4	29.3	11.3	29.7	6.1	28.6	3.2	28.6	4.1	27.7	7.2	25.9
2	13.4	29.3	11.3	29.7	6.1	28.6	3.1	28.5	3.7	27.7	7.2	25.9
3	13.4	29.2	11.4	29.5	6.0	28.6	3.0	28.5	3.6	27.5	7.1	25.9
4	13.5	29.0	11.4	29.4	5.9	28.6	2.8	28.4	3.4	27.5	6.8	25.9
5	13.1	28.9	11.3	29.3	5.8	28.5	2.4	28.4	3.2	27.5	6.5	25.8
6	12.4	28.7	10.3	29.2	5.7	28.5	0.6	28.2	2.3	27.4	6.2	25.8
Secchi Disc, (in.)	48		73		72		62		30		29	

Enclosure A: Control
Enclosure B: Copper sulfate - 10.8 lbs/acre, citric acid - 5.4 lbs/acre

DO - mg/L; Temperature - C

Table 16. Dissolved Oxygen (DO), Temperature, and Secchl Disc Values for Second Intensive Monitoring

Enclosure A

Depth, feet	8/4 DO	8/4 Temp.	8/5 DO	8/5 Temp.	8/7 DO	8/7 Temp.	8/9 DO	8/9 Temp.	8/11 DO	8/11 Temp.	8/14 DO	8/14 Temp.
0	8.4	30.6	7.6 .	29.0	7.5	28.6	7.2	28.1	6.5	28.1	5.8	28.1
1	8.4	30.6	7.6	29.0	7.5	28.7	7.2	28.2	6.4	28.2	5.8	28.1
2	8.4	30.7	7.5	29.0	7.4	28.7	7.0	28.2	6.2	28.1	5.8	28.1
3	8.4	30.7	7.4	29.0	7.3	28.6	6.9	28.1	6.0	27.9	5.8	28.1
4	8.4	30.7	7.4	28.9	7.1	28.6	6.7	28.1	5.8	27.8	5.7	28.1
5	8.4	30.7	7.4	28.9	5.9	28.6	6.6	28.0	5.7	27.8	5.6	28.1
6	8.4	30.7	7.3	28.9			6.6	28.0				
Secchi Disc, (in.)	65		70		46		42		58		50	

Enclosure B

Depth, feet	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	8.5	30.6	7.7	29.0	7.3	28.7	7.2	28.1	6.9	28.0	6.7	28.0
1	8.5	30.7	7.7	29.0	7.3	28.8	7.2	28.2	6.9	28.1	6.6	28.1
2	8.5	30.7	7.6	29.0	7.3	28.8	7.1	28.1	6.8	28.1	6.6	28.1
3	8.5	30.7	7.6	29.0	7.2	28.8	6.9	28.1	6.7	27.9	6.6	28.1
4	8.5	30.7	7.5	28.9	7.1	28.7	6.8	28.1	6.5	27.9	6.6	28.1
5	8.5	30.7	7.5	28.9	7.0	28.7	6.7	28.0	6.3	27.8	6.6	28.1
6	8.5	30.7	7.5	28.9	6.9	28.7	6.6	28.0	6.3	27.8	6.6	28.1
Secchi Disc, (in.)	58		70		51		54		60		65	

Enclosure A: Copper sulfate - 5.4 lbs/acre
Enclosure B: Copper sulfate - 5.4 lbs/acre, citric acid - 2.7 lbs/acre

DO - mg/L; Temperature - C

Table 17. Dissolved Oxygen (DO), Temperature, and Secchl Disc Values for Third Intensive Monitoring

Enclosure A

Depth, feet	9/23 DO	Temp.	9/24 DO	Temp.	9/76 DO	Temp.	9/28 DO	Temp.	9/30 DO	Temp.	10/3 DO	Temp.
0	8.8	18.9	8.7	18.7	10.7	20.6	8.9	20.7	7.1	18.8	8.2	14.4
1	8.3	18.5	8.7	18.7	10.8	20.5	8.8	20.6	6.9	18.7	8.2	14.3
2	8.0	18.5	8.6	18.6	10.5	20.3	8.5	20.4	6.8	18.6	8.1	14.3
3	7.7	18.4	8.5	18.6	10.1	19.9	8.4	20.3	6.8	18.6	8.1	14.2
4	7.7	18.4	8,2	18.6	9.9	19.8	8.3	20.3	6.7	18.6	7.9	14.1
Secchi Disc, (in.)	30		27		32		36		30		33	

Enclosure B

Depth, feet	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	8.9	19.0	8.7	18.8	10.1	20.5	8.7	20.7	7.1	18.8	8.6	14.2
1	8.9	18.9	8.7	18.7	10.1	20.5	8.5	20.6	7.0	18.7	8.6	14.2
2	8.7	18.7	8.6	18.7	9.7	20.5	8.3	20.4	7.0	18.7	8.6	14.2
3	8.2	18.5	8.5	18.6	9.6	19.8	8.1	20.3	6.8	18.6	8.4	14.0
4	8.0	18.4	8.5	18.6	9.2	19.8	7.9	20.2	6.8	18.6	8.4	14.0
Secchi Disc, (in.)	30		27		36		39		33		39	

Enclosure A: Copper sulfate - 10.8 lbs/acre
Enclosure B: Copper sulfate - 5.4 lbs/acre, citric acid - 16.2 lbs/acre

DO - mg/L; Temperature - C

Table 18. Percent Dissolved Oxygen Saturation in Enclosure Studies

Depth (feet)	6/17/87		6/18/87		6/20/87		6/22/87		6/24/87		6/27/87	
		A	B	A	B	A	B	A	B	A	B	A	B
0	179	176	165	152	113	80	79	42	65	54	72	90
1	179	178	165	151	114	80	79	42	64	53	72	90
2	178	178	168	151	114	80	82	41	63	48	72	90
3	173	177	169	152	114	79	81	39	60	46	72	88
4	164	178	168	152	112	77	77	37	58	44	68	85
5	148	173	165	150	111	76	66	31	55	41	67	81
6		163	152	136		74		8	54	29	67	77

Enclosure A: Control
Enclosure B: Copper sulfate - 10.8 lbs/acre, citric acid - 5.4 lbs/acre

Depth (feet)	8/4/87		8/5/87		8/7/87		8/9/87		8/11/87		8/14/87	
		A	B	A	B	A	B	A	B	A	B	A	B
0	114	116	100	102	98	96	93	93	84	89	75	87
1	114	116	100	102	98	96	94	94	83	90	75	86
2	114	116	99	100	97	96	91	92	80	88	75	86
3	114	116	98	100	96	95	90	90	78	87	75	86
4	114	116	97	99	93	93	87	88	75	84	74	86
5	114	116	97	99	77	92	85	87	74	81	73	86
6	114	116	96	99		91	85	85		81		86

Enclosure A: Copper sulfate - 5.4 lbs/acre
Enclosure B: Copper sulfate - 5.4 lbs/acre, citric acid - 2.7 lbs/acre

Depth (feet)	9/23/87		9/24/87		9/26/87		9/28/87		9/30/87		10/3/87	
		A	B	A	B	A	B	A	B	A	B	A	B
0	95	97	94	94	120	113	100	98	77	77	81	84
1	89	96	94	94	121	113	99	95	74	76	80	84
2	86	94	93	93	117	109	95	93	73	76	79	84
3	83	88	92	92	112	106	94	90	73	73	79	82
4	83	86	88	92	109	102	93	88	72	73	77	82
5												
6												

Enclosure A: Copper sulfate - 10.8 lbs/acre
Enclosure B: Copper sulfate - 5.4 lbs/acre, citric acid - 16.2 lbs/acre

Table 19. Chemical Characteristics in Enclosure A,
First Intensive Monitoring

Surface

	6/17	6/18	6/20	6/22	6/24	6/27
Chlorophyll-a	21.3	21.5	1.7	25.3	33.8	20.1
pH	9.85	9.79	9.55	9.48	9.24	9.24
Alkalinity	99	98	105	106	98	102
Conductivity	297	296	307	300	297	209
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17.0	16.6	26.2	16.7	17.4	16.0
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.08	0.01	0.01	0.01
Copper	0.10	0.07	0.19	0.05	0.04	0.03
Iron	0.08	0.10	0.12	0.11	0.16	0.09
Magnesium	20.7	20.4	20.5	19.8	20.2	19.1
Manganese	0.04	0.03	0.05	0.08	0.09	0.09
Nickel	0.02	0.02	0.01	0.02	0.02	0.02
Lead	0.04	0.03	0.02	0.01	0.02	0.02
Zinc	0.01	0.01	0.08	0.01	0.01	<0.01

Near Bottom

	6/17	6/18	6/20	6/22	6/24	6/27
Chlorophyll-a	16.8	13.0	4.4	28.7	39.0	18.9
pH	9.87	9.80	9.50	9.48	9.22	9.20
Alkalinity	99	96	104	106	100	100
Conductivity	297	297	306	300	295	290
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	18.1	16.6	16.6	16.0	16.3	15.8
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.02	0.01	0.01	0.02
Copper	0.02	0.10	0.04	0.05	0.03	0.01
Iron	0.20	0.15	0.08	0.12	0.15	0.07
Magnesium	21.3	20.6	20.8	20.4	19.5	18.6
Manganese	0.04	0.03	0.06	0.08	0.09	0.08
Nickel	0.02	0.02	0.02	0.02	0.02	0.01
Lead	0.04	0.04	0.02	0.03	0.01	0.01
Zinc	<0.01	0.02	0.01	0.01	<0.01	<0.01

Units: pH - units; Chlorophyll - µg/L; all others - mg/L

Table 20. Chemical Characteristics in Enclosure B,
First Intensive Monitoring

Surface

	6/17	6/18	6/20	6/22	6/24	6/27
Chlorophyll-a	19.3	31.3	13.1	13.9	28.3	38.5
pH	9.85	9.75	9.68	9.19	9.07	9.26
Alkalinity	100	100	102	113	102	104
Conductivity	296	301	294	310	303	295
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17.7	19.8	17.7	18.8	17.5	17.3
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.02	0.01	0.01	0.02
Copper	0.03	0.25	0.25	0.07	0.05	0.04
Iron	0.11	0.10	0.33	0.14	0.28	0.28
Magnesium	20.7	21.7	20.9	21.1	19.5	19.4
Manganese	0.04	0.03	0.08	0.11	0.11	0.09
Nickel	0.02	0.02	0.02	0.03	0.02	0.02
Lead	0.04	0.04	0.05	0.03	0.01	0.02
Zinc	0.01	0.02	0.01	0.01	0.01	<0.01

Near Bottom

	6/17	6/18	6/20	6/22	6/24	6/27
Chlorophyll-a	29.7	8.7	14.7	14.1	30.4	33.9
pH	9.87	9.72	9.70	9.21	8.99	9.19
Alkalinity	101	98	101	112	104	104
Conductivity	295	289	296	314	303	296
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17.5	17.4	18.8	18.6	18	17.2
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.01	0.01	0.02	0.01
Copper	0.02	0.19	0.14	0.07	0.05	0.03
Iron	0.10	0.07	0.13	0.16	0.23	0.33
Magnesium	20.8	21.4	21.4	20.9	19.9	19.2
Manganese	0.04	0.03	0.08	0.11	0.12	0.10
Nickel	0.02	0.02	0.02	0.02	0.02	0.02
Lead	0.04	0.03	0.04	0.03	0.01	0.02
Zinc	0.01	0.01	0.02	0.01	<0.01	0.01

Units: pH - units; Chlorophyll - μg/L; all others - mg/L

Table 21. Metals Analyses for Lake Samples Near Water Intake
during Intensive Monitoring after Algicide Application

Surface

	6/17	6/18	6/20	6/22	6/24	6/27
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	19.3	19.7	55.5	20.7	19.1	19.4
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.02	0.02	0.02	0.02	0.01
Copper	0.07	0.18	0.12	0.08	0.04	0.05
Iron	0.12	0.08	0.16	0.15	0.24	0.23
Magnesium	19.7	20.1	21.9	21.3	20.0	19.2
Manganese	0.03	0.03	0.05	0.10	0.11	0.16
Nickel	0.02	0.02	0.02	0.02	0.02	0.02
Lead	0.04	0.04	0.02	0.03	0.01	0.03
Zinc	0.05	0.02	0.04	0.04	0.01	0.04

Mid-depth

	6/17	6/18	6/20	6/22	6/24	6/27
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	24.2	18	23.2	20.4	19.4	18.1
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.02	0.02	0.01	0.01
Copper	0.03	0.18	0.10	0.08	0.04	0.03
Iron	0.19	0.07	0.11	0.15	0.30	0.21
Magnesium	20.6	18.8	21.3	20.6	19.8	18.6
Manganese	0.04	0.03	0.06	0.10	0.12	0.16
Nickel	0.02	0.02	0.02	0.02	0.02	0.02
Lead	0.03	0.03	0.07	0.04	0.01	0.03
Zinc	0.01	0.02	0.01	0.03	0.01	0.01

Near Bottom

	6/17	6/18	6/20	6/22	6/24	6/27
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	25.6	28.8	34.7	35.0	24.3	28.0
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.02	0.02	0.02	0.02	0.01
Copper	0.03	0.07	0.06	0.06	0.04	0.04
Iron	0.22	0.31	1.09	0.80	0.48	0.67
Magnesium	21.5	23.3	24.9	25.6	20.7	22.4
Manganese	0.16	0.44	0.96	0.94	0.73	1.23
Nickel	0.02	0.02	0.02	0.03	0.02	0.02
Lead	0.05	0.05	0.05	0.03	0.03	0.05
Zinc	0.01	0.02	0.02	0.02	0.01	<0.01

Units: All concentrations are expressed in mg/L
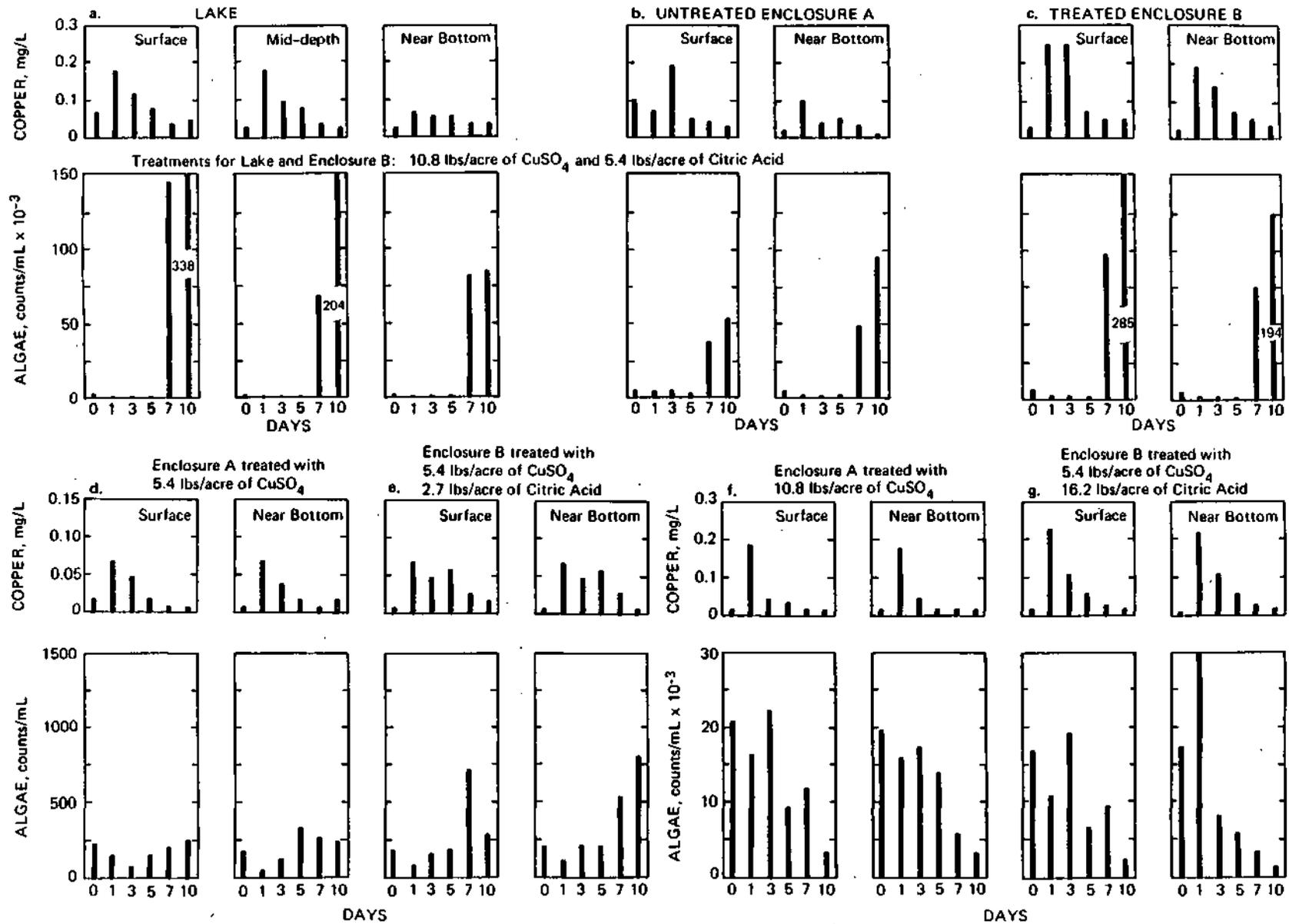
Figure 16. Changes in copper concentrations and algal densities in the lake and enclosures during first intensive monitoring (a-c), second intensive monitoring (d,e), and third intensive monitoring (f,g)

56

Table 22.   Chemical Characteristics in Enclosure A,
Second Intensive Monitoring

Surface

	8/4	8/5	8/7	8/9	8/11	8/14
Chlorophyll-a	15.8	12.9	14.2	18.1	11.8	12.7
pH	9.58	9.48	9.35	9.26	9.15	9.19
Alkalinity	106	108	108	107	107	107
Conductivity	287	276	289	274	281	279
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17	17	17	17	17	15
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.01	0.07	0.05	0.02	0.01	0.01
Iron	0.18	0.09	0.16	0.17	0.19	0.19
Magnesium	38	17	18	18	17	18
Manganese	0.07	0.06	0.08	0.08	0.08	0.05
Nickel	0.02	0.02	0.01	<0.01	0.01	<0.01
Lead	0.01	<0.01	<0.01	<0.01	0.01	0.02
Zinc	0.01	0.01	0.02	0.02	0.02	0.01

Near Bottom

	8/4	8/5	8/7	8/9	8/11	8/14
Chlorophyll-a	17.0	14.8	12.7	17.8	14.7	14.9
pH	9.50	9.40	9.32	9.20	9.09	9.26
Alkalinity	107	107	107	107	107	109
Conductivity	278	279	282	278	279	279
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	18	17	17	17	17	18
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.01	0.07	0.04	0.02	0.01	0.02
Iron	0.17	0.08	0.20	0.17	0.16	0.25
Magnesium	26	18	18	17	18	18
Manganese	0.07	0.06	0.08	0.09	0.08	0.06
Nickel	0.02	0.01	<0.01	<0.01	0.01	<0.01
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Zinc	0.02	0.02	0.02	0.01	0.02	0.02

Units: pH - units; Chlorophyll - µg/L; all others - mg/L

Table 23. Chemical Characteristics in Enclosure B, Second Intensive Monitoring

Surface

	8/4	8/5	8/7	8/9	8/11	8/14
Chlorophyll-a	18.0	15.4	12.8	12.6	10.1	8.2
pH	9.50	9.39	9.34	9.31	9.04	9.21
Alkalinity	107	107	108	107	107	108
Conductivity	279	277	277	277	279	279
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17	17	17	17	17	17
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.01	0.07	0.05	0.06	0.03	0.02
Iron	0.13	0.10	0.15	0.13	0.09	0.29
Magnesium	20	18	17	17	18	17
Manganese	0.07	0.05	0.07	0.09	0.09	0.07
Nickel	<0.01	0.02	<0.01	0.01	<0.01	0.01
Lead	0.01	<0.01	0.02	<0.01	0.01	0.03
Zinc	0.02	0.02	0.02	0.02	0.03	0.02

Near Bottom

	8/4	8/5	8/7	8/9	8/11	8/14
Chlorophyll-a	17.3	16.7	8.5	9.2	11.1	8.1
pH	9.49	9.38	9.31	9.19	9.02	9.20
Alkalinity	106	108	107	107	107	109
Conductivity	277	275	278	276	277	279
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Calcium	17	17	17	17	17	16
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.01	0.07	0.05	0.06	0.03	0.01
Iron	0.11	0.08	0.17	0.13	0.09	0.08
Magnesium	18	18	18	18	18	16
Manganese	0.07	0.05	0.08	0.09	0.09	0.06
Nickel	0.02	0.01	0.01	0.01	<0.01	<0.01
Lead	<0.01	<0.01	0.01	<0.01	0.01	0.05
Zinc	0.02	0.01	0.02	0.02	0.02	0.02

Units: pH - units; Chlorophyll - μg/L; all others - mg/L

Table 24. Chemical Characteristics in Enclosure A, Third Intensive Monitoring

Surface

	9/23	9/24	9/26	9/28	9/30	10/3
Chlorophyll-a	9.9	21.2	10.6	9.1	7.9	4.7
pH	8.87	8.90	9.10	9.18	8.90	9.05
Alkalinity	138	139	137	138	134	144
Conductivity	327	334	335	332	337	341
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	0.07	0.06	0.07	0.08	0.05	0.07
Calcium	24	24	24	23	22	24
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.02	0.19	0.05	0.04	0.02	0.02
Iron	0.78	0.50	0.43	0.45	0.46	0.47
Magnesium	19	19	19	20	19	19
Manganese	0.11	0.12	0.10	0.10	0.11	0.08
Nickel	<0.01	0.01'	<0.01	<0.01	0.01	<0.01
Zinc	0.02	0.01	0.01	0.02	0.03	<0.01

Near Bottom

	9/23	9/24	9/26	9/28	9/30	10/3
Chlorophyll-a	16.5	22.0	13.3	9.5	9.1	5.6
pH	8.82	8.91	9.12	9.05	8.99	9.02
Alkalinity	139	138	139	144	140	140
Conductivity	329	337	334	331	337	341
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	0.08	0.06	0.08	0.07	0.06	0.07
Calcium	24	23	24	24	23	24
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.02	0.18	0.05	0.02	0.02	0.02
Iron	0.98	0.49	0.49	0.47	0.43	0.53
Magnesium	19	19	19	20	20	19
Manganese	0.13	0.12	0.12	0.11	0.13	0.09
Nickel	<0.01	<0.01	0.01	<0.01	0.01	<0.01
Zinc	<0.01	<0.01	0.01	0.01	0.01	0.01

Units: pH - units; Chlorophyll - µg/L; all others mg/L

Table 25. Chemical Characteristics in Enclosure B,
Third Intensive Monitoring

Surface

	9/23	9/24	9/26	9/28	9/30	10/3
Chlorophyll-a	16.4	18.5	16.2	9.8	5.8	4.3
pH	8.87	8.86	9.02	9.18	8.95	9.05
Alkalinity	138	140	138	144	142	144
Conductivity	328	334	334	336	341	342
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	0.05	0.05	0.06	0.06	0.07	0.27
Calcium	24	24	23	23	24	24
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.02	0.23	0.11	0.06	0.03	0.02
Iron	0.60	0.43	0.37	0.56	0.23	0.34
Magnesium	19	19	18	19	19	19
Manganese	0.11	0.17	0.21	0.15	0.10	0.06
Nickel	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	<0.01	0.03	0.02	0.02	<0.01	0.02

Near Bottom

	9/23	9/24	9/26	9/28	9/30	10/3
Chlorophyll-a	6.3	20.6	17.2	12.1	7.1	4.9
pH	8.82	8.89	8.96	9.02	8.90	9.02
Alkalinity	137	136	140	140	140	153
Conductivity	328	337	337	339	341	342
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	0.08	0.06	0.06	0.05	0.16	0.07
Calcium	23	24	24	23	24	24
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.01	0.22	0.11	0.06	0.03	0.02
Iron	0.60	0.44	0.38	0.33	0.26	0.36
Magnesium	20	19	19	15	20	20
Manganese	0.13	0.18	0.24	0.16	0.10	0.06
Nickel	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Zinc	0.02	<0.01	0.02	<0.01	0.01	<0.01

Units: pH - units; Chlorophyll -µg/L; all others mg/L

SUGGESTED GUIDELINES FOR COPPER SULFATE USAGE

The primary reasons that water treatment plant managers decide to control algae at the source are 1) the taste and odor problems in the finished waters and 2) the filter clogging problems, which result in shorter filter runs and a consequent need for frequent backwashes, which in turn entail increased operating costs. There Is a general tendency to treat lakes with copper sulfate on a routine basis during summer months whether or not it is needed for prophylactic reasons.

Algae play an important role in the aquatic environment, and it is neither possible nor desirable to "kill" algae. It behooves water treatment systems managers to try to selectively control the problem-causing algae.

If there is a need to control taste and odor problems at the source, then it is imperative to characterize the problem so it becomes possible to identify the cause of the problem and take corrective measures on a rational basis rather than on a shot-in-the-dark basis. The experience of the senior author is that the root cause of the taste and odor problems in Illinois water supply systems using impoundments as their raw water supply source is more likely than not the use of hypolimnetic waters for water supply purposes during summer months primarily because the deeper waters are cooler than the surface waters. Experiences in the recent past with the water supply systems in Eureka, Palmyra, Altamont, Sparta, and Nashville provide evidence of this fact (Raman, 1988).

After extensive research done under the aegis of the U.S. Department of Health, Education, and Welfare (Public Health Service, Division of Water Supply and Pollution Control), Palmer (1962) published a treatise on algae in water supplies. He stated that green algae are associated with tastes and odors in water less often than are blue-green algae and that, in fact, their growth may help to keep blue-green algae and diatoms in check and thus may be a positive factor in the control of water quality.

The information that Palmer provides on typical odors from algae, which is very pertinent and useful to water treatment plant managers, is presented as Appendix C to this report. It is evident from Palmer's work (see Appendix C) that a qualitative evaluation of tastes and odors in raw and finished waters, whether they are fishy, musty, earthy, aromatic, etc., will give an indication of the cause of the problem. A qualitative assessment is simple to carry out and is within the capability of a treatment plant operator, unlike the tests for the determination of threshold odor number. A 100-mL water sample should be placed in an Erlenmeyer flask and covered tightly with aluminum foil. Its temperature should be brought gradually to 40°C (APHA, et al. 1985, page 87) by heating it in a water bath. The sample should not be heated directly over a naked flame. When the desired temperature is reached, the cover is removed and the sample is subjected to a nose test.

Microscopic examination of the raw water sample is the best means of identifying and enumerating algal growths in impoundments. However, this is not feasible except in the case of large water utilities. Other surrogate parameters or tell-tale signs need to be used to identify the incipient stages of algal blooms in the lake. Most algal blooms occur during warm summer months, but blooms in winter months cannot be ruled out.

Dissolved oxygen, percent saturation, pH, alkalinity, secchi disc readings, lake water color, increased rate of loss of head in the filters, and the consequent shortened filter runs can all be used to identify an ongoing algal bloom in the lake. Typically, with an active algal" bloom, dissolved oxygen will increase with supersaturated oxygen conditions, pH will increase above 8.0, alkalinity in the upper layers of the lake will decrease, secchi disc values will decline, and the changes in color due to algal bloom will be easily perceived by any lake worker who is observant about the changes in the lake water color over a period of time. Theoretical dissolved oxygen saturation values for various temperatures are given in Appendix D and can be used to calculate the extent of DO supersaturation prevailing in the lake.

The unique characteristics of blue-green algae (the prevalence of gas vacuoles in their cell structure that cause them to float to the surface forming a scum) can be utilized to delineate the occurrence of this group of algae in the lake. This is considered to be the most undesirable type of algae, and fortunately it is the most sensitive to copper toxicity. If there is an algal bloom occurring in the lake with blue-green as the dominant algae, these will tend to accumulate and form a scum on the lake surface under quiescent conditions, particularly in the early morning hours on the windward side of the lake and in protected coves and bay areas. The scum appears as pale-green in color and soft to the touch, resembling latex paint thrown in water. The blue-green algae are known to cause gastrointestinal disorders when ingested in large quantities and frequently are toxic to domestic animals.

Other issues to be considered here are the rate of application of copper sulfate and the need for using a safe chelating agent for copper in high-alkalinity waters.

Mackenthun (1969) and others (Fair et al., 1971; Kothandaraman et al., 1980} suggest the use of copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) at the rate of 1 mg/L for the top 2 feet of the lake surface, which translates to a rate of 5.4 lbs/acre. This dosage is equivalent to 0.25 mg/L as Cu^{2+} for the top 2 feet. If the average depth of the lake is 8 feet, then the whole-lake volume copper concentration is 0.06 mg/L as Cu^{2+}. Rates as high as 100 lbs/acre have been employed in Illinois lakes. This is probably because the whole-lake volume was considered in computing the dosage rate at 1 mg/L as $CuSO_4 \cdot 5H_2O$. As the active algal growth occurs in the euphotic zone, which is likely to be 8 to 10 feet deep in Illinois lakes, and as the application rate of 1 mg/L as $CuSO_4 \cdot 5H_2O$ to the top 2 feet of the lake was found to be effective in controlling blue-green algae (Kothandaraman et al., 1980; Kothandaraman and Evans, 1982), a rate of 5.4 lbs/acre appears to be adequate.

Another issue is the use of chelating agent for copper sulfate to prevent precipitation of copper as cupric carbonate, azurite, malachite, etc., rendering the added copper sulfate ineffective in controlling algae. At a pH of 8.0, less than 10% of the added copper remains in dissolved form. One has to keep in mind that pH increases well above 8.0 during algal blooms. A pH value as high as 10.00 was reached in Lake Loami during algal blooms, and pH values above 9.00 were not uncommon. Thus it becomes apparent that when the algal problem is acute, the effectiveness of the copper sulfate becomes minimal. <u>The main reason why lake managers tend to increase the copper</u>

sulfate application rates and the frequencies of application is to compensate for the ineffectiveness of the copper sulfate. The necessity for employing a chelating agent with copper sulfate in high-alkalinity waters cannot be overemphasized.

Reports on the effectiveness of chelated copper on the test species have been mixed. Strong chelating agents such as EDTA and NTA tend to reduce the effectiveness or toxicity of copper. However, Stern et al. (1978) report that citric acid enhanced the toxicity of copper to algae in laboratory studies. Kothandaraman et al. (1980) and Kothandaraman and Evans (1982) reported on the enhanced effectiveness of copper in controlling blue-green algae in field-scale applications.

Citric acid is a safe, biochemical acid which is an intermediary product in the Krebs cycle of biosynthesis. It is among the items included in the Food Chemical Codex (1966). The scope of the Codex is limited to substances amenable to chemical characterization or biological standardization which are added directly to food to perform some desired function. Such substances were selected from food additives generally recognized as safe (GRAS), those approved by prior sanctions, and those for which special use tolerances have been established by FDA (Food and Drug Administration) regulations.

Copies of written communications between the senior author and the Science and Technology Branch of the USEPA are given as Appendix E. Use of copper sulfate mixed with citric acid for algal control in high-alkalinity waters (alkalinity > 40 mg/L as $CaCO_3$) does not appear to be deleterious to the aquatic environment. As a matter of fact, the use of citric acid as a chelating agent for copper sulfate in high-alkalinity waters will faciliate the use of much less copper sulfate for the same effectiveness in control.

It is appropriate to mention here the senior author's personal experience in dealing with two tremendous algal blooms in water supply lakes without the use of copper sulfate.

Lake Eureka experienced an extraordinary sequence of events during July and August 1983. Raman et al. (1984) reported that the temperature and dissolved oxygen observations at the lake stations were normal until the end of July. The July 20 sample for algal assay indicated the dominance of the green alga *Tetraedron quadratum* in the lake. This was the first time this species of green algae had ever been found and identified by the Water Survey in surface waters of Illinois. The results of the August 2, 1983, monitoring survey were extraordinary. The entire lake appeared dark brown, and the secchi disc reading was 9 inches. The dissolved oxygen readings were in excess of 28 mg/L in the top 4 feet of the lake surface, dropping to 5.1 mg/L at 6 feet from the surface. The temperature varied from 31.0°C at the surface to 26.5°C near the bottom (18-foot depth). There was a tremendous algal bloom composed almost entirely of the green algae I. *quadratum,* which reached a density of 32,760 counts/mL of the total of 33,290 counts/mL.

The cells of these organisms are solitary and free-floating. They have from one to many chromatophores in their cell structure, which give them a greenish-brown hue. There is no recorded evidence to indicate that these organisms cause problems in water treatment systems. Since one of the primary

objectives of the water quality management in Lake Eureka was to control blue-green algae, which are known to cause problems in water supply systems, a decision was made not to treat the lake with chelated copper sulfate. As a matter of fact, there was no copper sulfate application to the lake during 1983.

However, it soon became apparent that this massive algal bloom observed on August 2, 1983, could create other water quality problems. The dissolved oxygen concentrations in the entire water column at the deep monitoring station decreased to less than 3.0 mg/L on August 17, 1983 and to zero or near zero at depths below 6 feet. This was presumably due to the death and decay of the extremely high numbers of algae observed earlier. Algal counts observed during the subsequent field visits were in general much lower than those observed on August 2, 1983. The oxygen demand exerted by the decaying algal cells was much higher than the oxygen transfer from the atmosphere. The mechanical destratifier kept the lake completely mixed during this period, as evidenced by the depth-temperature relationship at the deep station.

A massive fish kill (shad) occurred during the waning days of August 1983. Surprisingly, there was not much public commotion, and the fish kill episode was considered a blessing in disguise to rid the lake of unwanted fish population. This episode did not cause any taste and odor or filter clogging problems. The only change in the plant operation during this period was to use activated carbon as a precautionary measure. Such an episode has not recurred since then.

The second experience is the tremendous algal growth in Lake Loami under ice cover during January 1988. Microscopic examination of the lake waters indicated the presence of *Chlorella vulgaris*, a green alga, too numerous to count. This caused filter clogging, air binding of the filter media, shortened filter runs from 48 hours to less than 6 hours, loss of filter media during backwash cycles, and other operational problems. Algicide could not be used, as the bloom was occurring under ice cover. The treatment plant operator was advised to increase the alum dosage to remove the algae during the coagulation sedimentation process. (Lin et al. [1971] reported, on the basis of their laboratory study with Illinois River water samples, that most of the troublesome algae were removed and an overall algal reduction in excess of 85% was achieved with a coagulant [aluminum sulfate] concentration of 30 mg/L). The plant operator was also advised to physically rake the surface of the filter media during the backwash operation (Raman, personal communication, January 14, 1988). The filter beds are not furnished with mechanical rakes or surface sprays to break up the surface film. The plant operation returned to normalcy with these modifications in the routine operation.

These experiences reinforce the facts that it is almost impossible to predict the dynamics of algal growth in water supply impoundments and that there are alternative economical and environmentally safe and acceptable means of dealing with algal blooms. The Lake Loami experience indicates that there are circumstances when algicidal treatments are not feasible.

Based on the foregoing, the following suggestions are made for dealing with algal blooms in water supply impoundments.

- The basis of lake chemical treatment should be the control of blue-green algae.

- If copper sulfate treatment is needed, a rate of 5.4 lbs/acre appears to be adequate.

- In high-alkalinity waters (>40 mg/L as $CaCO_3$) citric acid in the weight ratio 2:1 (2 copper sulfate to 1 citric acid) is advantageous. The chemicals may be mixed and applied in any traditional manner.

- The practice of routine application of the algicide, whether or not it is needed, should be discouraged.

- If an algicide application is needed and carried out, a detailed record needs to be kept at the treatment plant outlining the necessity for the treatment and the outcome of the treatment. This will greatly facilitate proper lake management and future decisions regarding the use of algicides.

- A qualitative assessment of the nature of taste and odor problems should be made as part of routine plant operation.

- The number, frequency, and nature of consumer complaints about taste and odor problems should be recorded.

- Periodic monitoring, at least once in two weeks, of the dissolved oxygen and temperature profiles at the deepest part of the lake or near the water intake will greatly aid in water system management.

- Methods of dealing with the lake algal problem other than chemical treatment (such as water intake manipulation, coagulation and sedimentation, and possibly aeration/destratification) should be explored prior to algicide treatment of the lake.

SUMMARY

Lake Loami, a side-channel impoundment situated 12 miles southwest of Springfield, serves as a water supply source to the village of Loami with a population of about 800 people. Water is pumped to the lake as needed from behind the channel dam on Lick Creek. The 10-acre lake, which has a maximum depth of 16 feet and a mean depth of 7.1 feet, received copper sulfate treatment at the rate of 750 pounds per application four times a year during 1979 to 1983 and at the rate of 100 pounds of copper sulfate along with 50 pounds of citric acid per application four times each year during 1984 to 1986. Detailed limnological studies were carried out during calendar year 1987 to assess the physical, chemical, and biological characteristics of the lake. The primary objective of the investigation was to develop criteria for applying copper sulfate to control algae in water supply impoundments. A unique feature of this investigation was the enclosure and intensive monitoring studies to delineate the concentrations of copper in the aqueous

phase and the environmental impact during the first 10 days after copper sulfate treatment.

The lake developed a temperature gradient during summer months, with consequent depletion of oxygen in the deeper waters. During the peak stratification period there was no oxygen at depths below 8 feet from the surface, and about 29% of the lake volume was anoxic. On the basis of winter total phosphorus levels and summer chlorophyll-a and secchi disc values, the lake is deemed to be eutrophic.

Green algae were the dominant algae found in the lake, and blue-greens were insignificant. Two copper sulfate treatments (100 pounds each) were carried out: one on June 17, 1987 with the concurrence of the authors and another on August 17, 1987 when the senior author was away on vacation. In retrospect, these treatments were not necessary.

There were no taste and odor complaints by consumers during 1987, and the raw water intake structure was manipulated in such a way as to draw water at depths between 3 and 4 feet below the lake surface, which had adequate oxygen. It is surmised that taste and odor problems in the past were due to the withdrawal of anoxic waters from the deep zones of the lake and not to algal blooms in the lake.

Significant findings of this investigation are:

- The use of citric acid as a chelating agent enhances the solubility of copper and causes copper to remain in solution longer than when no chelating agent is used.

- An algal bloom composed of different species invariably develops within a very few days after copper sulfate treatment to control the standing crop.

- It is difficult to predict the dynamics or species succession of algal growths.

- A copper sulfate dosage rate of 5.4 pounds/acre along with 2.7 pounds/acre of citric acid was adequate to control problem-causing blue-green algae in waters with high alkalinity.

- The use of citric acid as a chelating agent did not cause any increase of other heavy metals in the water column.

REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1985. <u>Standard Methods for the Examination of Water and Wastewater</u>. Sixteenth Edition, 1268 p.

American Water Works Association. 1950. <u>Water Quality and Treatment</u>. American Water Works Association, New York, N.Y.

Bogner, W.C. 1987. <u>Sedimentation Survey of Lake Loami. Sangamon County. Illinois</u>. Illinois State Water Survey Contract Report 433, 9 p.

deBussey, I. 1969. <u>Control of Aquatic Plant Nuisances</u>. Verhandlungen der Internationalen Vereinigung Fur-Theoretische und Angewandte Limnologic, vol. 17, pp. 539-545.

Demayo, A., and M.C. Taylor. 1981. <u>Guidelines for Surface Water Quality. Vol. 1. Inorganic Chemical Substances Copper</u>. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada, 55 p.

Effler, S.W., S.D. Field, T. Tong-Ngork, F. Hale, M. Meyer, and M. Quirk. 1980. <u>Whole Lake Responses to Low Level Copper Sulfate Treatment</u>. Water Research, Vol. 14, No. 10, pp. 1489-1499.

Elder, J.F., and A.J. Horne. 1978. <u>Copper Cycles and CuSO$_4$ Algicidal Capacity in Two California Lakes</u>. Environmental Management, Vol. 2, pp. 17-30.

Fair, M.G., C.J. Geyer, and D.A. Okun. 1971. <u>Elements of Water Supply and Wastewater Disposal</u>. Second Edition, John Wiley and Sons, Inc., New York, 752 p.

Ficek, K.J. 1983. <u>Raw Water Reservoir Treatment with Potassium Permanganate</u>. Paper presented at the 74th Annual Meeting of the Illinois American Water Works Association, Chicago, IL, March 23.

Fillos, J., and W.R. Swanson. 1975. <u>The Release Rate of Nutrients from River and Lake Sediments</u>, Journal Water Pollution Control Federation, Vol. 47, No. 5, pp. 1032-1042.

Fitzgerald, G.P. -1963. <u>Factors Affecting the Toxicity of Copper to Algae and Fish</u>. Paper Presented at ACS National Meeting, New York, NY, September 8-13.

<u>Food Chemical Codex</u>. 1966. Committee on Specifications of the Food Chemical Codex of the Food Protection Committee, National Academy of Science - National Research Council, National Academy Press, First Edition, pages 189 and 190.

Fruh, E.G. 1967. <u>The Overall Picture of Eutrophication</u>. Journal Water Pollution Control Federation, Vol. 39, No. 9, pp. 1449-1463.

Gachter, R., R.S. Davies, and A. Mares. 1978. Regulation of Copper Availability to Phytoplankton by Macromolecules in Lake Water. Environ. Sci. Technol. 12: 1416-1422.

Gachter, R.K., Lum-Shue-Chan, and Y.K. Chau. 1974. Complexing Capacity of the Nutrient Medium and Its Relation to Inhibition of Algal Photosynthesis by Copper. Schweizerische Zeitschrift fur Hydrologie, Vol. 35, pp. 252-261.

Gibson, C.E. 1972. The Algicidal Effect of Copper on a Green and a Blue-Green Algae and Some Ecological Implications, Journal of Applied Ecology, Vol. 9, pp. 513-518.

Gratteau, J.C. 1970. Potential Algicides for Control of Algae. Water and Sewage Works, pp. R24-R48.

Guy, R.D., and A.R. Kean. 1979. Algae as a Speciation Monitor - A Comparison of Algal Growth and Computer Calculated Speciation. Water Research, Vol. 14, No. 7, pp. 891-899.

Hanson, M.J., and H.G. Stefan. 1984. Side Effects of 58 Years of Copper Sulfate Treatment of the Fairmont Lakes. Minnesota. Water Resources Bulletin, Vol. 20, No. 6, pp. 889-900.

Harrison, F.L., and D.J. Bishop. 1984. A Review of the Impact of Copper Released into Freshwater Environments. NUREG/CR-3478, Lawrence Livermore National Laboratory, Livermore, CA, 89 p.

Horne, A.J., and C.R. Goldman. 1974. Suppression of Nitrogen Fixation by Blue-Green Algae in a Eutrophic Lake with Trace Additions of Copper. Science, Vol. 183, pp. 409-411.

Illinois Pollution Control Board. 1982. State of Illinois Rules and Regulations. Title 35: Environmental Protection, Subtitle F: Public Water Supplies, Chapter I, 19 p.

James, R.O., and T.W. Healy. 1972. Adsorption of Hydrolvzeable Metal Ions at the Oxide-Water Interface, J. Colloid Interface Sci. 40: 42.

Jones, R.A., and G.F. Lee. 1982. Chlorophyll. A Raw Water Quality Parameter. Journal American Water Works Association, Vol. 74, No. 9, pp. 490-494.

Kothandaraman, V., and R.L. Evans. 1975. Some Water Quality Aspects in a Nascent Impoundment in Central Illinois. Transactions Illinois State Academy of Science, Vol. 68, No. 3, pp. 292-309.

Kothandaraman, V., and R.L. Evans. 1982. Aeration-Destratification of Lake Eureka Using a Low Energy Destratifier, Illinois State Water Survey Circular 155, 32 p.

Kothandaraman, V., and R.L. Evans. 1983a. Diagnostic-Feasibility Study of Johnson Sauk Trail Lake. Illinois State Water Survey Contract Report 312, 126 p.

Kothandaraman, V., and R.L. Evans. 1983b. <u>Diagnostic-Feasibility Study of Lake Le-Aqua-Na</u>. Illinois State Water Survey Contract Report 313, 133 p.

Kothandaraman, V., D. Roseboom, and R.L. Evans. 1980. <u>Pilot Lake Restoration Investigations - Aeration and Destratification in Lake Catherine: Second Year Operation</u>. Illinois State Water Survey Contract Report 228, 47 p.

Kott, P. 1969. <u>Effects of Halogens on Algae</u>. Water Research, Vol. 3, pp. 251-256.

Landers, D.H. 1979. <u>A Durable. Reusable. Enclosure System That Compensates for Changing Water Levels</u>. Limnology and Oceanography, Vol. 24, No. 5, pp. 991-994.

Lewis, M.A. 1986. <u>Comparison of the Effects of Surfactants on Freshwater Phytoplankton Communities in Experimental Enclosures and on Algal Population Growth in the Laboratory</u>. Environmental Toxicology and Chemistry, Vol. 5, pp. 319-332.

Lin, S., and R.L. Evans. 1981. <u>Relationships between Odor and Commonly Measured Water Quality Characteristics in Surface Water Supplies</u>. Illinois State Water Survey Report of Investigation 100, 35 p.

Lin, S.D., R.L. Evans, and D.B. Beuscher. 1971. <u>Algal Removal by Alum Coagulation</u>. Illinois State Water Survey Report of Investigation 68, 20 P.   .

Mackenthun, K.M. 1969. <u>The Practice of Water Pollution Biology</u>. U.S. Department of Interior, U.S. Government Printing Office, pp. 239-245.

Mackenthun, K., and H.L. Cooley. 1952. <u>The Biological Effect of Copper Sulfate Treatment on Lake Ecology</u>. Wisconsin Academy of Science, Arts, and Letters, Vol. 41, pp. 177-187.

Mackenthun, K.M., and Keuple, L.E. 1970. <u>Biological Problems Encountered in Water Supplies</u>. Journal American Water Works Association, Vol. 62, No. 8, pp. 520-526.

McGuire, M.J., R.M. Jones, E.G. Means, G. Izaguirre, and E.A. Preston. 1984. <u>Controlling Attached Blue-Green Algae with Copper Sulfate</u>. Journal American Water Works Association, Research and Technology, May, pp. 60-65.

McKinney, R.E. 1962. <u>Microbiology for Sanitary Engineers</u>. McGraw Hill Book Co., Inc., New York, pp. 157-159.

McKnight, D.M. 1981. <u>Chemical and Biological Processes Controlling the Response of a Fresh Water Ecosystem to Copper Stress: A Field Study of the Mill Pond Reservoir. Burlington. Massachusetts</u>. Limnology and Oceanography, Vol. 26, No. 3, pp. 518-531.

McKnight, D.M., G.L. Feder, E.M. Thurman, and R.L. Wershaw. 1983. Complexation of Copper by Aquatic Humic Substances from Different Environment. The Science of the Total Environment, Vol. 28, pp. 65-76.

McQueen, D.J., and D.R.S. Lean. 1983. Hvpolimnetic Aeration and Dissolved Gas Concentrations Enclosure Experiments,Water Research, Vol. 17, No. 12, pp. 1781-1790.

McQueen, D.J., and V.A. Story. 1986. Impact of Hvpolimnetic Aeration on Zooplankton and Phytoplankton Populations, Environmental Technology Letters, Vol. 7, pp. 31-44.

Meadows, M.D. 1984. Reservoir Management, Southwest and Texas Waterworks Journal, Vol. 65, No. 11, pp. 8-12.

Muchmore, C.B. 1973. Algae Control in Water Supply Reservoir. Illinois Institute for Environmental Quality, IIEQ Document No. 73-9, 29 p.

Palmer, CM. 1962. Algae in Water Supplies. An Illustrated Manual on the Identification. Significance and Control of Algae in Water Supplies. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 88 p.

Raman, R.K. 1985. Experiences of Long-Term Destratification in a Water Supply Impoundment. Lake and Reservoir Management, Vol. II, Proceeds of the Fifth Annual Conference and International Symposium on Applied Lake & Watershed Management, November 13-16, Lake Geneva, WI, North American Lake Management Society, pp. 271-276.

Raman, R.K. 1988. Aeration Destratification Succeeds in Illinois Lakes. Lake Line, Vol. 8, No. 1, pp. 6-7.

Raman, R.K., D.B. Beuscher, and B.R. Arbuckle. 1984. In-Lake Water Quality Management for Lake Eureka: Highlights of Third Year (1983) Operation. Illinois State Water Survey Circular 162, Champaign, 16 p.

Raman, R.K., D.B. Beuscher, D.H. Schnepper, and D.L. Hullinger. 1986. Water Quality Monitoring of Johnson Sauk Trail Lake after Implementation of Management Techniques, Illinois State Water Survey Contract Report 407, Peoria, IL, 66 p.

Raman, R.K., and B.K. Cook. 1986. Optimal Chelant/Copper Ratios for Maximizing Copper Solubility in Natural Waters Using Citric Acid and Triethanolamine, Illinois State Water Survey Contract Report 392, 52 p.

Richey, D. , and D. Roseboom. 1978. Acute Toxicity of Copper to Some Fishes in High Alkalinity Water. Illinois State Water Survey Circular 131, 24 P.

Solomon, K.R., J.J. Yoo, D. Lean, N.K. Kaushik, K.E. Day, and G.L. Stephenson. 1986. Methoxvchlor Distribution. Dissipation, and Effects in Freshwater Limnocorrals, Environmental Toxicology and Chemistry, Vol. 5, No. 6, pp. 577-586.

Spear, P.A., and R.C. Pierce. 1979. Copper in Aquatic Environment Chemistry. Distribution, and Toxicology. NRCC No. 16454, National Research Council of Canada, 227 p.

Stern, M.S., D.H. Stern, and L.L. Ray. 1978. Citric Acid Enhancement of Copper Sulfate Toxicity to Blue-Green Algae and Other Nuisance Organisms. Department of Biology, University of Missouri, Kansas City, MO, Project No. A-099-MO, 84 p.

Stiff, M.J. 1971. The Chemical States of Copper in Polluted Fresh Water and a Scheme of Analysis to Differentiate Them. Water Research, Vol. 5, p. 585-599.

Sylva, R.N. 1976. The Environmental Chemistry of Copper (II) in Aquatic Systems. Water Research, Vol. 13, pp. 515-523.

Symmes, K.H. 1975. Preliminary Investigation into Copper Cycling in Indian Lake. Massachusetts: A Lake Treated Annually with Copper Sulfate. ONER Project Number A-064-MASS, Water Resources Center, University of Massachusetts, Amherst, Massachusetts, 37 p.

U.S. Environmental Protection Agency. 1980. Clean Lakes Program Guidance Manual, EPA-440/5-81-003, Office of Water Regulations and Standards, Washington, D.C., 103 p. plus appendices.

U.S. Government Printing Office. 1968. Report of the Committee on Water Quality Criteria, pp. 60-64.

Wagemann, R. and J. Barica. 1979. Speciation and Rate of Loss of Copper from Lakewater with Implications of Toxicity. Water Research, Vol. 13, pp. 515-523.

Whitaker, J., J. Barcia, H. Kling, and M. Buckley. 1978. Efficacy of Copper Sulfate in the Suppression of *Aphanizonemon Flos-aquae* Blooms in Prairie Lakes. Environmental Pollution, Vol. 15, pp. 185-194.

Wilbur, C.G. 1969. The Biological Aspects of Water Pollution. Charles Thorns Publishing Co., Springfield, IL, 111 p.

Appendix A. Dissolved Oxygen and Temperature Observations
for Lake Loami near Water Intake

Depth	1/21		2/19		3/25		4/22		5/6		5/20	
	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	12.3	1.8	13.4	3.0	10.0	10.7	8.5	19.5	9.4	18.4	12.6	26.9
2	11.8	2.3	13.4	2.4	9.9	10.7	8.4	19.5	9.5	18.3	12.6	26.4
4	11.5	2.4	13.3	2.3	9.9	10.7	8.4	19.5	9.4	18.0	13.7	25.9
6	11.4	2.4	13.4	2.3	9.8	10.8	7.2	16.4	9.4	18.0	13.3	24.8
8	11.2	2.5	13.4	2.2	9.8	10.7	7.2	14.2	8.7	17.6	13.3	22.7
10	10.8	2.6	13.3	2.3	9.7	10.7	6.7	13.3	4.7	16.7	11.6	20.0
12	9.8	2.8	13.3	2.2	9.6	10.7	4.0	12.4	0.6	14.6	9.0	19.8
14	8.9	2.9	13.3	2.4	4.4	8.4	0.8	11.5	0.2	13.6	1.5	18.7
16			12.7	2.5			0.4	11.3	0.2	13.2		

Depth	6/3		*6/17		6/18		6/20		6/22		6/24	
	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	9.0	25.1	12.6	29.0	11.8	29.4	7.4	28.5	4.0	28.5	3.8	27.9
2	8.9	25.1	12.8	29.0	11.7	29.4	7.4	28.5	4.0	28.5	3.6	27.7
4	8.9	25.1	13.4	29.0	11.3	29.4	7.4	28.5	3.9	28.5	3.4	27.5
6	8.9	25.1	14.4	28.4	11.4	29.2	7.3	28.5	3.9	28.5	2.9	27.3
8	8.8	25.1	14.1	25.7	9.9	25.9	3.4	27.7	3.4	28.4	2.2	26.9
10	8.8	24.7	2.3	24.5	1.5	24.7	0.5	25.8	0.5	27.3	1.1	26.8
12	5.2	21.9	0.3	23.1	0.3	23.5	0.4	23.9	0.4	25.5	0.4	24.7
14	1.8	20.8	0.3	22.7	0.3	22.4	0.4	22.6	0.4	23.0	0.4	22.9

Depth	6/27		7/1		7/14		7/28		8/11		8/25	
	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	6.6	26.0	4.6	25.2	6.7	26.1	9.3	31.1	8.6	28.3	4.7	23.9
2	6.6	26.0	4.5	25.2	6.7	26.1	9.1	31.0	8.6	28.1	4.7	23.9
4	6.5	26.0	4.5	25.2	6.7	26.1	9.1	30.9	8.6	28.0	4.7	24.0
6	6.5	25.9	4.5	25.2	6.6	26.0	6.6	30.8	8.4	27.9	4.7	23.9
8	6.5	25.9	3.7	25.2	4.3	25.5	1.8	29.6	7.5	27.8	4.7	23.9
10	6.4	25.9	1.5	24.9	0.8	24.4	0.5	26.5	5.3	27.7	4.3	23.9
12	1.3	24.9	0.4	24.4	0.5	23.0	0.5	23.6	1.3	27.4	4.3	23.8
14	0.5	23.1	0.4	23.4	0.5	22.2	0.5	21.7	0.4	22.3		
16	0.4	22.6	0.4	23.0								

Depth	9/8		9/23		10/14		11/10		12/10	
	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.
0	7.7	24.4	9.0	18.7	10.3	11.0	10.0	8.7	12.1	6.4
2	7.7	24.4	8.9	18.8	10.3	10.9	10.0	8.9	12.1	6.3
4	7.7	24.4	8.9	18.8	10.3	10.8	9.9	8.9	12.1	6.3
6	5.9	23.9	8.9	18.8	10.2	10.7	9.9	9.0	12.0	6.2
8	2.4	22.9	8.6	18.7	10.2	10.7	9.9	8.9	12.0	6.2
10	0.7	22.5	8.0	18.3	10.3	10.7	9.9	8.9	12.0	6.2
12	0.4	22.1	7.9	18.3	10.3	10.7	9.9	9.0	11.9	6.2
14					10.3	10.7				

DO - mg/l

Temperature - degrees Celsius

*Copper sulfate was applied on 6/17/87 after DO and temperature observations were made.
Potassium permanganate was applied on 6/20/87.

Appendix B-l. Physical and Chemical Characteristics of Surface Waters
              in Lake Loami Near Water Intake

	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	7/1
Secchi Disc	60	27	25	44	66	82	84	65	31
Chlorophyll-a	4.4	16.0	14.8	2.0	3.8	1.6	2.5	7.0	36.2
pH	7.81	8.00	8.18	8.30	8.55	9.43	9.68	9.98	8.69
Alkalinity	158	182	179	171	167	100	101	104	108
Hardness	180	206	216	202	203	143	146	133	126
Conductivity	372	461	437	415	416	295	309	298	294
Suspended Solids	4	8	16	12	5	5	6	9	21
PO4 Total	0.03	0.06	0.07	0.05	0.03	0.02	0.03	0.04	0.10
PO4 Dissolved	0.02	0.06	0.01	0.02	0.02	0.01	0.01	0.01	0.02
NH3 Total	0.25	0.14	0.08	0.15	<0.01	0.05	0.03	0.05	0.22
N03/2	0.79	2.40	1.60	5.12	1.06	0.70	0.68	0.02	0.02
Cu Total	0.04	0.03	0.04	0.01	0.02	0.01	0.01	0.07	0.03
Fe Total	0.15	0.27	0.40	0.54	0.26	0.12	0.16	0.12	0.29
Mn Total	0.06	0.05	0.05	0.02	0.01	0.02	0.04	0.03	0.13
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10
Secchi Disc	48	78	38	27	42	30	39	33	31.5
Chlorophyll-a	36.7	7.5	15.8	13.3	9.1	7.9	7.9	11.9	17.4
pH	8.80	9.42	9.41	8.00	8.54	8.87	8.92	9.18	8.42
Alkalinity	119	110	111	124	130	138	141	136	132
Hardness	143	137	132	143	152	159	175	165	178
Conductivity	296	289	276	311	317	330	359	342	367
Suspended Solids	19	9	11	13	5	13	10	16	15
PO4 Total	0.08	0.04	0.08	0.13	0.05	0.07	0.05	0.06	0.07
PO4 Dissolved	0.03	0.02	0.02	0.04	0.01	0.02	0.02	0.02	0.02
NH3 Total	0.06	0.07	0.09	0.21	0.03	0.07	0.11	0.10	0.15
N03/2	0.13	0.04	<0.01	0.03	0.01	0.05	0.05	0.14	0.23
Cu Total	0.03	0.03	0.04	0.03	0.06	0.07	0.02	0.03	0.02
Fe Total	0.23	0.09	0.22	0.21	0.40	0.57	0.39	0.40	0.39
Mn Total	0.16	0.08	0.08	0.40	0.07	0.10	0.08	0.08	0.04
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Units of measurement: Secchi - inches; Chlorophyll - µg/L; pH - units;
                       Conductivity - umhos/cm; others - mg/L

Appendix B-2. Physical and Chemical Characteristics of Mid-Depth Waters
in Lake Loami Near Water Intake

	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	7/1
Secchi Disc	60	27	25	44	66	82	84	65	31
Chlorophyll-a	6.0	26.0	15.5	5.6	4.8	2.6	3.9	10.1	31.7
pH	7.85	7.60	8.15	8.00	8.55	9.20	9.76	10.00	8.75
Alkalinity	153	184	176	174	.167	110	106	106	108
Hardness	179	207	218	210	202	168	147	134	129
Conductivity	358	439	427	419	414	314	297	290	287
Suspended Solids	4	8	17	15	9	6	5	11	19
P04 Total	0.05	0.06	0.15	0.07	0.03	0.02	0.04	0.05	0.10
P04 Dissolved	0.01	0.06	0.01	0.03	0.02	0.01	0.02	0.01	0.03
NH3 Total	0.42	0.05	0.10	0.12	0.05	0.04	0.06	0.01	0.17
N03/2	0.31	2.41	1.53	0.74	1.14	1.76	0.35	0.04	0.01
Cu Total	0.02	0.02	0.04	0.03	0.02	0.01	0.02	0.03	0.05
Fe Total	0.16	0.34	0.39	0.74	0.27	0.10	0.22	0.19	0.26
Mn Total	0.07	0.05	0.05	0.03	0.01	0.03	0.09	0.05	0.14
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10
Secchi Disc	4.8	78	38	27	42	30	39	33	31.5
Chlorophyll-a	34.3	9.0	17.4	13.3	10.5	6.2	7.0	10.8	17.7
pH	8.70	9.42	9.41	8.30	8.42	8.87	8.92	9.17	8.42
Alkalinity	119	107	111	128	130	137	144	138	132
Hardness	142	136	132	146	152				
Conductivity	293	285	279	306	319	329	360	344	367
Suspended Solids	18	7	15	10	6	10	12	15	16
P04 Total	0.08	0.04	0.07	0.12	0.05	0.07	0.05	0.07	0.07
P04 Dissolved	0.03	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.02
NH3 Total	0.23	0.11	0.01	0.13	0.18	0.05	0.08	0.17	0.14
N03/2	0.12	0.13	<0.01	0.03	0.01	0.05	0.07	0.16	0.62
Cu Total	0.04	0.02	0.04	0.02	0.02	0.05	0.02	0.03	0.02
Fe Total	0.21	0.08	0.25	0.20	0.18	0.63	0.43	0.44	0.38
Mn Total	0.16	0.09	0.09	0.41	0.08	0.10	0.09	0.08	0.04
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Units of measurement: Secchi - inches; Chlorophyll - µg/L; pH - units;
Conductivity - µmhos/cm; others - mg/L

Appendix B-3. Physical and Chemical Characteristics of Near-Bottom Waters
in Lake Loami Near Water Intake

	1/21	2/19	3/25	4/22	5/6	5/20	6/3	6/17	7/1
Secchi Disc	60	27	25	44	66	82	84	65	31
Chlorophyll-a	5.9	22.0	14.0	13.8	3.6	135.0	29.0	36.8	34.6
pH	7.79	7.90	8.09	7.70	7.71	8.18	9.05	8.78	8.12
Alkalinity	149	165	180	185	188	202	144	159	121
Hardness	179	218	221	218	211	249	171	188	152
Conductivity	358	435	431	432	440	485	355	387	307
Suspended Solids	81	26	30	53	13	21	10	12	27
PO4 Total	0.09	0.05	0.16	0.14	0.06	0.06	0.08	0.08	0.55
PO4 Dissolved	0.02	0.03	0.01	0.04	0.02	0.01	0.03	0.05	0.10
NH3 Total	0.24	0.07	0.14	0.50	0.47	0.32	0.27	0.15	1.93
NO3/2	0.26	2.45	1.63	0.96	0.60	4.13	0.88	0.78	0.05
Cu Total	0.02	0.07	0.09	0.05	0.03	<0.01	0.01	0.02	0.06
Fe Total	0.34	1.94	2.70	1.40	0.68	0.16	0.26	0.23	0.59
Mn Total	0.10	0.10	0.23	0.25	0.60	0.22	0.18	0.17	1.24
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

	7/14	7/28	8/11	8/25	9/8	9/23	10/13	11/10	12/10
Secchi Disc	4.8	78	38	27	42	30	39	33	31.5
Chlorophyll-a	18.4	16.8	24.1	13.2	22.3	9.9	6.8	13.8	16.5
pH	7.25	9.05	8.89	8.30	7.62	8.86	8.95	9.22	8.40
Alkalinity	189	118	123	126	139	137	144	140	131
Hardness	156	139	142	144					
Conductivity	372	296	300	308	327	331	357	341	368
Suspended Solids	19	7	10	13	19	19	13	15	20
PO4 Total	0.80	0.39	0.27	0.14	0.21	0.10	0.11	0.07	0.07
PO4 Dissolved	0.70	0.02	0.14	0.03	0.09	0.02	0.02	0.02	0.02
NH3 Total	4.32	1.30	0.92	0.24	0.03	0.08	0.08	0.19	0.09
NO3/2	0.22	0.68	0.05	0.03	0.02	0.05	0.07	0.21	0.22
Cu Total	0.05	0.02	0.05	0.05	0.20	0.04	0.11	0.03	0.02
Fe Total	1.67	0.20	0.31	1.52	5.64	0.70	5.04	0.53	0.47.
Mn Total	1.10	0.52	0.97	0.39	1.53	0.11	0.30	0.08	0.04
CN-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Units of measurement: Secchi - inches; Chlorophyll - µg/L; pH - units;
Conductivity - umhos/cm; others - mg/L

Appendix B-4. Chemical Characteristics of Lick Creek at Loami, IL

	1/21	2/19	3/25	4/22	5/6	5/20	6/3
Chlorophyll-a	2.3	3.2	9.3	5.0	1.7	4.5	4.2
pH	7.86	8.00	8.00	8.10	8.29	8.02	7.95
Alkalinity	284	276	280	278	262	273	257
Hardness	365	363	357	339	339	324	314
Conductivity	684	656	657	647	655	623	599
Suspended Solids	18	6	12	53	16	31	56
P04 Total	0.05	0.04	0.06	0.12	0.05	0.10	0.19
P04 Dissolved	0.04	0.02	0.03	0.05	0.03	0.04	0.10
NH3 Total	0.26	0.03	0.11	0.13	0.10	0.12	0.09
N03/2	7.82	9.89	7.25	11.60	10.70	8.56	6.74
Cu Total	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Fe Total	0.34	0.22	0.38	1.60	0.78	1.04	2.44
Mn Total	0.10	0.08	0.18	0.09	0.04	0.07	0.10
CN-	<0.01	0.02	<0.01	0.06	0.03	0.02	0.01

	6/17	7/1	7/14	7/28	8/11	12/10
Chlorophyll-a	4.3	6.1	3.8	13.2	32.5	3
pH	7.93	8.05	8.20	7.96	8.15	7.69
Alkalinity	262	244	317	292	233	136
Hardness	305	289	364	328	261	
Conductivity	592	571	661	624	505	542
Suspended Solids	86	72	46	37	17	42
P04 Total	0.40	0.32	0.17	0.20	0.23	1.06
P04 Dissolved	0.14	0.10	0.08	0.10	0.15	0.81
NH3 Total	0.13	0.12	0.17	0.12	0.17	0.53
N03/2	3.86	7.20	7.41	1.44	0.14	2.18
Cu Total	0.02	0.01	0.01	<0.01	<0.01	0.01
Fe Total	3.14	4.07	1.68	1.46	0.86	1.96
Mn Total	0.22	0.16	0.08	0.14	0.26	0.17
CN-	<0.01	0.01	0.01	<0.01	<0.01	0.01

Units of measurement: Chlorophyll - µg/L; pH - units;
                       Conductivity - µmhos/cm; others - mg/L

Note: There was no flow in the period
       between 8/4 and 12/10

Some of the algae produce an "aromatic" odor which is described more specifically for certain organisms as that resembling a particular flower or vegetable. Common examples of these would be geranium, nasturtium, violet, muskmelon, and cucumber. In some cases it is described as an attractive spicy odor, but in others it may be very objectionable, as for example, a skunk or garlic odor. Some pigmented flagellates and diatoms produce the aromatic odors when these organisms are present in small numbers in the water.

A second type of odor, the "fishy" odor, is produced often by the same algae that are responsible for the aromatic odors. The organisms generally are present in much larger numbers when the fishy odor is evident. More specific terms that have been used to describe the fishy odors of various algae are clam-shell, cod-liver oil, sea weed, Irish moss, rockweed, and salt marsh. The differences between these are probably insignificant in water supply studies.

A third type of odor is the somewhat aromatic one which is described as "grassy." It is the most common one produced by green algae and generally is apparent only when the organisms are present in large numbers. It is reported also for certain blue-green algae and occasionally for diatoms and pigmented flagellates.

The fourth type of odor is the one which includes those described as "musty" and "earthy." The latter is commonly associated with actinomycetes (3,4) and with a few algae. It can vary from mild to decidedly pungent. The earthy odor of soil also has been considered to be due to the presence of actinomycetes. The very common musty odor in water is encountered in the presence of certain blue-green algae and a few other forms. It has been described by additional terms such as potato bin and moldy. Some waters have been reported as having weedy, swampy, marshy, peaty, straw-like and woody odors and these are possibly a modification or a combination of the grassy and musty odors.

A "septic" odor has been associated frequently with the presence of large accumulations of blue-green algae and occasionally of the green algae, *Hydrodictyon* and *Cladophora.* Other names applied to this type of odor are pigpen, foul, objectionable, vile, fermentation, and putrefactive (5). As these terms suggest, it is produced as a result of the decomposition of

masses of algae, especially where a lack of sufficient oxygen permits the formation of odoriferous intermediate products from the algal proteins.

Chlorophenolic, iodoform, or medicinal odors may be produced by the action of chlorine on the products of certain algae although somewhat similar odors may be present in the water at other times because of industrial wastes.

Measurement of Odors

For the measurement of odors in water the threshold odor test is commonly employed (6). The threshold odors due to algae tend, in some areas, to be comparatively low, ranging from 1 to 14, but in other areas they frequently go up to 30 or 40, and occasionally reach as high as 90 or more. Algal odors are generally objectionable, however, even when the threshold odor number is low. For satisfactory treatment, the threshold odor usually has to be reduced to 5 or less. However, each water supply and often each odor outbreak must be judged independently, in determining the threshold number below which the water is considered palatable.

In some plants the treatment is instituted as soon as any taste and odor algae increase to a predetermined number of areal standard units per ml. The number varies according to the particular kind of alga involved; for *Asterionella.* it may be 3,000, and for Synura, 200 (7).

Tastes produced by algae are seldom separated from and are often confused with odor. Sweet and bitter are the two tastes which have been recorded and it is quite possible that a sour taste may be present whenever the odor is acid or is the putrefactive, septic, or pigpen type. A salty taste apparently has not been recorded as an accompaniment of the fishy, clam-shell, salt marsh, rockweed, Irish moss, or sea weed-like odors.

An additional sensation which the tongue can detect might be listed as the "feel" or "touch." Included here would be the slick or "oily" feel as well as a "metallic," a "dry," and an "astringent" sensation. Odor, taste, and feel, as recorded for each algal genus are given in table 5. The word "flavor" could be used as an inclusive term embracing taste, odor, and touch or feel (8).

Principal Odor-Producing Algae

Synura is one of the more potent algae in production of an odor in water which is often described as resembling that of a ripe cucumber or muskmelon. A comparatively few colonies per ml. may be sufficient to cause a very perceptible odor. This organism also produces a bitter taste in the water and leaves a persistent

dry metallic sensation on the tongue. When present in large numbers, this, as well as other flagellates, may develop a fishy odor. In Massachusetts, for example, *Dinobryon, Uroglenopsis*, and the "armored" flagellate Peridinium produced a strong fishy odor in a large reservoir holding over 600 million gallons of water. These forms developed in February under a 16-inch layer of ice (9).   There is some evidence that *Uroglenopsis* is stimulated to rapid growth following an abundant growth of other algae.

In California one of the worst offenders is the armored flagellate *Ceratium* which produces a fishy to pronounced septic odor.   The organism is capable of very rapid multiplication and may develop in large numbers during any season (10).

Table 4. Taste and Odor Algae, Representative Species

Group and Algae	*Plate*
Blue-Green Algae (Myxophyceae):	
Anabaena circinalis	
Anabaena planctonica	1
Anacystis cyanea	1
Aphanizomenon flos-aquae	1
Cylindrospermum musicola	
Gomphosphaeria lacustris, kuetzingianum type	1
Oscillatoria curviceps	
Rivularia haematites	
Green Algae (nonmotile Chlorophyceae, etc.):	
Chara vulgaris	
Cladophora insignis	
Cosmarium portianum	
Dictyosphaerium ehrenbergianum	
Gloeocystis planctonica	
Hydrodictyon reticulatum	1
Nitella gracilis	1
Pediastrum-tetras	
Scenedesmus abundans	
Spirogyra majuscula	
Staurastrum paradoxum	1
Diatoms (Bacillariophyceae):	
Asterionella gracilima	1
Cyclotella compta	
Diatoma vulgare	2
Fragilaria construens	
Stephanodiscus niagarae	
Synedra ulna	1
Tabellaria fenestrata	1
Flagellates (Chrysophyceae, Euglenophyceae, etc.):	
Ceratium hirundinella	1
Chlamydomonas globosa	

```
Chrysosphaerella longispina
Cryptomonas erosa
Dinobryon divergens                                          1
Euglena sanguinea
Glenodinium palustre
Mallomonas caudata                                           1
Pandorina morum                                              1
Peridinium cinctum                                           1
Synura uvella                                                1
Uroglenopsis americana                                       1
Volvox aureus                                                1
```

Dinobryon develops in the southern end of Lake Michigan, in June and July, almost every year, in numbers sufficient to impart a prominent fishy odor to the water. As many as 700 areal standard units per ml. of this alga have been reported and it has represented, at times, up to 47 percent of the total algal count. Its odor has the reputation of being readily adsorbed by activated carbon. In spite of this, it is estimated that one treatment plant required over $70,000 worth of the carbon to control, for a period of 2 months, the odor due specifically to this alga (11).

Asterionella is considered one of the worst offenders among the diatoms, having a characteristic aromatic geranium-like odor that changes to fishy when the alga is present in large numbers. *Tabellaria* produces a similar effect, while *Synedra* has an earthy to musty odor and *Stephanodiscus* is blamed for a "vegetable to oily taste" with very little odor.

Certain blue-green algae are well known for developing very foul "pigpen" odors in water. Three of these algae, illustrated on plate 1, are *Anabaena, Anacystis* (formerly known as *Microcystis, Polycystis,* and *Clathrocystis),* and *Aphanizomenon.* All of these are capable of collecting in large masses sufficient to form water "blooms." The foul odor undoubtedly develops from products of decomposition as the algae begin to die off in large numbers. These same blue-green algae, together with others such as *Gomphosphaeria* (which now includes *Coelosphaerium),* *Cylindrospermum,* and *Rivularia* have a natural odor which is commonly described as "grassy." This often changes to the odor of nasturtium stems, probably as a result of oxidation.

Green algae are less often associated with tastes and odors in water. In fact, their growth may help to keep in check the blue-green algae and the diatoms and thus be a positive factor in the control of water quality. However, *Hydrodictyon* (water net), the desmid, Staurastrum, and the large massive stone-warts, *Nitella* and *Chara,* may offend rather than help in this biological competition between types. *Dictyosphaerium* is regarded as one of the worst offenders among the green algae, giving a fishy, as well as a grassy to nasturtium odor (12). Some of the swimming green algae which are listed with the flagellates, including *Volvox, Pandorina,* and *Chlamydomonas,* are able to produce fishy odors.

Table 5.   Odors, Tastes, and Tongue Sensations Associated With Algae in Water

Algal genus	Algal group	Odor when algae are Moderate	Abundant	Taste	Tongue sensation
Actinastrum	Green		Grassy, musty		
Anabaena	Blue-green	Grassy,nasturtium. musty.	Septic		
Anabaenopsis	Blue-green		Grassy		
Anacystis	Blue-green	Grassy	Septic	Sweet	
Aphanizomenon	Blue-green	Grassy,nasturtium, musty.	Septic	Sweet	Dry.
Asterionella	Diatom	Geranium, spicy	Fishy		
Ceratium	Flagellate	Fishy	Septic	Bitter	
Chara	Green	Skunk,garlic	Spoiled,garlic		
Chlamydomonas	Flagellate	Musty,grassy	Fishy,septic	Sweet	Slick.
Chlorella	Green		Musty		
Chrysosphaerella	Flagellate		Fishy		
Cladophora	Green		Septic		
(Clathrocystis)	See Anacystis.				
Closterium	Green		Grassy		
(Coelosphaerium)	See Gomphosphaeria.				
Cosmarium	Green		Grassy		
Cryptomonas	Flagellate	Violet	Violet	Sweet	
Cyclotella	Diatom	Geranium	Fishy		
Cylindrospermum	Blue-green	Grassy	Septic		
Diatoma	Diatom		Aromatic		
Dictyosphaerium	Green	Grassy,nasturtium	Fishy		
Dinobryon	Flagellate	Violet	Fishy		Slick.
Eudorina	Flagellate		Fishy		
Euglena	Flagellate		Fishy	Sweet	
Fragilaria	Diatom	Geranium	Musty		
Glenodinium	Flagellate		Fishy		Slick.
(Gloeocapsa)	See Anacystis.				
Gloeocystis	Green		Septic		
Gloeotrichia	Blue-green		Grassy		
Gomphosphaeria	Blue-green	Grassy	Grassy	Sweet	
Gonium	Flagellate		Fishy		
Hydrodictyon	Green		Septic		
Mallomonas	Flagellate	Violet	Fishy		
Melosira	Diatom	Geranium	Musty		Slick.
Meridion	Diatom		Spicy .		
(Microcystis)	See Anacystis.				
Nitella	Green	Grassy	Grassy,septic	Bitter	
Nostoc	Blue-green	Musty	Septic		
Oscillatoria	Blue-green	Grassy	Musty,spicy		
Pandorina	Flagellate		Fishy		
Pediastrum	Green		Grassy		
Peridinium	Flagellate	Cucumber	Fishy		
Pleurosigma	Diatom		Fishy		
Rivularia	Blue-green	Grassy	Musty		
Scenedesmus	Green		Grassy		
Spirogyra	Green		Grassy		
Staurastrum	Green		Grassy		

Appendix C.   Concluded

Stephanodiscus	Diatom	Geranium	Fishy		Slick.
Synedra	Diatom	Grassy	Musty		Slick.
Synura	Flagellate	Cucumber, muskmelon,spicy.	Fishy	Bitter	Dry, metallic slick.
Tabellaria	Diatom	Geranium	Fishy		
Tribonema	Green		Fishy		
(Uroglena)	See Uroglenopsis.				
Uroglenopsis	Flagellate	Cucumber	Fishy		Slick.
Ulothrix	Green		Grassy		
Volvox	Flagellate	Fishy	Fishy		

Appendix D.   Theoretical Dissolved Oxygen Saturation Values
(Dissolved oxygen in milligrams per liter)

Temperature

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	14.65	14.61	14.57	14.53	14.49	14.45	14.41	14.37	14.33	14.29
1	14.25	14.21	14.17	14.13	14.09	14.05	14.02	13.98	13.94	13.90
2	13.86	13.82	13.79	13.75	13.71	13.68	13.64	13.60	13.56	13.53
3	13.49	13.46	13.42	13.38	13.35	13.31	13.28	13.24	13.20	13.17
4	13.13	13.10	13.06	13.03	13.00	12.96	12.93	12.89	12.86	12.82
5	12.79	12.76	12.72	12.69	12.66	12.62	12.59	12.56	12.53	12.49
6	12.46	12.43	12.40	12.36	12.33	12.30	12.27	12.24	12.21	12.18
7	12.14	12.11	12.08	12.05	12.02	11.99	11.96	11.93	11.90	11.87
8	11.84	11.81	11.78	11.75	11.72	11.70	11.67	11.64	11.61	11.58
9	11.55	11.52	11.49	11.47	11.44	11.41	11.38	11.35	11.33	11.30
10	11.27	11.24	11.22	11.19	11.16	11.14	11.11	11.08	11.06	11.03
11	11.00	10.98	10.95	10.93	10.90	10.87	10.85	10.82	10.80	10.77
12	10.75	10.72	10.70	10.67	10.65	10.62	10.60	10.57	10.55	10.52
13	10.50	10:48	10.45	10.43	10.40	10.38	10.36	10.33	10.31	10.28
14	10.26	10.24	10.22	10.19	10.17	10.15	10.12	10.10	10.08	10.06
15	10.03	10.01	9.99	9.97	9.95	9.92	9.90	9.88	9.86	9.84
16	9.82	9.79	9.77	9.75	9.73	9.71	9.69	9.67	9.65	9.63
17	9.61	9.58	9.56	9.54	9.52	9.50	9.48	9.46	9.44	9.42
18	9.40	9.38	9.36	9.34	9.32	9.30	9.29	9.27	9.25	9.23
19	9.21	9.19	9.17	9.15	9.13	9.12	9.10	9.08	9.06	9.04
20	9.02	9.00	8.98	8.97	8.95	8.93	8.91	8.90	8.88	8.86
21	8.84	8.82	8.81	8.79	8.77	8.75	8.74	8.72	8.70	8.68
22	8.67	8.65	8.63	8.62	8.60	8.58	8.56	8.55	8.53	8.52
23	8.50	8.48	8.46	8.45	8.43	8.42	8.40	8.38	8.37	8.35
24	8.33	8.32	8.30	8.29	8.27	8.25	8.24	8.22	8.21	8.29
25	8.18	8.16	8.14	8.13	8.11	8.10	8.08	8.07	8.05	8.04
26	8.02	8.01	7.99	7.98	7.96	7.95	7.93	7.92	7.90	7.89
27	7.87	7.86	7.84	7.83	7.81	7.80	7.78	7.77	7.75	7.74
28	7.72	7.71	7.69	7.68	7.66	7.65	7.64	7.62	7.61	7.59
29	7.58	7.56	7.55	7.54	7.52	7.51	7.49	7.48	7.47	7.45
30	7.44	7.42	7.41	7.40	7.38	7.37	7.35	7.34	7.32	7.31

Appendix E
Copies of Written Communications between
the Illinois State Water Survey (Division of the Department of Energy
and Natural Resources) and the Science And Technology Branch, USEPA

April 22, 1985

Dr. Jitendra Saxena
USEPA
Office of Drinking Water (WH-550)
401 M Street, SW
Washington D.C. 20460

Dear Dr. Saxena:

I was recently advised to contact you concerning the in-lake application
of copper sulfate to control algal blooms in Illinois water supply im-
poundments.

Most of the lakes in the North and North Central Illinois have high
alkalinity and consequently the copper in $CuSO_4 \cdot 5H_2O$ applied to the lakes
tend to precipitate out as oxides or carbonates of copper. This essen-
tially renders the copper sulfate application ineffective at the gen-
erally accepted application rates of 5.4 lbs/acre. To overcome this problem
lake managers tend to apply copper sulfate at an exorbitantly high rate to
control algae. Kates as high as 100 lbs/acre have been used in Illinois
lakes. This is not only uneconomical but also is ecologically undesirable.

State Water Survey's United experience on three lakes indicate that the use
of copper sulfate at a rate of 5.4 lbs/acre mixed with citric acid as a che-
lating agent resulted in a five to ten fold increase in the dissolved copper
in lake waters. Use of copper sulfate mixed with citric acid on site was
found to be very effective in controlling problem causing algae and econo-
mical. Use of proprietary formulations such as "Cutrine", "Aquazine" which
are USEPA approved compounds are five to ten times more expensive.

Since copper sulfate is an approved algicide, and since citric acid is
covered in the Food Chemical Codex (page 86) which has no limitation on use,
will the use of copper sulfate mixed with citric acid for in-lake treatment
to control algae be in compliance with USEPA regulations? If this is not
true, I would like to know the steps I need to take to obtain soecial permission
from USEPA for applying copper sulfate mixed with citric acid in a recreational
lake for research purposes. I would also like to know whether there are any
USEPA approved copper sulfate formulations with citric acid as a chelant.

I appreciate very much your advice on this matter.

Sincerely yours,

Raman K. Raman, Ph.D., P.E.
Head, Water Quality Section
ILLINOIS STATE WATER SURVEY
P. O. Box 697
Peoria, IL 61652

Phone: 1-309-671-3196

RR/lj

State Water Survey Division

ENR

Water Quality Section
Foot of MacArthur Hwy
P.O. Box 697
Peoria, Illinois 61652
309/671-3196

June 27, 1985

Dr. Jitendra Saxena
USEPA
Office of Drinking Water (WH-550)
401 M Street, SW
Washington, D.C. 20460

Dear Dr. Saxena:

At the outset, I want to thank you for your prompt attention to my letter dated April 22, 1985 concerning copper sulfate applicaton practices in water supply impoundments and for providing copies of relevant segments from the chemical and food chemical codex.

I was able to persuade the Illinois EPA (IEPA) to permit the use of citric acid in addition to the copper sulfate. However, IEPA. does not want to allow the mixing of copper sulfate with citric acid before chemical treatment but insists that these two chemicals be applied separately. The reasoning is that copper sulfate is a USEPA approved algicide and citric acid is not registered as a herbicide or algicide. Consequently, the latter does not meet the FIFRA regulations. You may recall that the citric is intended to be used as a chelating agent for copper sulfate to prevent or minimize the precipitation of copper in high alkalinity waters.

Since copper sulfate is an approved algicide, and since citric acid is covered in the Food Chemical Codex, which has no limitation on use, will the use of copper sulfate mixed with citric acid for in-lake treatment to control algae be in general compliance with the applicable regulations? I would appreciate receiving a reply at an early date indicating the policy of the Office of Drinking Water in this matter.

I once again thank you for all your assistance in this matter.

Sincerely yours,

Raman K. Raman, Ph.D., P.E.
Head, Water Quality Section
ILLINOIS STATE WATER SURVEY
P. O. Box 697
Peoria, IL 61652

Phone: 1-309-671-3196

RR/lj

87

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON. D.C. 20460

JUL 17 1985

Dr. Raman K. Raman
Illinois State Water Survey
P. O. Box 697
Peoria, Il 61652

RE: File No. 07-001.00-AEB-85

Dear Dr. Raman:

Please be advised that we are in receipt of your June 27, 1985 letter requesting an opinion concerning safety of copper sulfate with citric acid for use in potable water systems. It has been assigned the following number for internal control purposes 07-001.00-AEB-85. In any future correspondence, please refer to this number.

We are making a concerted effort to process petitions as quickly as possible. However, EPA may not be able to process your request for an opinion on an additive product before the establishment of an alternative program as described in the Federal Register, Vol. 49, No. 97, 21003-8, May 17, 1984. You will receive a reply when the petition is processed.

If you have any questions or wish to provide further information, please write: Additives Program, Science and Technology Branch, Criteria and Standards Division, Office of Drinking Water (WH-550), U.S. Environmental Protection Agency, Washington, D.C. 20460.

Sincerely,

Arthur H. Perler, Chief
Science and Technology Branch (WH-550)

Water Quality Section
Foot of MacArthur Hwy
P.O. Box 697
Peoria, Illinois 61652
309/671-3196

March 26, 1986

Dr. Joyce Donohue
Additives Program
Science and Technology Branch
Criteria and Standards Division
Office of Drinking Water (WH-550)
U.S. Environmental Protection Agency
Washington, D.C. 20460

RE: File No. 07-001-00-AEB-85

Dear Dr. Donohue:

Pursuant to our recent telephone conversation, I am enclosing herewith two reports which give details of the amounts of copper sulfate and citric acid applied in two different lakes (page 9 in each of the two reports), methods of chemical application, and the results. The amount of copper sulfate applied was based on a concentration requirement suggested in the literature of 1 mg/1 (as $CuSO_4 \cdot 5 H_2O$) for the top 2 feet of the lake volume. This is equivalent to an application rate of 5.4 lbs/acre of the surface area of a lake. Citric acid was applied at the rate of 2.7 lbs/acre.

If you need any additional information, please let me know. Thank you very much for your assistance in this matter.

Sincerely,

Raman K. Raman, Ph.D., P.E.
Head, water Quality Section
ILLINOIS STATE WATER SURVEY
P. O. Box 697
Peoria, IL 61652

Phone: 1-309-671-3196

RKR/ljj
enc.

State Water Survey Division

ENR

Water Quality Section
Foot of MacArthur Hwy
P.O. Box 697
Peoria, Illinois 61652
309/671-3196

**Illinois Department of
Energy and Natural Resources**

June 12, 1986

Dr. Joyce Donohue
Additives Program
Science and Technology Branch
Criteria and Standards Division
Offic of Drinking Water (W H - 550)
U. S. Environmental Protection Agency
401 M Street SW
Washington, D. C. 20460

RE: File No. 07-001-00 AEB - 85

Dear Dr. Donohue:

Immediately after your telephone call concerning the use of $CuSO_4 \cdot 5H_2O$ in
water supply impoundments on March 25, 1986, I wrote a letter dated March
26, 1986 enclosing two published reports relevant to the subject matter
to the above cited address. The mail was returned to us a few days ago as
undeliverable.

I am writing this letter to make sure that the address as shown above, which
was given in Mr. Arthur H. Perler's letter dated July 1985, is correct.
I would appreciate, very much, your response to this letter so that I can
mail back the materials which I mailed earlier on March 26, 1986.

Sincerely,

Raman K. Raman, Ph. D., P. E.
Head, Water Quality Section

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON. D.C. 20460

Raman K. Raman, PhD, PE
Head, Water Quality Section
Illinois State Water Survey
P.O. Box 697
Peoria, XL 61652

**OFFICE OF
WATER**

JAN 25 1988

RE: File Number 07-001.00-AEB-85

Dear Dr. Raman:

   Based on the information submitted, the water treatment chemical listed below is acceptable for potable water applications when used within the stated restrictions, if any.

| | Maximum Recommended |
Product	Concentration
Copper Sulfate	1 mg/l Copper Sulfate
Citric Acid	0.5 mg/l Citric Acid

   Restriction: Application procedures should lead to uniform dispersion of chemicals in the treated water.

   We would not anticipate any adverse health effects resulting from use of this product when used at or below the requested feed rates, assuming the product continues to meet the supplied specifications and the specifications of the Water Chemicals Codex, 1982 edition (National Academy Press). and the Water Chemicals Codex: Supplementary Recommendations for Direct Additives, 1984 edition (National Technical Information Service).

   This opinion is granted on an interim basis only. EPA is in the process of establishing an alternative advisory program for drinking water additives as described in the Federal Register. Vol. 49. No. 97. 21003-8, May 17. 1984. When the new program is in place, all existing advisories may be periodically reviewed.

   Our opinion concerning the safety of the product does not constitute an endorsement, nor does it relate to product effectiveness for the intended use. If this letter is to be used in any way, we require that it be quoted in its entirety.

Sincerely,

Arthur H. Perler, Chief
Science and Technology Branch

REPORT DOCUMENTATION PAGE	1. REPORT NO. ILENR/RE-WR-88/19	2.	3. Recipient's Accession No.

4. Title and Subtitle
Guidelines for Applying Copper Sulfate as an Algicide: Lake Loami Field Study

5. Report Date
October 1988

6.

7. Author(s)
Raman K. Raman and Billy C. Cook

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Illinois State Water Survey
Water Quality Section
P.O. Box 697
Peoria, IL 61652

10. Project/Task/Work Unit No.
87/064

11. Contract(C) or Grant(G) No.
(C) WR 16
(G)

12. Sponsoring Organization Name and Address
Illinois Department of Energy & Natural Resources
Office of Research and Planning
325 West Adams, Room 300
Springfield, IL 62704-1892

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A field-scale investigation was carried out at Lake Loami, located 12 miles southwest of Springfield, Illinois, to develop criteria for applying copper sulfate to control algae in water supply impoundments. Detailed limnological studies were carried out during 1987 to assess the physical, chemical, and biological characteristics of the lake. A unique feature of this investigation was the enclosure and intensive monitoring studies to delineate the concentrations of copper in the aqueous phase and the environmental impact during the first 10 days after copper sulfate treatment.

The study found that the use of citric acid as a chelating agent enhances the solubility of copper and causes copper to remain in solution longer than when no chelating agent is used. An algal bloom composed of different species invariably develops within a few days after a copper sulfate treatment. It is difficult to predict the dynamics or species succession of algal growths. A copper sulfate dosage rate of 5.4 pounds/acre along with 2.7 pounds per acre of citric acid was adequate to control problem causing blue-green algae in waters with high alkalinity. The use of citric acid as a chelating agent did not cause any increase of other heavy metals in the water column.

17. Document Analysis a. Descriptors
Algae, Algicides, Chelating agents, Citric acid, Copper sulfate, Illinois, Lakes, Water supply

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 13/B

18. Availability Statement No restriction on distribution.
Available at IL Depository Libraries or from National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report) Unclassified	**21. No. of Pages** 91
20. Security Class (This Page) Unclassified	**22. Price**