Contract Report 569

Water Qualify Characteristics of Lake Bloomington and Lake Evergreen

by Raman K. Raman and Richard M. Twait
Office of Water Quality Management

Prepared for the
City of Bloomington

March 1994

Illinois State Water Survey
Chemistry Division
Champaign, Illinois

A Division of the Illinois Department of Energy and Natural Resources

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Introduction

Lake Bloomington, located approximately 15 miles north of the city of Bloomington in McLean County, was constructed in 1929 by impounding Money Creek. Hickory Creek, a tributary of Money Creek, also empties into Lake Bloomington. The lake was constructed to expand the city's water supply, and its primary use is as a water supply source for domestic, commercial, industrial, and agricultural purposes. It is also used for recreation and serves as a selling point for the residential developments that sprang up along its shores. The lake capacity was increased in 1957 by raising the dam 5 feet. Lake Evergreen, located about six miles west of Lake Bloomington, serves as a supplemental water source. Water is drawn from Lake Evergreen when Lake Bloomington is drawn down 5 feet from spillway level or when its water quality is better than that of Lake Bloomington.

The Bloomington water-supply system currently supplies about 62,000 people in the city of Bloomington, Hudson and Towanda Townships, and half of the population of Dale and Dry Grove Townships. The current average daily demand is 14 million gallons, and the maximum daily pumpage has varied from 18 to 20 million gallons per day (mgd). In order to meet both the short- and long-term supply needs, the city completed construction of the Mackinaw River Pumping Pool adjacent to Lake Evergreen in early 1990. When needed, river water can be pumped into Lake Evergreen. The raw water from Lake Evergreen can be delivered directly to the water treatment plant on the shores of Lake Bloomington. The city is also taking steps to raise the dam of Lake Evergreen by 5 feet to better meet the city's long-term water needs.

Owned by the city of Bloomington, Lake Bloomington has a surface area of 572 acres, a maximum depth of about 35 feet, an average depth of 12.9 feet, and a volume of 7380 acre-feet. The lake's 43,100-acre watershed includes corn and soybean cropland (86 percent), pasture (4 percent), woodland (5 percent), and water and urban areas (5 percent) (Soil and Water Conservation District, McLean County, 1991).

Lake Evergreen was created in 1971 by damming Six-Mile Creek where it flows northward into the Mackinaw River. The topography of the watershed is characterized by gently rolling uplands with slopes leading to the shoreline, unlike the flat open farmland of the surrounding region. There are no industries in the 25,730-acre watershed, and the village of Hudson, population 1,000, is the only community within the watershed. The lake has a surface area of 700 acres at spillway level, a maximum depth of 48 feet, a mean of 17 feet, and a storage capacity of 11,900 acre-feet. The predominant land use is row crops (87 percent) and other uses include small grains, pasture, alfalfa, residential development, and water.

McLean County experienced a severe two-year drought beginning in the spring of 1988. Lake water levels declined to well over 30 feet below normal pool levels in both lakes. Consequently, the city began to plan and develop an additional water supply for emergency use, the Mackinaw River Pumping Pool adjoining Lake Evergreen.

There was a distinct possibility that the water treatment system's intake in Lake Bloomington could run dry because of the lake's declining water level. To guard against this possibility, the city procured ten 30-horsepower, 480 volt, three-phase Dobbs floating pumps. The maximum rated capacity of the pumps is about 870 gallons per minute (gpm) against a total head of 70 feet for each pump. Because the drought ended before the need for the pumps arose, the pumps remained in their original packing at the treatment plant.

The water quality in the lakes was also extremely poor during the drought due to a combination of factors: high temperature, increased retention time due to lack of adequate flow through the lakes, algal blooms, and intense anoxic conditions and the resulting release of by-products of anaerobic decomposition such as iron, manganese, ammonia, hydrogen sulfide, etc. These factors subsequently resulted in finished waters with less than desirable qualities. There were numerous consumer complaints about taste and odor in the city's potable water supplies despite the efforts by the water treatment personnel to control these problems at the treatment plant.

Using destratification as a lake management tool, the Illinois State Water Survey has successfully controlled taste and odor problems in finished waters of Illinois communities with impoundments as raw water sources. Notable examples include Eureka, Palmyra, Altamont, Sparta, and Nashville. The city decided to follow these successful examples and install one of the floating pumps in Lake Bloomington near the water treatment plant intake in order to destratify the lake and enhance its water quality characteristics.

The primary objectives of this investigation were to assess the limnological characteristics of Lake Bloomington prior to the installation of the pump and to determine the changes in lake water quality characteristics, if any, after the installation.

Acknowledgments

This investigation was supported and partially funded by the city of Bloomington. The late Mr. George Sweir, Mr. George Drye (Director of Engineering and Water), Mr. Surinder Sethi (City Engineer), and Mr. Ron Schultz (Superintendent of Water Treatment) were very supportive. They greatly facilitated the efforts to carry out various facets of the project in a timely fashion, for which the authors are indebted to them.

The city provided a boat for routine sampling and monitoring of Lake Bloomington. Several waterworks personnel, namely Messrs. Tracy Gunther, Richard Alwood, Chuck Otte, Ron Stanley, Don Thompson, and Greg Montague, assisted with the field work from time to time. Also Messrs. Bill Wasson and Mike Steffa, McLean County Department of Parks and Recreation, provided a boat and helped monitor Lake Evergreen. Their assistance and cooperation are very much appreciated.

Several other Water Survey personnel were very helpful during this project. Mr. David Hullinger carried out laboratory chemical analyses, Mr. Davis Beuscher identified and enumerated algal samples, Dr. Shundar Lin provided an analysis and discussion of algal dynamics in the lakes, Mr. David Cox and Ms. Linda Hascall prepared the figures, Ms. Linda Dexter typed the draft and final reports, and Ms. Eva Kingston edited the report.

Materials and Methods

On the recommendation of the senior author, the city of Bloomington decided to install one of the ten Dobbs floating pumps in Lake Bloomington adjacent to the water treatment plant intake. This recommendation was based on the extensive research and successful results in destratifying large lakes using floating pumps reported by Dr. James M. Symons, Public Health Service, U.S. Department of Health, Education, and Welfare (Symons, 1969). The floating pumps used in the Symons study pumped water from the hypolimnetic zone for discharge to the surface during the summer stratification period.

Figure 1 shows front and side views of the 30-horsepower Dobbs floating pump used in Lake Bloomington, as well as the details of the suction hose and screen. The suction end of the intake pipe could be moved vertically up or down by about 3 feet by means of a winch. The suction end was initially located about 2 feet above the lake bottom. Figure 2 shows installation details and the pump's location in the lake about 80 feet from the shore near the water intake. Lake water depth at this location is 30 feet. The pump discharged in the form of three jet streams very near the surface about 100 feet away from the pump. This was done for better oxygenation of the hypolimnetic waters and to minimize the possibility of short-circuiting the pumped water back towards the suction end of the pump.

Figure 3 shows a view of the pump after installation with the lake's spillway in the background. The pump was completely installed and tested for proper operation on October 1, 1991, and then turned off. It was too late in the season to be of any benefit to run the pump because the lake was undergoing fall turnover. The pump was started again on May 4, 1992, and operated continuously until mid-October 1992.

In order to assess lake water quality conditions before and after installation of the floating pump, certain physical, chemical, and biological characteristics of Lake Bloomington were monitored biweekly from April through October 1991, and again from May through October 1992. Lake Evergreen was also monitored concomitantly for purposes of comparison. Figure 4 shows the sampling locations in both lakes.

In-situ observations were made at all the sampling stations for temperature, dissolved oxygen (DO), and secchi disc readings. An oxygen meter (Yellow Springs Instrument Company, Model 58 probe with a 50-foot lead) was used to measure DO and temperature. The probe was calibrated using a saturation chamber. Temperature and DO measurements were obtained in the water column at 2-foot intervals from the lake surface at stations 1, 2, and Hickory Creek (Lake Bloomington) and station 1 (Lake Evergreen). Observations were made at 1-foot intervals at the other two stations.

To measure secchi disc transparencies, an 8-inch-diameter secchi disc with black and white quadrant markings, was attached to a calibrated line. The disc was lowered until it disappeared from view, and the depth of immersion was noted. The disc was lowered further and then raised slowly until it reappeared. Again the depth of immersion was noted. The secchi disc reading recorded was the average of these two observations.

Laboratory determinations included pH, total alkalinity, specific conductivity, turbidity, hardness, total phosphate-P, dissolved ammonia-N, nitrate-N, nitrite-N, and total dissolved and suspended solids. Water samples were collected at a depth of 1 foot from the surface at all stations and at a depth of 2 feet from the bottom using a Kemmerer sampler only at stations 1 and 2 (Lake Bloomington) and at station 1 (Lake Evergreen). The samples 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

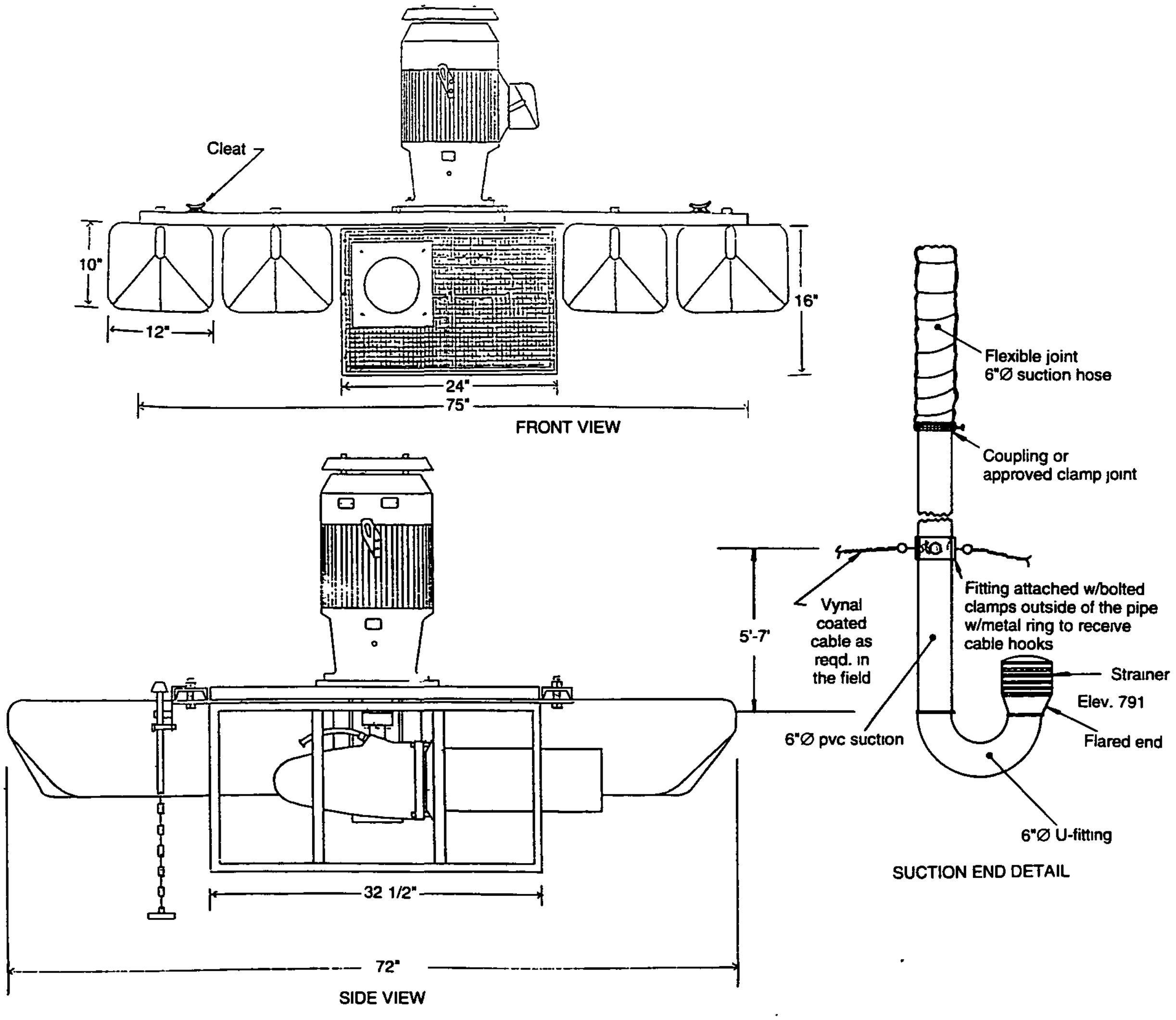

Figure 1. Front and side views and suction end details of the floating pump

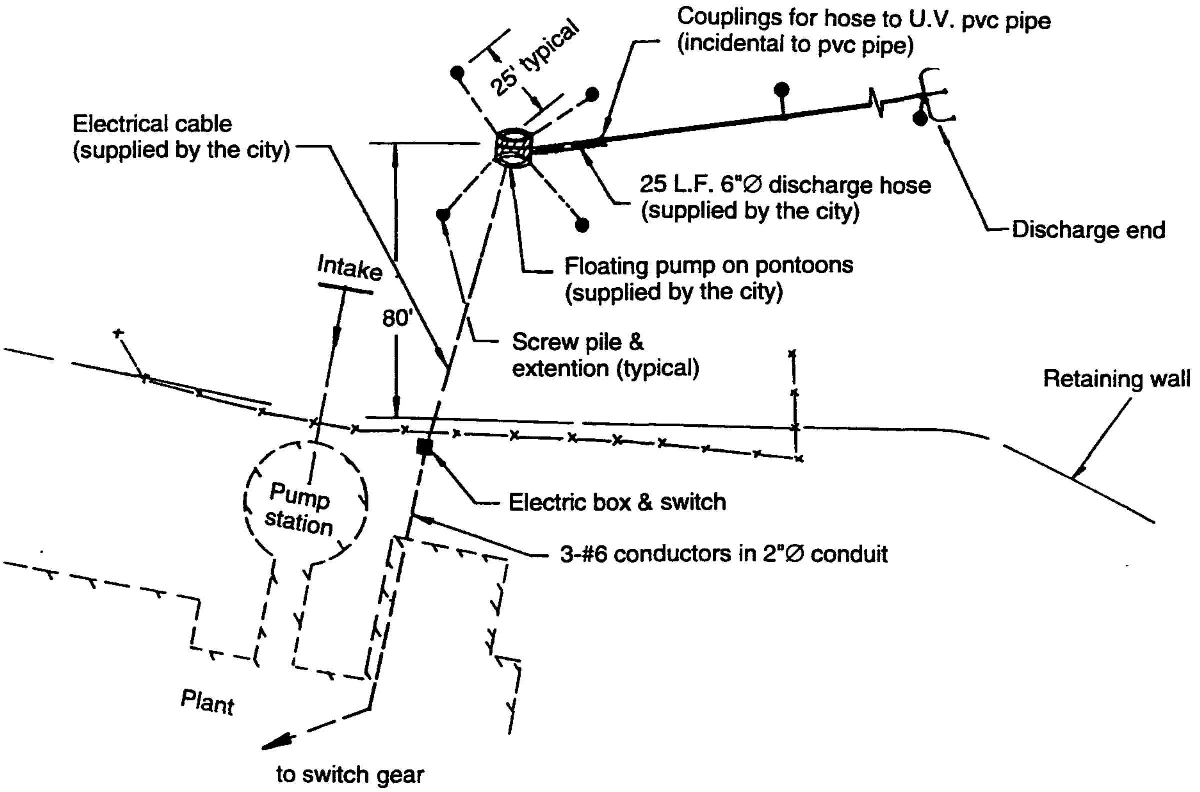

Figure 2. Installation details and pump location

Figure 3. View of floating pump in Lake Bloomington

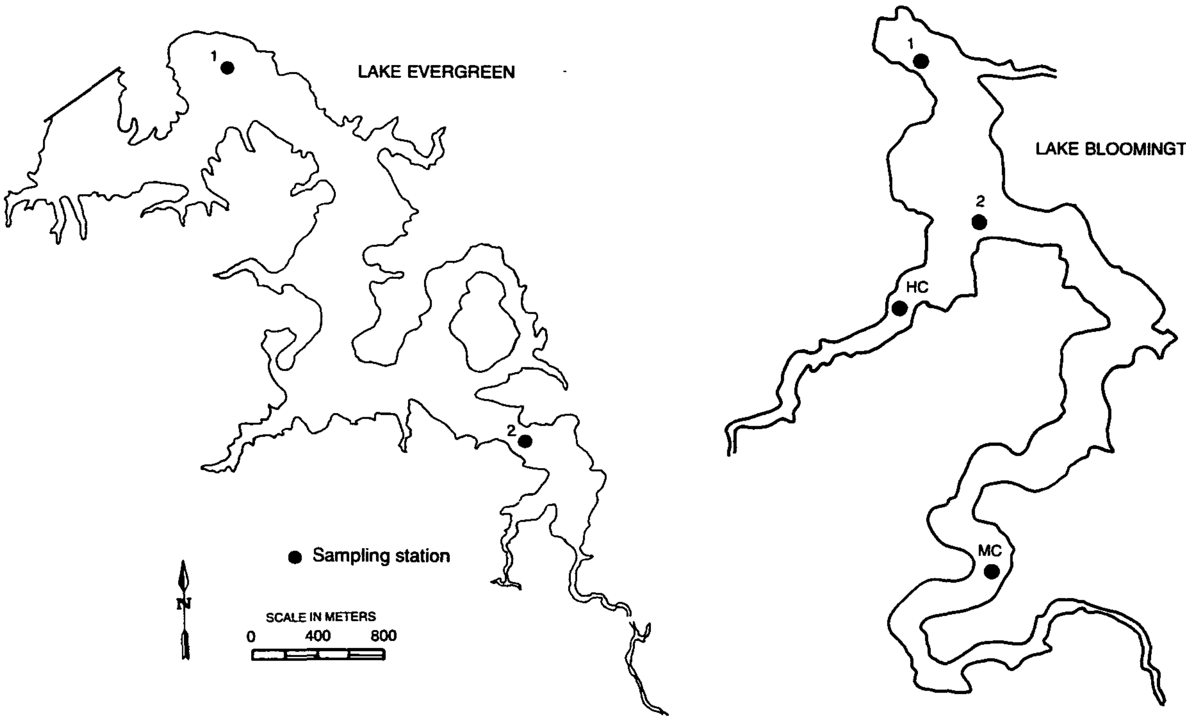

Figure 4. Sampling locations in Lake Bloomington and Lake Evergreen

were made at the lake site soon after sample collection. The methods and procedures for chemical analyses are given in table 1.

Water samples were collected in a volume of 380 milliliters (mL) for algal identification and enumeration. Samples were preserved with 20 mL of formalin at the time of collection and stored at room temperature until they could be examined.

Each sample was thoroughly mixed and a 1-mL aliquot was pipetted into a Sedgwick Rafter Cell. To identify and count algae, a differential interference contrast microscope equipped with a 10X or 20X eyepiece, a 20X or 100X objective, and a Whipple disc was used. Five short strips were counted. The algae species were identified and classified into five main groups: blue-greens, greens, diatoms, flagellates, and others. Individual cells of green algae were counted except for *Actinastrum, Coelastrum,* and *Pediastrum,* which were recorded by each colony observed. Each cell packet of *Scenedesmus* was counted. 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.

Results and Discussion

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 temperatures rise, the upper layers of water warm up, and wind action mixes them with the lower layers. By late spring, the differences in thermal resistance cause the mixing to cease, and the lake approaches the thermal stratification of the summer season. The physical phenomenon of increasing density with decreasing temperature occurs up to a certain point shortly after the temperature variation in water. These two interrelated forces are capable of creating strata of water of vastly differing characteristics within a 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 cooler air temperatures during the fall season, the temperature of the epilimnion decreases until it 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.

Table 1. Analytical Procedures

Turbidity	Nephelometric method, using Turner Fluorometer (model 110), Formazine used as a standard
pH	Glass electrode method with portable Metrohm-Herisau meter (model E588)
Total alkalinity	Titration with standard sulfuric acid solution to an end point pH of 4.5 using glass electrode
Conductivity	Yellow Springs Instrument model 33 conductivity meter corrected to 25°C
Hardness	Ethylene Diamine Tetra Acetic acid titrimetric method
Total Phosphate-P	Sample was digested with sulfuric acid mixture and determined by ascorbic acid method
Ammonia-N	Phenate method
Nitrate-N	Chromotropic method
Nitrite-N	Diazotization method
Suspended solids	Dry weight of solids retained on gooch crucible with fiberglass filter
Total dissolved solids	Residue on evaporation overnight of filtrate on a steam bath at 103 - 105°C

Declining air temperatures 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 temperature again becomes uniform, 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 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. The absence of oxygen leads to conditions favorable for chemical reduction 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 that 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. After an initial stimulus, the recycling of nutrients within a lake might be sufficient to sustain highly productive conditions for several years.

Also, 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 parameters. The physical changes in the configuration of the water mass after 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 the 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 in Illinois were also found to be anaerobic within a year of their formation.

Although Lake Bloomington and Lake Evergreen are different in areal extent, their depth at station 1, the deep station, is similar. These two stations are sited close to the water intakes. Isothermal and isodissolved oxygen plots for Lake Bloomington at station 1 for the years 1991 and 1992 are shown in figure 5. Similar plots for station 1 in Lake Evergreen are shown in figure 6. The plots for 1991 were very similar at station 1 for both lakes. Stratification began in late April or early May and prevailed through September. Both lakes reached a maximum observed surface water temperature of about 27.7°C in late July and experienced fall turnover at the end of September.

Both lakes experienced intense anoxic conditions to a depth of 20 feet from the surface in early June. Thereafter the anoxic zones gradually diminished, disappearing totally in both lakes after the fall turnover. The extent of anoxic zones in these lakes was not as large as in other lakes of similar depths monitored by the authors, however. For example, during summer stratification the anoxic zones extended to depths of 15 feet from the surface in Lake Catherine and Channel Lake of the Fox Chain of Lakes system, which

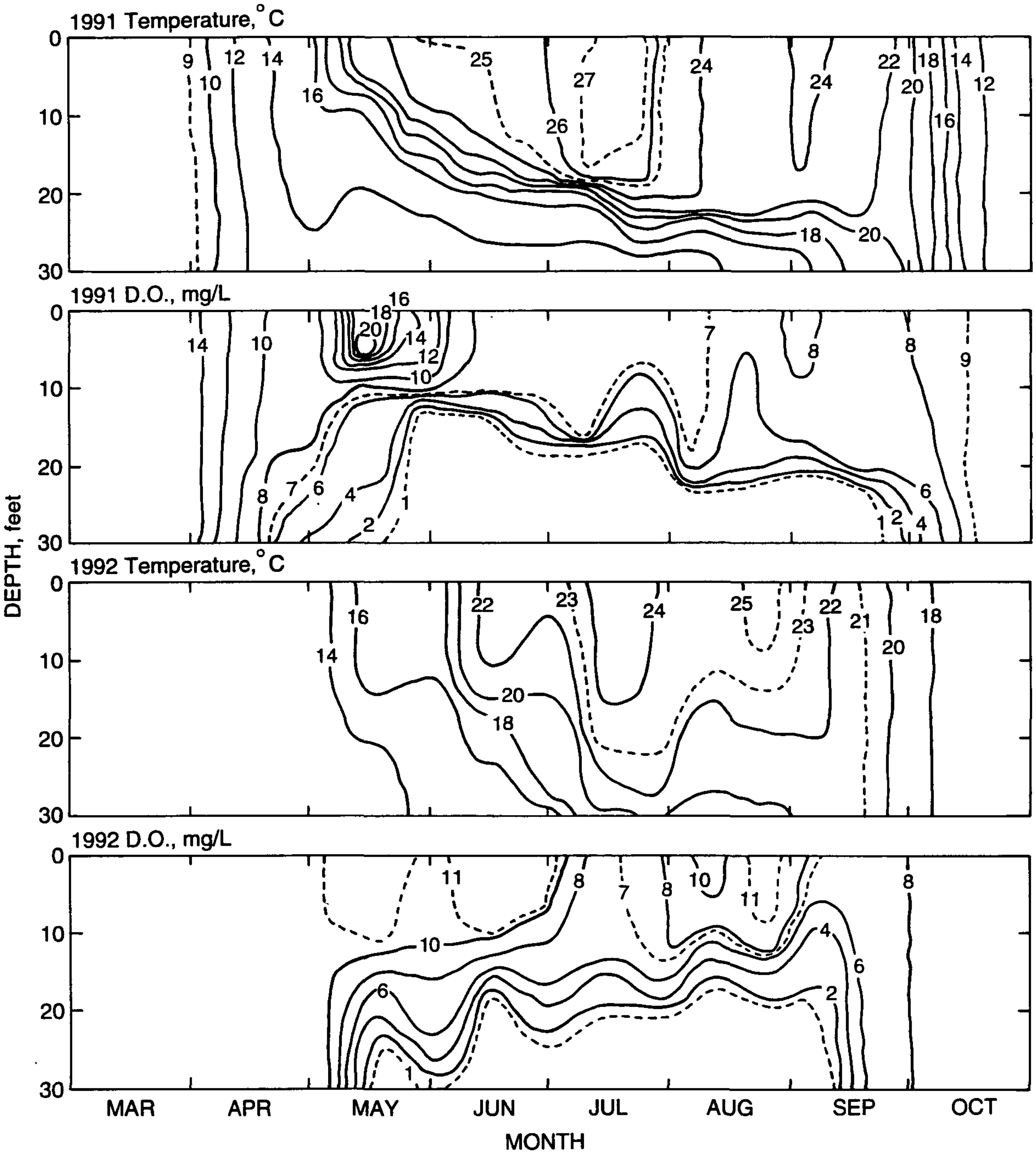

Figure 5. Isothermal and isodissolved oxygen plots at station 1 in Lake Bloomington

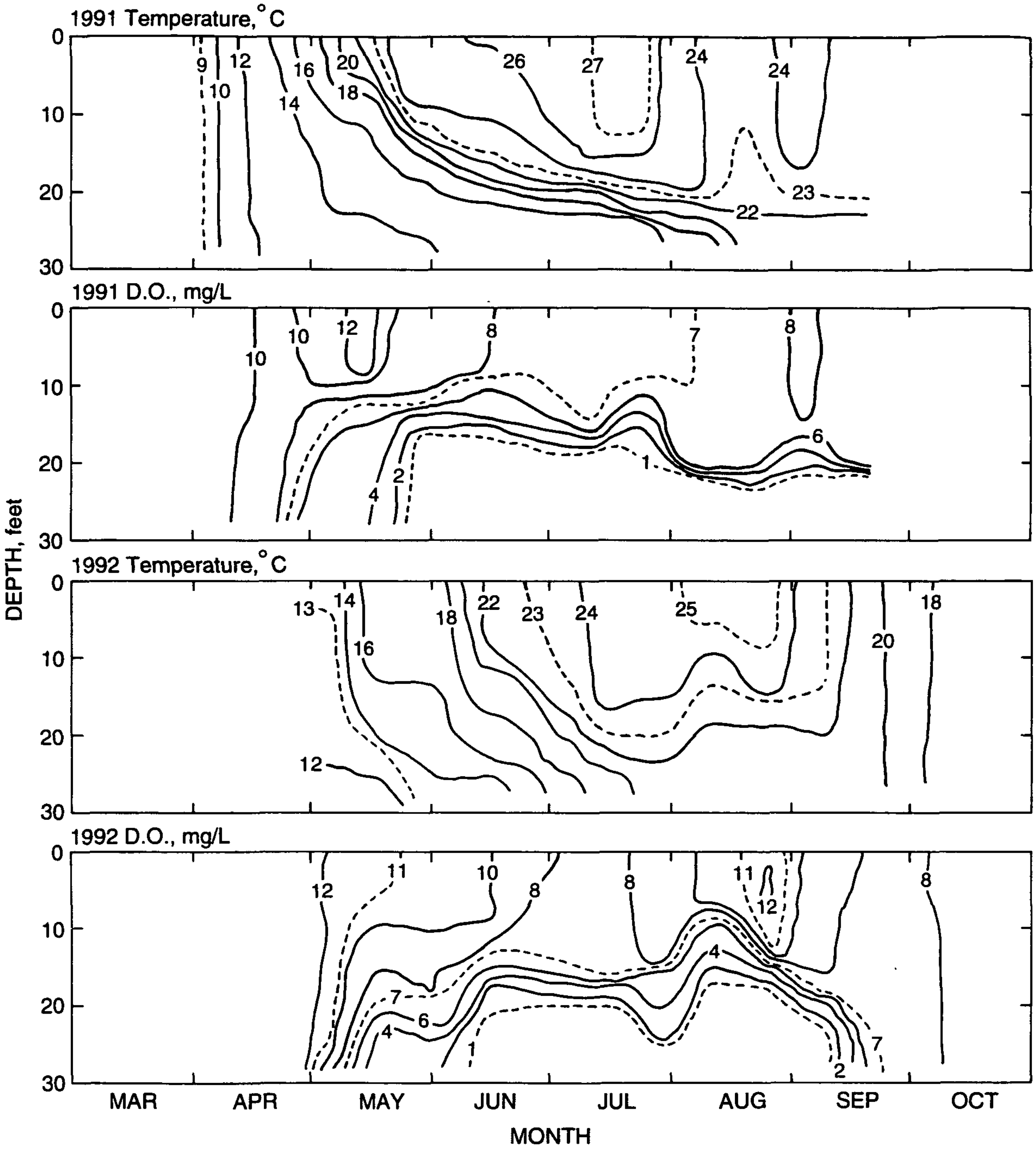

Figure 6. Isothermal and isodissolved oxygen plots at station 1 in Lake Evergreen

had maximum depths of about 35 feet. These two lakes encompass between 150 and 200 acres, which is much smaller than Lake Bloomington and Lake Evergreen. Trees surrounding these lakes also protect them from wind effects to some degree (Kothandaraman et al., 1977). On the other hand, the larger Lake Bloomington and Lake Evergreen have long fetch, subjecting them more to the influence of wind mixing.

The isothermal and isodissolved oxygen plots for Lake Bloomington and Lake Evergreen were also similar in 1992. The maximum observed surface water temperature was a low 25°C for both lakes in late August. The destratifier did not seem to be effective in preventing the onset and persistence of the anoxic zone in Lake Bloomington. The anoxic zones in both lakes extended to depths of 20 feet from the surface. Both lakes appear to attain isothermal conditions in late September. Based on the temperature and DO conditions in the two lakes during 1992, the system installed in Lake Evergreen has proved to be ineffective. The reasons for this will be discussed later.

Vertical temperature profiles for station 1 of Lake Bloomington on selected dates are shown in figure 7. Profiles for station 1 of Lake Evergreen on the corresponding dates are given in figure 8. Likewise, DO profiles at station 1 of Lakes Bloomington and Evergreen are shown in figures 9 and 10, respectively. The temperature and DO profiles for these lakes exhibit very similar patterns in the corresponding years. Figure 9 shows that anoxic conditions persisted at depths below 20 feet from the surface from June through September in spite of attempts to destratify Lake Bloomington during 1992.

Symons (1969) reported the results of mixing several reservoirs in the Midwest using pontoon-mounted gasoline engine-driven pumps. The reservoirs varied in size from 8 acres to 142 acres with maximum depths ranging from 30 feet to 62 feet. The horse power (hp) of the gasoline engines was either 16 or 26 hp. Pumping against a low-elevation head and a water discharge velocity of 8.4 feet per second, the larger pump had a capacity of 2,880 gpm. The 12-inch diameter mixed-flow pump suction line to the near bottom was discharged in the immediate vicinity.

In all these investigations, stratification was permitted to develop before pumping was begun. Symons found that the entire lake volume could be mixed by pumping at a single position at the deepest part of the lake. He also observed that nothing was gained by moving the pump. Based on his extensive investigations, Symons concluded that artificial destratification using floating pumps could effectively improve water quality in lakes and reservoirs. He further observed that mixing provides "a nearly uniform water temperature throughout a lake or reservoir; adds DO to the water; decreases the concentration of any reduced materials such as ferrous iron, manganous manganese, and/or sulfides that may be present; stops reducing reactions; and prevents development of large blooms of blue-green algae by providing a uniform water quality" (Symons, 1969, p. 386).

Symons also cited Ridley's investigation of the King George VI Reservoir to improve water quality conditions by using a raft-mounted electrically driven axial flow pump capable of transferring up to 40 mgd (27,500 gpm) of bottom waters. The reservoir, located in the United Kingdom, has a surface area of 350 acres and a maximum depth of 52.5 feet.

Although the horsepower of the pump installation in Lake Bloomington was adequate compared to that of the ones used by Symons (1969), it did not destratify or mix the lake to any practical degree. The primary reason for this is that the pump used in Lake Bloomington is a centrifugal pump with low-volume, high-head pumping characteristics as opposed to the high-volume low-head characteristics of the mixed-flow pumps investigated by Symons. Having had no previous experience with this type of destratification device,

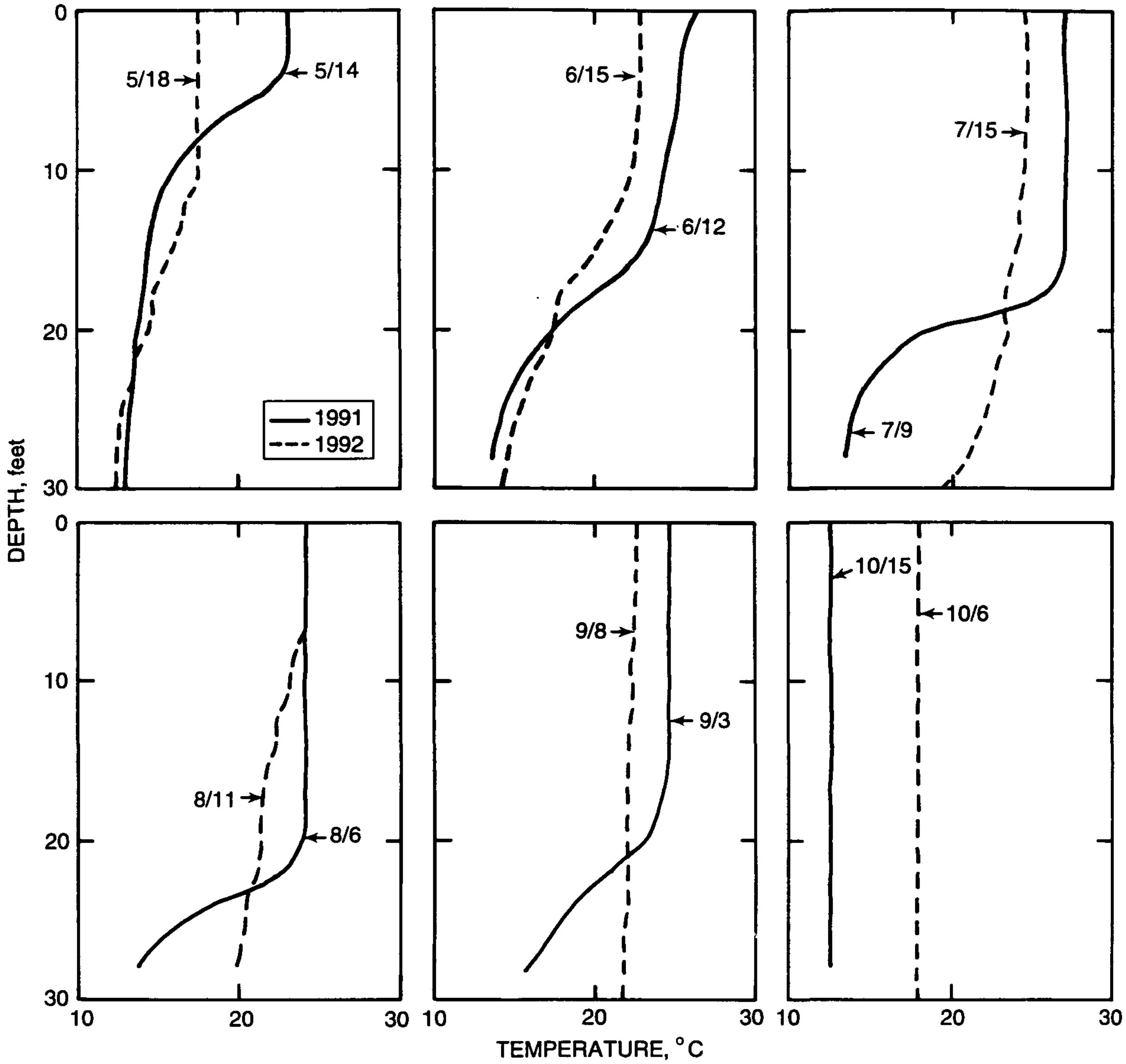

Figure 7. Temperature profiles at station 1 of Lake Bloomington on selected dates

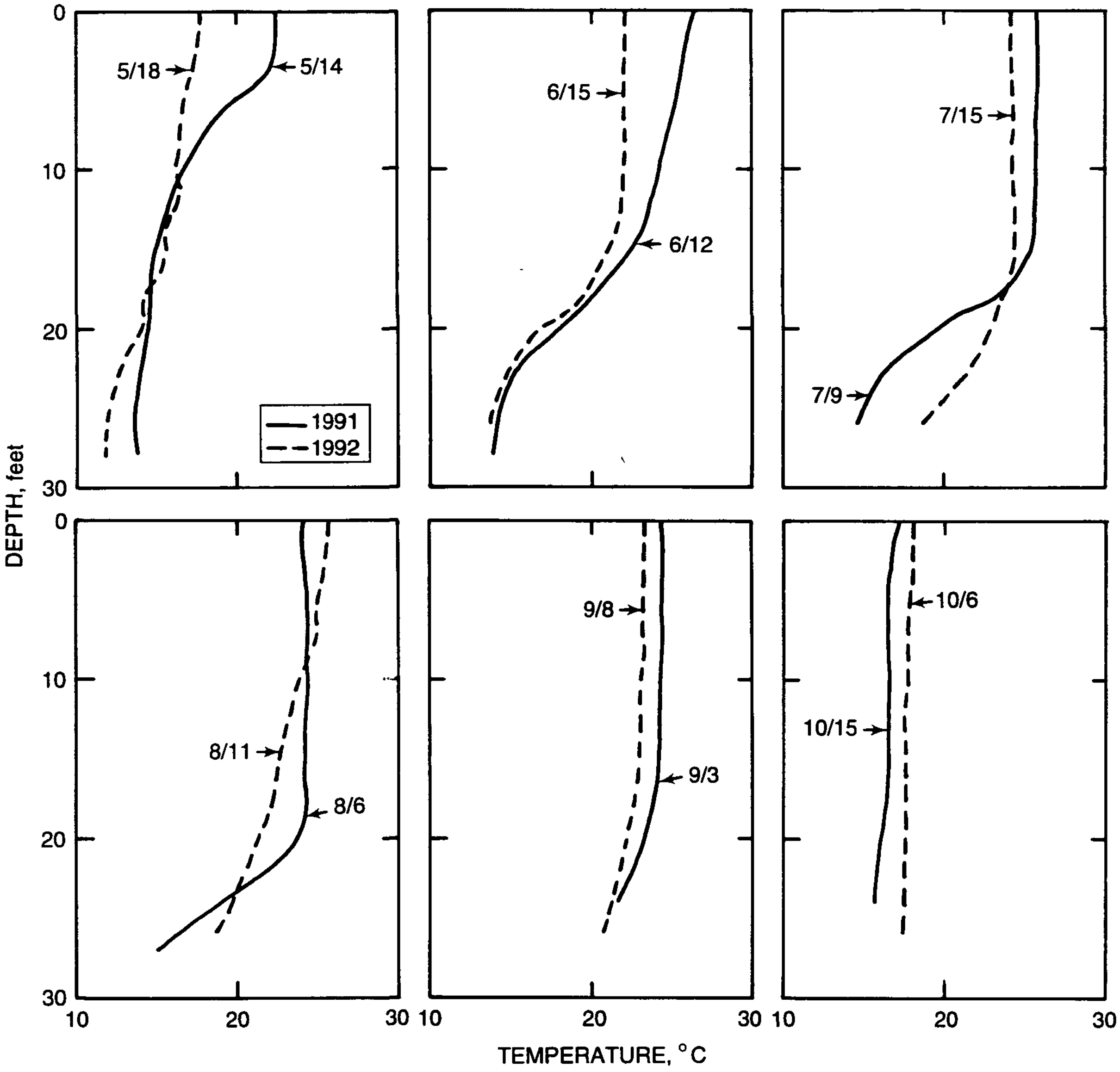

Figure 8. Temperature profiles at station 1 of Lake Evergreen on selected dates

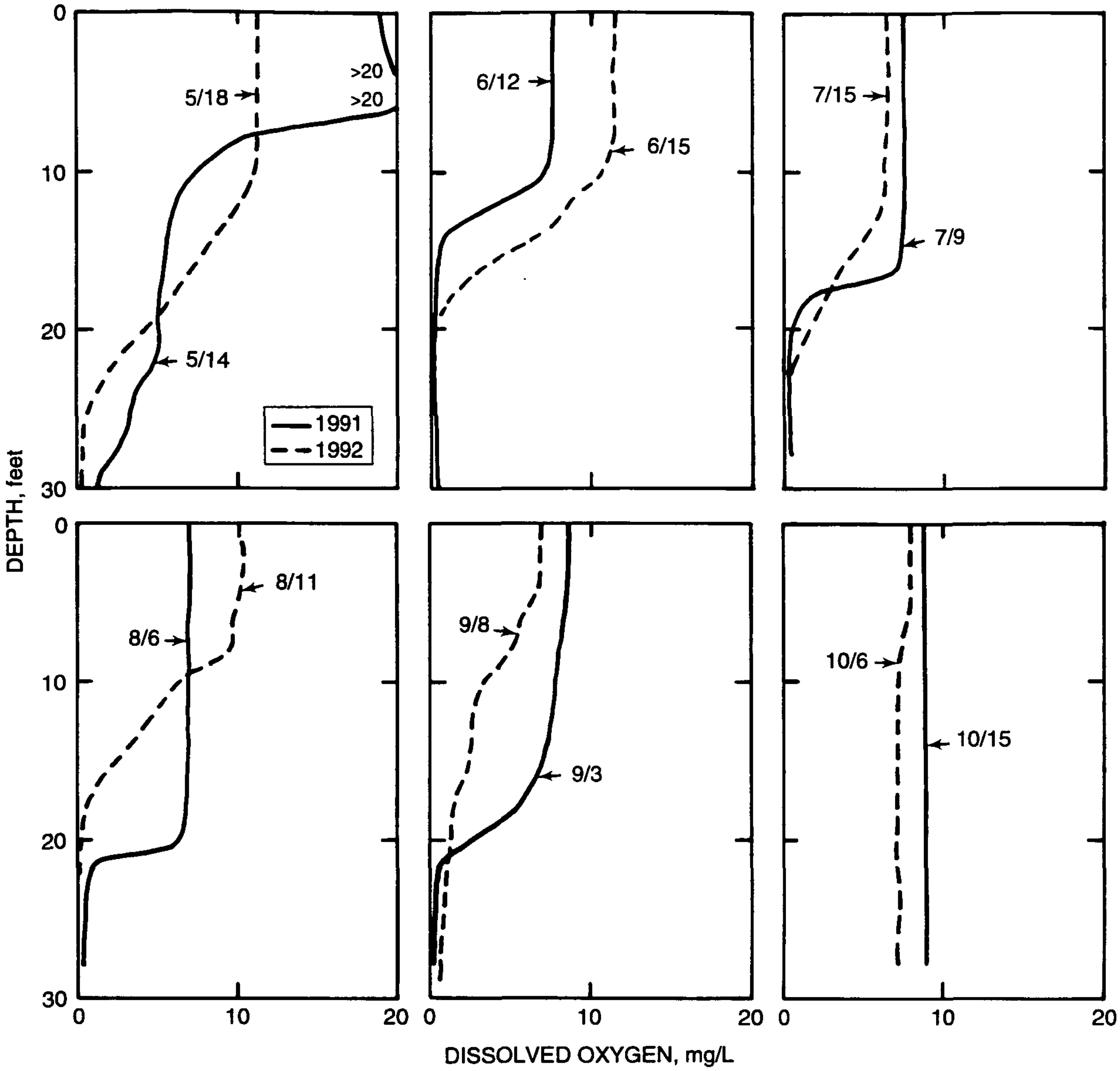

Figure 9. Dissolved oxygen profiles at station 1 of Lake Bloomington on selected dates

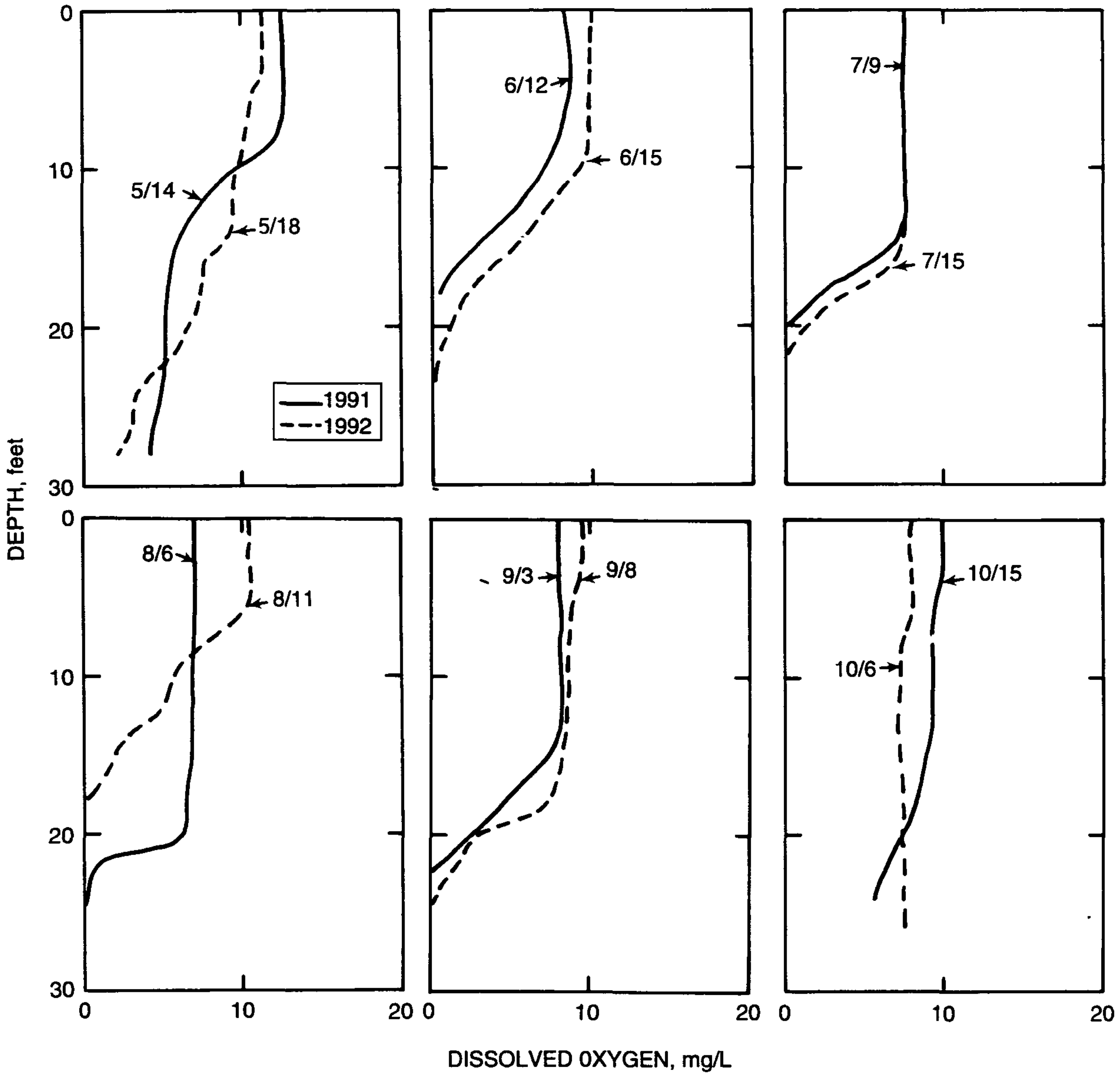

Figure 10. Dissolved oxygen profiles at station 1 of Lake Evergreen on selected dates

the senior author made the initial recommendation to install a Dobbs floating pump adjacent to the water treatment plant intake, taking into account only the horsepower of the system. The finer details of high-volume, low-head requirements for lake destratification were initially overlooked. It was also of paramount importance to use one of the pumps purchased earlier by the city. With the experience gained from the Lake Bloomington installation, it is suggested that it would be more effective to use a low-head, floating pump with a capacity of 12,000 to 15,000 gpm.

Figure 11, the schematic of the Lake Bloomington water intake, shows the relative position of the upper and lower intake strainers with respect to the full pool level. The upper and lower intake strainers are 18.75 feet and 33 feet below spillway level, respectively. Referring to figure 8, it is seen that during the summer stratification period, even the upper intake strainer is in the zone of marginal raw water quality with anoxic conditions prevailing in the adjoining lake water strata. Oxygen conditions in the zone about 10 feet below the surface are very good even without any artificial aeration/destratification, however. These conditions suggest that water withdrawal at a level of 710 feet instead of at the current upper level (701.25 feet) will result in better raw water quality and thus avoid taste and odor problems. This will also avoid problems associated with reduced conditions resulting in higher concentrations of dissolved iron, manganese, ammonia, sulfides, etc. The current operating procedures for Lake Bloomington stipulate a maximum drawdown of 5 feet below the spillway before the Lake Evergreen source is tapped. This will still leave a hydraulic head of at least 5 feet, if another intake facility is provided at an elevation of 710 feet in addition to the two existing intakes. Alternatively, a floating intake with its inlet always 5 to 10 feet from the surface could be considered.

Chemical Characteristics

The chemical quality characteristics observed in these lakes were typical of man-made lakes in Illinois. Even the mean and range of the nitrate concentrations were similar to values observed in other water-supply impoundments such as Lake Eureka, Lake Decatur, etc. Summaries of water quality characteristics observed at station 1 of both Lake Bloomington and Lake Evergreen for 1991 and 1992 are shown in tables 2 and 3, respectively. The field and raw chemical data for all the monitoring stations are in open files available in machine-readable form to anyone interested in using them to make a more in-depth limnological assessment of the lake water characteristics. Because nitrate has a significant impact on the operation and management decisions for the Bloomington water-supply system, the discussion of the chemical characteristics is limited to the different forms of nitrogen.

Nitrogen. Nitrogen in natural waters is generally found in the form of nitrate, organic nitrogen, and ammonia-nitrogen. Nitrates are the end-product of the aerobic stabilization of organic nitrogen, and as such they occur in polluted waters that have undergone self-purification or aerobic treatment processes. Nitrates also occur in percolating ground waters. Ammonia-nitrogen, being a constituent of the complex nitrogen cycle, results from the decomposition of nitrogenous organic matter. It can also result from municipal and industrial waste discharges to streams and rivers, however. Watershed agricultural management practices, along with rainfall, runoff, and antecedent conditions, have a profound impact on the concentrations of ammonia and nitrate levels in a lake's water column.

The concerns about nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because the traditional water

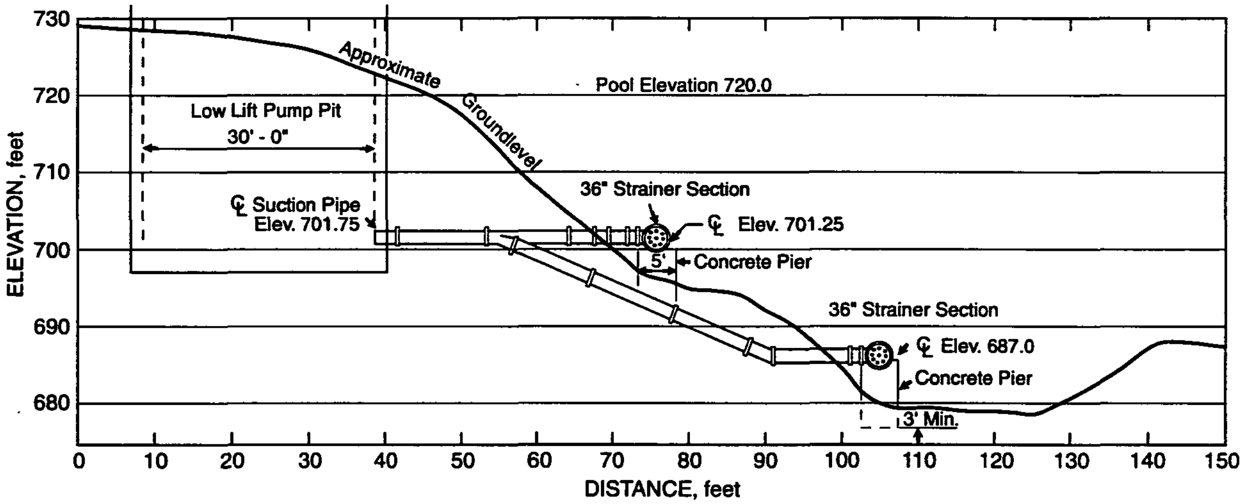

Figure 11. Schematic of Lake Bloomington water intake

Table 2. Water Quality Characteristics of Lake Bloomington at Station 1

	1991				1992			
	Near surface		Near bottom		Near surface		Near bottom	
Parameter	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Secchi readings (inches)	37	18-59	-	-	42	25-59	-	-
Turbidity, NTU	14	8-29	43	11-106	12	8-20	26	10-69
pH (units)	-	8.25-8.69	-	7.42-8.61	-	8.08-8.55	-	75.8-8.31
Total alkalinity	154	130-176	220	147-287	159	142-174	180	155-219
Conductivity (µmho/cm)	522	476-607	602	480-656	528	469-611	559	508-608
Hardness	255	228-290	298	234-335	262	245-299	275	248-300
Total phosphate-P	0.05	0.03-0.07	0.12	0.04-0.23	0.04	0.02-0.06	0.07	0.03-0.19
Dissolved ammonia-N	0.07	0.02-0.15	1.02	0.05-3.06	0.09	0.03-0.19	0.41	0.07-1.15
Nitrate-N	10.19	3.34-14.8	6.47	0.86-13.90	7.71	4.16-11.40	6.56	3.77-11.40
Nitrite-N	0.15	0.03-0.30	0.09	0.01-0.28	0.14	0.07-0.20	0.16	0.06-0.37
Total suspended solids	9	1-26	39	7-124	10	5-22	22	2-73
Total dissolved solids	340	298-398	380	314-430	352	306-405	368	326-412

Note: Values in mg/L unless otherwise indicated

Table 3. Water Quality Characteristics of Lake Evergreen at Station 1

Parameter	1991				1992			
	Near surface		Near bottom		Near surface		Near bottom	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Secchi readings (inches)	41	17-61	-	-	43	27-52	-	-
Turbidity, NTU	13	9-33	27	11-64	12	10-17	25	15-45
pH (units)	-	8.26-8.80	-	7.68-8.71	-	7.99-8.79	-	7.52-8.52
Total alkalinity	154	142-176	175	145-211	151	132-175	162	141-179
Conductivity (µmho/cm)	520	484-571	544	485-584	498	453-566	513	468-563
Hardness	245	178-271	257	178-289	240	215-284	249	225-277
Total phosphate-P	0.04	0.02-0.09	0.14	0.03-1.09	0.04	0.02-0.06	0.06	0.04-0.08
Dissolved ammonia-N	0.06	0.02-0.13	0.21	0.04-0.56	0.07	0.02-0.15	0.24	0.06-0.46
Nitrate-N	9.35	5.45-12.10	8.50	5.24-12.40	5.44	3.02-7.38	5.08	3.09-7.20
Nitrite-N	0.17	0.03-0.32	0.17	0.03-0.32	0.10	0.05-0.16	0.11	0.05-0.22
Total suspended solids	6	0-19	16	2-53	8	4-13	18	9-40
Total dissolved solids	330	296-398	342	310-384	331	288-382	336	286-374

Note: Values in mg/L unless otherwise indicated treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen should not exceed 10.0 mg/L. Second, nitrogen in the aquatic environment tends to stimulate the growth of algae and other aquatic plants. It is one of the principal elemental constituents of amino acids, peptide, proteins, urea, and other organic matter. Various forms of nitrogen (for example, dissolved organic nitrogen and inorganic nitrogen such as ammonium, nitrate, nitrite, and elemental nitrogen) cannot be used to the same extent by different groups of aquatic plants and algae.

The mean and range of values for ammonia in Lake Bloomington and Lake Evergreen were within the general use standards stipulated by the Illinois Pollution Control Board. The mean concentrations of nitrate in Lake Bloomington were higher than those in Lake Evergreen for the corresponding years.

The temporal variations in nitrate during 1991 and 1992 for both lakes are shown in figure 12. Surface water nitrate concentrations in both lakes were higher than the 10 mg/L drinking water standard from April through July 1991. Even the near-bottom waters exhibited high levels from April through mid-June that year. The nitrate levels in Lake Evergreen were lower in 1992 than in 1991, and the concentrations never exceeded 10 mg/L in 1992 either in the surface or near-bottom waters. The nitrate levels in Lake Evergreen appeared to be better than in Lake Bloomington.

Biological Characteristics

Algae. Algal densities, expressed as counts per milliliter (cts/mL), ranged from a low of 27 cts/mL on June 12, 1991 at station 1 (Lake Evergreen) to a high of 26,000 cts/mL at station 1 (Lake Bloomington) on April 2, 1991. A similar range of variations in algal densities in other lakes has been reported elsewhere. There were extreme fluctuations in algal densities at each of the four stations monitored in both the lakes. Generally, algal densities at the two Lake Bloomington stations were comparable. The densities at station 2 of Lake Evergreen were higher than those at station 1, however.

The number of algal species identified in each sample examined ranged from two (at station 2 of Lake Bloomington and station 1 of Lake Evergreen, both on April 2, 1991) to 19 (at station 1 of Lake Evergreen on August 19, 1992). There were a total of 67 algal species identified in all the water samples examined. They include: 8 blue-greens (Cyanophytes), 16 greens (nonmobile Chlorophytes), 24 diatoms (Bacillariophytes), 17 flagellates (Euglenophytes), and 2 desmids. In both lakes, green algae or diatoms or flagellates were generally the predominant algae present, not the problem-causing blue-green algae. The most frequently occurring algae in the two lakes were *Coelastrum microporum, Crucigenia rectanglularis, Oocystis borgei, Scenedesmus dimorphus, Cyclotella meneghiniana, C. ocellata, Melosira granulata, Synedra acus, Euglena gracilis, Glenodinium* sp., *Phacus pleuronectes,* and *Trachelomonas crebea.* Only one blue-green alga *(Aphanizomenon flos-aquae)* occurred frequently in both lakes, but at low densities. During the two years of this investigation, the treatment plant experienced no problems with taste and odor or clogged filters. All the algal data, as in the case of physical and chemical data, are readily available in open-file machine-readable form.

Summary

During the most recent drought in central Illinois from early 1988 to late 1989, the city of Bloomington water treatment system experienced severe water shortages and taste and odor problems in its finished waters. The city procured ten 30-horsepower floating,

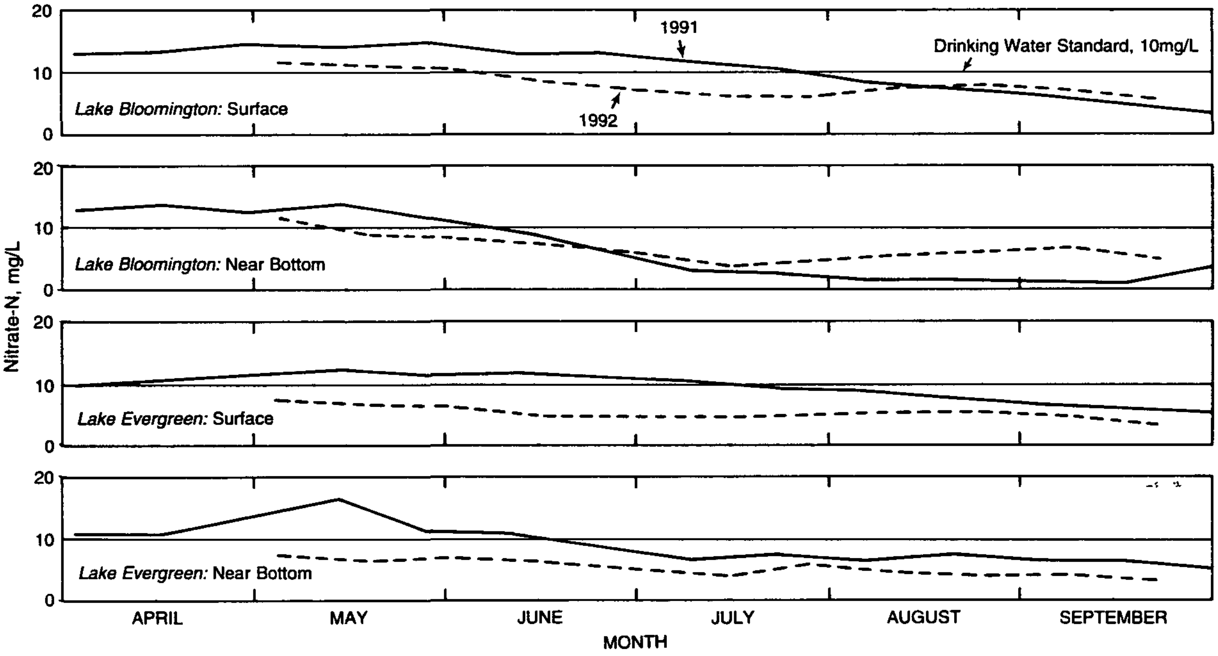

Figure 12. Temporal variations of nitrate in Lake Bloomington and Lake Evergreen

self-priming high-head, low-flow centrifugal pumps. It was anticipated that they would be used to pump water from the rapidly receding pool in Lake Bloomington. However, they were kept in storage and never used.

Based on the recommendations and experience of the State Water Survey in mitigating taste and odor problems in water treatment systems with impoundments as their raw water sources, the city installed one pump in Lake Bloomington near the water intake. The pump operated continuously from early May through mid-October 1992 for the purpose of improving the raw water quality. Destratification and aeration using floating pumps to withdraw anoxic hypolimnetic waters for discharge at the surface during summer months is a concept that has been widely researched and reported in Europe and in the United States during the 1960s.

Physical, chemical, and biological water quality characteristics were monitored prior to the installation and operation of the destratifier in 1991, and again in 1992 to delineate the impacts of destratification. Lake Evergreen, which serves as the secondary water-supply source, was also monitored concomitantly for purposes of comparison.

The DO and temperature data for the lakes reveal that the anoxic zones in these lakes are not as extensive as in some other deep lakes in Illinois. This is primarily because the long fetches in Lake Bloomington and Lake Evergreen facilitate a higher degree of mixing during the summer months. Adequate oxygen levels were found in both lakes to depths between 15 and 18 feet from the surface during summer 1991.

The DO and temperature conditions in both lakes were similar in 1992. The floating pump used in Lake Bloomington did not break up the temperature gradient in the water column. These DO and temperature data lead one to believe that the pump was ineffective in destratifying the lake. Earlier studies reported use of very high-volume, low-head axial flow pumps to mix the lake waters instead of the low-volume, high-head centrifugal pump available for use in Lake Bloomington.

Nitrate levels in Lake Bloomington and Lake Evergreen were often found to exceed 10 mg/L, but the levels in Lake Evergreen were generally lower than those in Lake Bloomington. Problem-causing, blue-green algae were not significant in the algal dynamics of the ecosystems of these lakes. Diatoms or greens or flagellates were the dominant algal species in the lakes.

The DO conditions are excellent in the top 15 to 18 feet of lake. Providing an additional intake at an elevation of 710 feet would ensure water withdrawal of superior quality and thus avoid taste and odor problems associated with the withdrawal of anoxic hypolimnetic waters. An alternative solution would be a floating or telescopic intake arrangement with its opening maintained at 5 feet below the water surface.

During periods of low rainfall-runoff conditions when the hydraulic retention time in the impoundments increases and results in poor water quality conditions, destratification with floating pumps would be much more effective in the lakes.

References

Kothandaraman, V., R.L. Evans, N.G. Bhowmik, J.B. Stall, D.L. Gross, J.A. Lineback, and G.B. Dreher. 1977. *Fox Chain of Lakes Investigation and Water Quality Management Plan,* Cooperative Resources Report 5, Illinois State Water Survey, Urbana, Illinois, 200p.

Soil and Water Conservation District, McLean County. 1991. *Lake Bloomington Watershed- Watershed Plan Environmental Assessment,* McLean County, Illinois, 47p. + appendices.

Symons, J.M. 1969. *Water Quality Behavior in Reservoirs,* A Compilation of Published Research Papers, U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Water Hygiene, Cincinnati, OH, 616p.