Contract Report 610

Phase III, Post-Restoration Monitoring of Lake Le-Aqua-Na

by
Shun Dar Lin and Raman K. Raman
Office of Water Quality Management

Prepared for the
Illinois Environmental Protection Agency

March 1997

Illinois State Water Survey
Chemistry Division
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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EXECUTIVE SUMMARY

Lake Le-Aqua-Na, a 43.4-acre lake formed in 1956 by impounding Waddams Creek, is located in Stephenson County. A long-term post-restoration study of the lake was undertaken from April 1992 through March 1994 by the Illinois Environmental Protection Agency (IEPA) in cooperation with the Illinois State Water Survey (ISWS). This monitoring study comprised *in-situ* observations; lake water and sediment sample collections for physical, chemical, and biological assessments, and monitoring of the quantity and quality of base flow and storm event flows in Waddams Creek. The primary objective of the current (Phase III) post-restoration monitoring program was to assess and delineate the long-term effectiveness of the restoration techniques implemented in the lake and its watershed during 1984-1985.

The Phase III study was funded by the U.S. Environmental Protection Agency (USEPA) through IEPA with nonfederal cost sharing provided by IEPA and Illinois Department of Natural Resources (EDNR), all under the provisions of Section 314 of Public Law 95-217 of the Clean Water Act.

Implementation of soil conservation practices in the watershed began in 1984 and continued through 1985. The practices implemented by the Soil Conservation Service (SCS), Soil and Water Conservation District (SWCD), and EDNR included conservation tillage, strip cropping, terracing, water and sediment control structures, and streambank protection. A reversible-draft, mechanical destratifier was installed in July 1985 at the deepest site in the lake.

Conservation practices implemented in the Lake Le-Aqua-Na watershed have proven to be successful. The net sediment loading to the lake during 1993, the wettest year during the study period, was found to be only 11.8 percent of that in 1981, when pre-implementation monitoring was carried out. The sedimentation survey done for the lake in 1995 did not show any measurable reduction in lake volume since 1981.

Success of the watershed program is additionally supported by significant reductions in nutrient loadings to the lake. Both total phosphorus and nitrogen loads were significantly smaller during this study than in 1981.

During this investigation, the lake was either thermally stratified or a significant temperature gradient existed during summer periods, probably due to the breakdown of the destratification system. Consequently, dissolved oxygen (DO) conditions in the near-bottom waters were not as good as those observed in 1986 by IEPA, when the aeration system was fully operational. The DO and temperature data bear out the fact that proper maintenance and operation of the destratifier is imperative. Even though significant improvements in lake watershed management have been made over the past decade, hypolimnetic oxygen resources in most Illinois lakes cannot be improved without adequately sized and properly maintained aeration systems.

Diatoms and green algae were generally the dominant species during this investigation rather than the problem-causing blue-green algae dominant during the summer of 1981.

Macrophyte growths occurred along the north bank and in the shallow west end of the lake. One to two feet of soft, organic-rich muck was found in the west end, which is covered every year with dense aquatic vegetation.

The lake continues to be eutrophic, and the trophic state has not changed from pre-implementation conditions. The overall use support of the lake was classified as providing a partial/minor degree of use support. Aquatic life use, recreational use, and swimming use of the lake were assessed as full/threatened, partial/moderate, and partial/minor, respectively.

Phase III, Post-Restoration Monitoring of Lake Le-Aqua-Na

INTRODUCTION

Long-term post-restoration monitoring of Lake Le-Aqua-Na in Stephenson County, Illinois, was undertaken from April 1992 to March 1995 by the Illinois Environmental Protection Agency (IEPA) in cooperation with the Illinois State Water Survey (ISWS) and the former Illinois Department of Conservation (the latter two entities have since become part of the Illinois Department of Natural Resources, IDNR). This monitoring study, comprising in-situ observations and collection of water and sediment samples for physical, chemical, and biological assessments, was designed to build an extensive database dating from June 25, 1979. While IEPA gathered most of the data, ISWS collected data for the period January 21, 1981, to December 3, 1981, under the Phase I diagnostic/feasibility study.

The primary objective of the current (Phase III) post-restoration monitoring program was to assess and delineate the long-term effectiveness of restoration techniques employed in the past for the lake and its watershed by comparing current lake conditions with pre-restoration conditions and the conditions documented by IEPA during intensive monitoring in 1984, 1985, and 1986. Data for 1984 and 1985 pertain to the lake and watershed conditions when restoration recommendations from the 1981 Phase I study were being implemented. 1986 data are the results of assessment for the immediate post-restoration monitoring.

The long-term post-restoration monitoring study was funded by the U.S. Environmental Protection Agency (USEPA) through the IEPA with nonfederal cost sharing provided by IEPA and IDNR all under the provisions of Section 314 of Public Law 95-217 of the Clean Water Act. The federal share of this study amounted to $125,000, and the state agencies contributed collectively $53,571, for a total of $178,571.

Acknowledgments

This final report represents the cooperative efforts of many individuals representing local, state, and federal agencies.

Le-Aqua-Na State Park personnel David Salley, Jeff Hensal, Alec Pulley, and others provided outstanding assistance in local project coordination and data collection. They constructed and installed the wooden platform overhanging the creek to house a Sigma automatic sampler to collect storm event samples. They willingly assisted ISWS staff on numerous occasions with streamgaging and sample collection during storm events, and they provided information on fish management, macrophyte control, park attendance, etc. Their assistance was essential to the successful completion of this post-restoration monitoring effort.

The IEPA's Lake and Watershed Unit (Planning Section, Division of Water Pollution Control) under the direction of Gregg Good was responsible for overall state administration and coordination of this project. Jeff Mitzelfelt and Steve Kolsto conducted various data entry, management, and interpretation activities necessary to insure the integrity of the monitoring program results. Amy Burns coordinated data collected under the Volunteer Lake Monitoring Program (VLMP) and VLMP-Water Quality Programs.

The authors are very grateful to Gregg Good for his tireless efforts in coordinating the endeavors of various individuals connected with this project and for forwarding the results. Jeff

Mitzelfelt provided excellent technical support in carrying out the project and compiled all the raw data into a manageable tabular form.

IEPA's Maywood regional field office staff under the direction of Wallace Matzunaga conducted lake and tributary monitoring activities over the three-year monitoring period. Staff involved in collection activities included Howard Essig, John Lesnak, Craig Boatright, and Stan Lampa. Analyses of various water and sediment samples collected were carried out by the IEPA's Springfield laboratory under the direction of John Hurley and its Champaign laboratory under the direction of Roy Frazier.

This project was funded in part with financial assistance provided by the USEPA under Clean Lakes Program Grant #S995203-01. Tom Davenport and Don Roberts, USEPA Region V in Chicago, were responsible for federal administration of the Phase III project.

Several ISWS personnel contributed to the successful completion of the field work, laboratory analyses, and this report. David Hullinger, Rick Twait, and Davis Beuscher assisted in macrophyte surveys. Bill Bogner and James Slowikowski were the scuba divers who collected macrophyte samples contained in the quadrats. Thomas Hill identified and enumerated the benthos, and Davis Beuscher identified and enumerated algae and zooplankton in the water samples. Bill Bogner carried out the bathymetric and sedimentation surveys and evaluated the data. Linda Hascall and Dave Cox prepared the illustrations. Long Duong and John Beardsley prepared all the computer graphics used in this report. Linda Dexter prepared the draft and final reports, and Sarah Hibbeler edited the report. All of their efforts and assistance are gratefully acknowledged and appreciated.

STUDY AREA

Lake Le-Aqua-Na

Lake Le-Aqua-Na, located in Stephenson County, is a 43.4-acre lake with a maximum depth of about 23 feet. The lake was formed in 1956 by the impoundment of Waddams Creek. This publicly owned lake and the surrounding park are managed by the Illinois Department of Natural Resources (IDNR) for outdoor recreational activities, such as bank and boat fishing, boating, canoeing, swimming, camping, picnicking, hiking, and horseback riding. Winter sports such as ice fishing, sledding, ice skating, and cross-country skiing are popular during winter months, but there are no trails or facilities for snowmobiling. Seven miles of marked self-guided trails exist for visitors interested in nature study.

A small beach, particularly suited to children, is open daily from 8 a.m. to 8 p.m. from Memorial Day through Labor Day. No lifeguards are in attendance and hence swimming is at one's own risk. Alcoholic beverages are strictly prohibited.

The lake is stocked and managed by the Fisheries Division of the IDNR. Periodic stocking of walleye, northern pike, and channel catfish complement the lake's self-reproducing largemouth bass, bluegill, crappie, and bullheads. Brush piles and fish cribs are scattered throughout the lake and provide excellent habitat for the large fish population. To keep the supply abundant, regulations governing catch limit and sizes are strictly enforced. Fishing is limited to pole and line fishing only and the catch regulations are: large and smallmouth bass, one per day, 14-inch minimum; channel catfish, six per day; walleye and sauger, six per day, 14-inch minimum; northern pike, three per day, 24-inch minimum; crappie, 25 per day; and bluegill and redear sunfish, 10 per day.

Lake Le-Aqua-Na State Park, in which the lake is located, is open year-round to the general public from sunrise to 10 p.m. The park has an abundant tree population of oak, hickory, walnut, butternut, and other hardwoods along with large tracts of pine plantation. Wild flowers are prevalent, particularly in the spring. All small animals common to northern Illinois live in the park. Deer are frequently sighted, but the unique mammal found in the park is the badger.

The park offers more than 180 camp sites in three designated areas accommodating recreational vehicles, tents, and equestrians and youth groups. Facilities include gravel pads, hydrants located at various points, electricity, a dump station, and a shower building with flush toilets. The camping areas are open from May 1 to October 31 and most are available on a first-come-first-served basis.

Figure 1 shows the location of the park; figure 2 shows the public access points and facilities in and around the lake; and table 1 provides other relevant general information. The impoundment was created solely for recreational purposes with no other designated uses such as flood control or water supply. Morphometric details of the lake pertinent to the current investigation and those gathered in 1981 during the diagnostic/feasibility study are shown in table 2.

Topography

The landscape of the Le-Aqua-Na State Park was shaped partially by glacial ice, running water, and wind. The area, one of moderate relief, is composed of undulating hills of the stage from late youth to early maturity. The highest elevation is approximately 1160 feet above sea level and the lowest point is about 820 feet above sea level. The major uplands and valleys are shaped by the form of the bedrock surface, and the topography of the lake's watershed ranges from nearly level to 30 percent slopes. The percentage of total acreage in various slope categories is: 0 to 2 percent - 12.2, 2 to 4 percent - 32.9, 4 to 7 percent - 30.5, 7 to 12 percent - 15.2, 12 to 18 percent - 4.4, and 18 to 30 percent - 4.8.

Watershed Soil Characteristics and Land Uses

Soils in the watershed are derived mainly from outwash material carried by Illinoian glaciation meltwater and deposited on floodplains. The main soil type in the area is silt loam. Common soil association classifications include Tama-Downs-Muscatine, Flagg-Pecatonica, Dubuque-Dunbarton-Palsgrove, and Eleroy-Derinda-Keltner.

Watershed land uses as delineated in the 1981 diagnostic-feasibility report (Kothandaraman and Evans, 1983) are: cropland - 66.8 percent, woodland - 17.7 percent, pasture or hayland - 7.8 percent, recreational development - 4.6 percent, farmsteads - 1.7 percent, and water - 1.7 percent. The state of Illinois owns 31 percent of the watershed with the remainder divided into small private holdings. Watershed land uses have not changed since 1981 except for some changes in farmstead characteristics, e.g., closing of dairy operations (J.A. Ritterbusch, USDA District Conservationist, personal communication, 1995).

Climate and Precipitation

Illinois experiences a continental climate due to its location midway between the Continental Divide and the Atlantic Ocean and north of the Gulf of Mexico. Three air masses dominate Illinois during the year. The coldest, driest air, most commonly experienced in the winter, comes from Canada, while the warmest, most humid air mass, found mainly in the

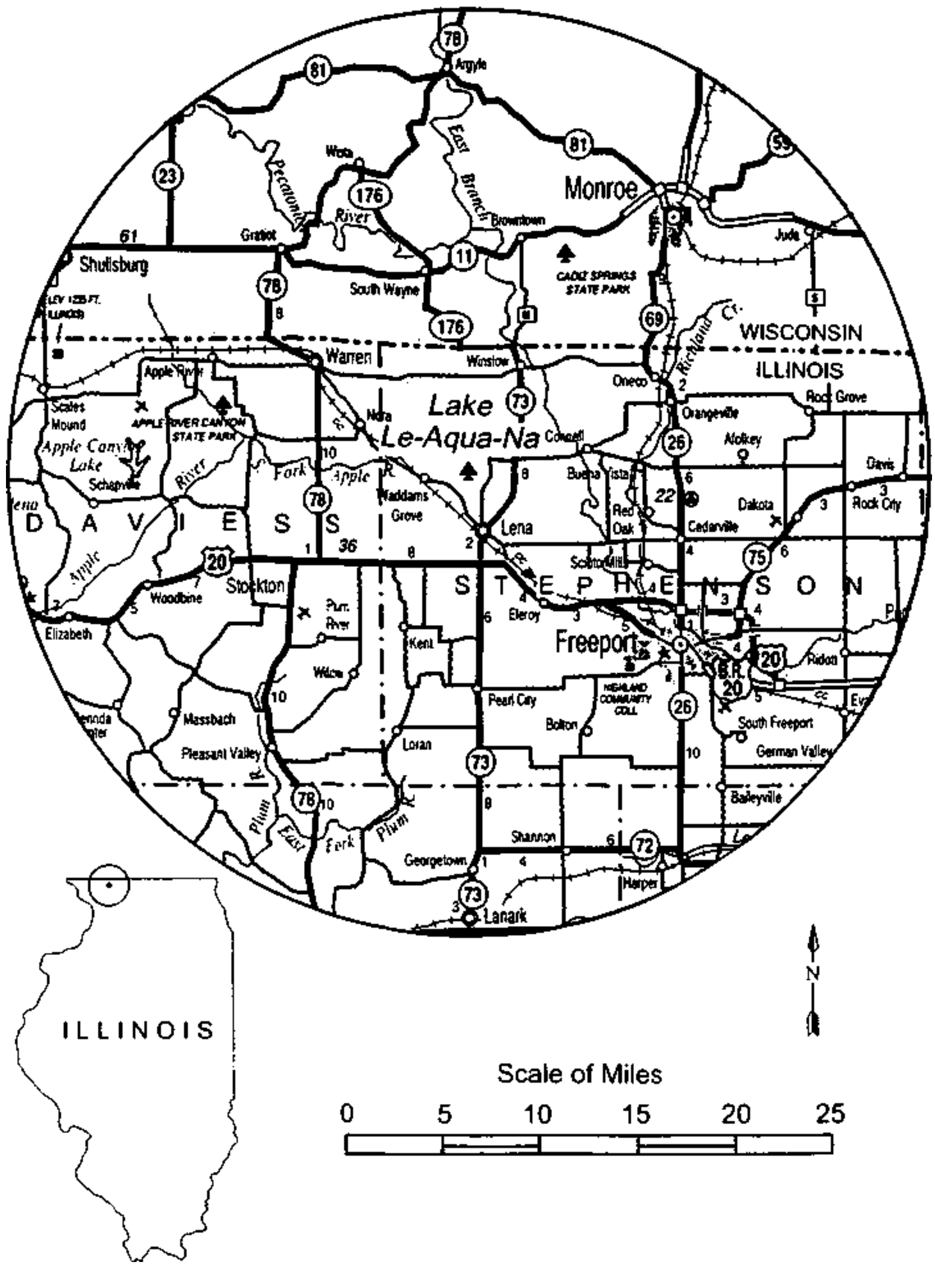


Figure 1. Location map, Lake Le-Aqua-Na

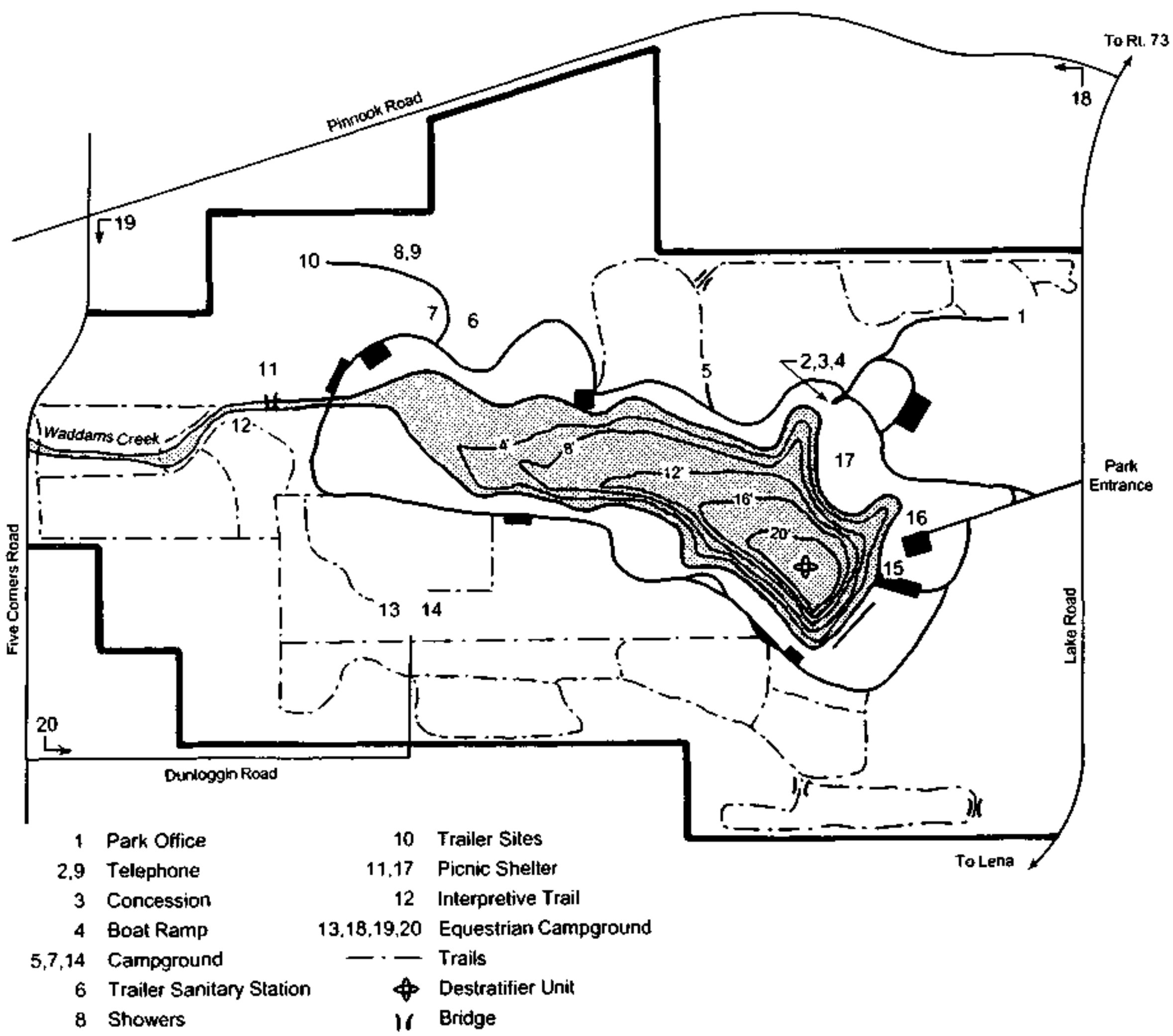


Figure 2. Public access points and facilities in Lake Le-Aqua-Na

Table 1. General Information Pertaining to Lake Le-Aqua-Na

Lake name	Le-Aqua-Na
State	Illinois
County	Stephenson; T28N., R6E., Section 17
Nearest municipality	Lena, Illinois
Latitude	42°-25'-09"
Longitude	89°-49'-54"
USEPA region	V
IEPA major basin name and code	Mississippi River, 07
IEPA minor basin name and code	Rock River, 09
Major tributary	Main branch of Waddams Creek
Receiving water body	Rock River via Waddams Creek and Pecatonica River
Water quality standards	General standards promulgated by the Illinois Pollution Control Board and applicable to waters designated for aquatic life

Table 2. Morphometric Details regarding Lake Le-Aqua-Na

	1981		*1994*	
Surface area, acres	43.4	(16.0 ha)	43.4	
Volume, acre-feet	476.2	($0.60 \times 10^6 m^3$)	452.4	
Mean depth, feet	11.6	(3.54 m)	10.4 (3.17 m)	
Maximum depth, feet	25.0	(7.62 m)	23.0	
Length of shoreline, miles	1.4 (2.25 km)		1.4 (2.25 km)	
Average retention time, years	0.186		0.216	
Total original capacity loss, percent	15.9		20.1	
Annual capacity loss, percent	0.6		0.5	
Watershed area, acres	2348.1	($9.5 km^2$)	2348.1	($9.5 km^2$)

summer, originates over the Gulf of Mexico. The third air mass develops over the Pacific Ocean, losing its moisture through precipitation on the windward side of the Rocky Mountains, and brings Illinois mild, dry air. Any one of these air masses can be found over Illinois in any season, creating the variable weather the state experiences.

Based on climate data gathered at the Freeport, Illinois, weather station by the ISWS, the long-term mean annual precipitation for this area is 33.08 inches. Table 3 provides long-term mean monthly precipitation and temperature for Freeport, along with total monthly precipitation and mean daily temperatures for each month of the calendar year from 1992 to 1995, the period covering the current investigation. Total precipitation during 1992 and 1994 was near normal, whereas in 1993, the second year of lake monitoring, the total precipitation was 43.66 inches, or 32 percent higher than normal. The mean annual snowfall for the area is 27.8 inches, and the mean monthly snowfall is 0.6, 7.9, 8.9, 5.9, 3.8, and 0.6 inches, respectively, for the months November through April.

Public Access to Lake Area

The major population centers reasonably close to the lake area are Lena and Freeport, Illinois, which are 3 and 15 miles away, respectively. There is no public transportation available between these cities and the lake and state park; however, an excellent blacktop road provides access to the park area from Lena.

A public road circling the lake provides ready and easy access for bank fishing, nature study, and use of playground facilities. Strategic lookout points with adequate parking facilities also exist around the lake. As indicated earlier, figure 2 provides a detailed map of the lake access points and the amenities found in the state park.

Information pertaining to the potential user population, socioeconomic data for the surrounding counties, and details about lakes within a 50-mile radius of Lake Le-Aqua-Na are given elsewhere (Kothandaraman and Evans, 1983). This information has not changed to any significant extent in the intervening period.

DIAGNOSTIC STUDY SUMMARY

A Phase I diagnostic-feasibility study was undertaken for Lake Le-Aqua-Na from 1981-1983 under the provisions of the Federal Clean Lakes Program authorized by Section 314 of the Clean Water Act. The study was funded 70 percent by the U.S. Environmental Protection Agency (USEPA), with 30 percent of the nonfederal costs provided by the former Illinois Department of Conservation (EDOC). The Illinois Environmental Protection Agency (IEPA) was responsible for overall project coordination and administration and applied for funds on behalf of IDOC. The ISWS conducted the study, with considerable assistance from the local U.S. Department of Agriculture (USDA) - Soil Conservation Service (SCS) and Soil and Water Conservation District (SWCD) located in Stephenson County.

The Phase I Study (Kothandaraman and Evans, 1983) identified the following major problems in the lake and its watershed:

1. <u>High nutrient levels</u>. Mean lake total phosphorus (TP), dissolved phosphorus (DP), and inorganic nitrogen (IN) were 0.323, 0.217, and 1.85 milligrams per liter (mg/L), respectively, in 1981. Gross loadings of TP, DP, and IN in 1981 were 1,802, 950, and 28,271 kilograms per year (kg/yr); internal regeneration accounted for 7.3, 13.8, and

Table 3. Precipitation (inches) and Temperature (°F) Data for Freeport, Dlinois

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Total*
Long-term mean monthly precipitation	1.15	1.08	2.25	3.09	3.66	3.90	3.60	3.80	3.86	2.46	2.42	1.81	33.08
Total monthly precipitation													
1992	0.75	1.43	1.91	4.97	0.56	1.48	7.21	3.19	5.01	0.74	5.01	2.35	34.61
1993	2.08	0.70	2.86	6.19	4.00	11.48	3.84	4.09	4.72	1.28	1.56	0.86	43.66
1994	1.36	1.88	0.25	1.83	1.57	5.15	2.80	7.04	4.13	0.89	4.50	1.44	32.84
1995	1.93	0.17	1.58	4.69	5.68	1.01	3.65	2.90	2.51	6.25	3.42		
Long-term mean daily temperature	17.1	21.7	34.1	47.6	58.9	68.8	72.9	70.1	61.9	50.3	37.4	23.0	
Mean daily temperature													
1992	24.7	30.5	36.0	44.1	58.4	65.4	67.5	64.2	59.6	48.9	35.1	24.8	
1993	20.9	21.7	31.1	43.7	60.0	66.1	72.2	71.2	57.0	48.3	34.7	25.7	
1994	10.7	14.7	35.3	48.8	57.5	70.5	70.2	66.6	63.3	53.1	39.7	28.9	
1995	18.3	22.5	36.5	42.8	56.4	71.1	73.7	76.5	58.6	50.6	29.2	22.9	

Source: W.M. Wendland, State Climatologist, personal communication, 1996

55.7 percent of these loadings. In 1981, two major storm events accounted for 73 percent of the total annual phosphorus loadings to the lake.

2. Nuisance algal blooms. Chlorophyll *a* ranged from 2 to 93 micrograms per liter -(ug/L), with an average of 44.9 ug/L. Algal populations were dominated by blue-greens, which produced frequent odors, "pea soup", and "blue-green paint slick" conditions.

3. Excessive aquatic macrophytes. One-third of the lake surface area was covered by a dense growth of aquatic macrophytes (predominantly *Ceratophyllum* and *Elodea).*

4. Dissolved oxygen depletion. During peak summer stratification, 51 percent of the lake volume was anoxic, with depths below 6 feet (1.83 meters, m) from the surface totally devoid of oxygen. Several winter fish kills were also reported.

5. Turbidity and sedimentation. The lake was turbid, primarily from algal growth and runoff from the watershed during storm events, which brought large amounts of suspended solids into the lake. The incoming sediment was filling at 0.61 percent of its original volume per year. Although the main creek and tributaries did not carry abnormally heavy suspended solids loadings during normal flow conditions, they delivered enormous loads during storm events.

Proposed desirable water quality goals for Lake Le-Aqua-Na were:

1. Year-round dissolved oxygen concentrations of at least 5 mg/L throughout the lake.
2. Secchi transparencies of not less than 4 feet during the summer months.
3. Total phosphorus concentrations of less than 0.05 mg/L at the time of the lake spring turnover.
4. Reduction of nutrient loading to the maximum practicable extent.
5. Reduction of soil erosion in the watershed to the maximum practicable extent.
6. Reduction in the number and severity of algal blooms.
7. Reduction of the coverage of aquatic macrophytes to increase recreational opportunities.

FEASIBILITY STUDY RECOMMENDATIONS

Based on technical, environmental, and economic considerations, the following in-lake and watershed management techniques were chosen for implementation at Lake Le-Aqua-Na:

1. Aeration/destratification of the lake to improve dissolved oxygen concentrations and reduce internal loading of nutrients.

2. Weed harvesting twice per year to control aquatic macrophytes.

3. Periodic applications of chelated copper sulfate followed by potassium permanganate for algae control.

4. Control of nonpoint sources of nutrients and sediments in the watershed through best management practice application to reduce nutrients and sediments reaching the lake.

5. Shoreline stabilization to reduce nutrient and sediment loading from areas of the shoreline prone to bank erosion.

SUMMARY OF PHASE II IMPLEMENTATION

Four major funding components were established for the Lake Le-Aqua-Na Phase II implementation project. They included a National Agricultural Conservation Program (ACP) special grant in 1983, an initial Clean Lakes Phase II grant in 1984, a State ACP special grant in 1985, and a Supplemental Clean Lakes Phase II grant, also in 1985 (IEPA, 1990b).

Since most of the lake's problem stemmed from nutrient and sediment loading from the watershed, IEPA and IDOC decided not to apply for Phase II assistance until watershed protection was underway. A public awareness and information program was implemented to generate landowner interest in protecting the watershed. To further demonstrate local interest, the Agricultural Stabilization and Conservation Service (ASCS) County Committee applied for and received a National Agricultural Conservation Program (ACP) special project grant of $38,000 in 1984. The purpose of the project was to increase the use of conservation tillage in the watershed on all tillable, cropland acreage to reduce soil erosion.

After implementation of the National ACP special conservation tillage project, a Phase II Clean Lakes Program grant was awarded to IEPA in the amount of $65,163 (July 1984). IDOC provided the 50 percent nonfederal match. Project funds were used for installation of a lake destratification system, aquatic macrophyte harvesting, monitoring, project administration, and implementation of agricultural best management practices.

Field investigations of the watershed by local SCS and SWCD staff revealed that additional land treatment was warranted to control megarill, gully, and streambank erosion problems. In January 1985, $26,500 of State ACP special funds were received for additional watershed work to be completed in 1985-1986.

Finally, in May 1985, a supplemental Phase II Clean Lakes Program grant in the amount of $30,446 was awarded to IEPA to help complete necessary watershed work and to fund another year of water quality monitoring. Nonfederal costs were shared by IDOC, IEPA, and local landowners. Table 4 shows the total project budget for the implementation of the Lake Le-Aqua-Na restoration project. The total cost of the project was $269,742.

Watershed Treatments

Table 5 shows the chronology of Phase II implementation of watershed and lake management for improving water quality conditions in Lake Le-Aqua-Na. The whole implementation scheme was initiated with the conservation tillage project, the purpose of which was to increase crop residues from 20 to 40 percent on the tillable land and thus reduce average soil loss rates. Cost-share rates with landowners varied with the amount of residue remaining. Figure 3 indicates that conservation tillage was applied on the majority of cropland acreage. This was attributed, in part, to a successful public information program that utilized informational meetings, news articles, and lake/watershed briefs to gain project support.

Successful implementation of the National ACP special conservation tillage project prompted USEPA to award a Clean Lakes Phase II grant for $65,481 to IEPA in July 1984. Of this, $22,860 was dedicated to install additional watershed best management practices. Specifically, these funds were used to cost-share terracing on two parcels of land (see figure 3, areas #1 and #2) that were identified as critical areas contributing to lake water quality problems in the Phase I study. A total of 103 acres (41.7 hectares, ha) of tile outlet terrace systems were

Table 4. Budget for Lake Le-Aqua-Na
Phase II Implementation and Management Plan

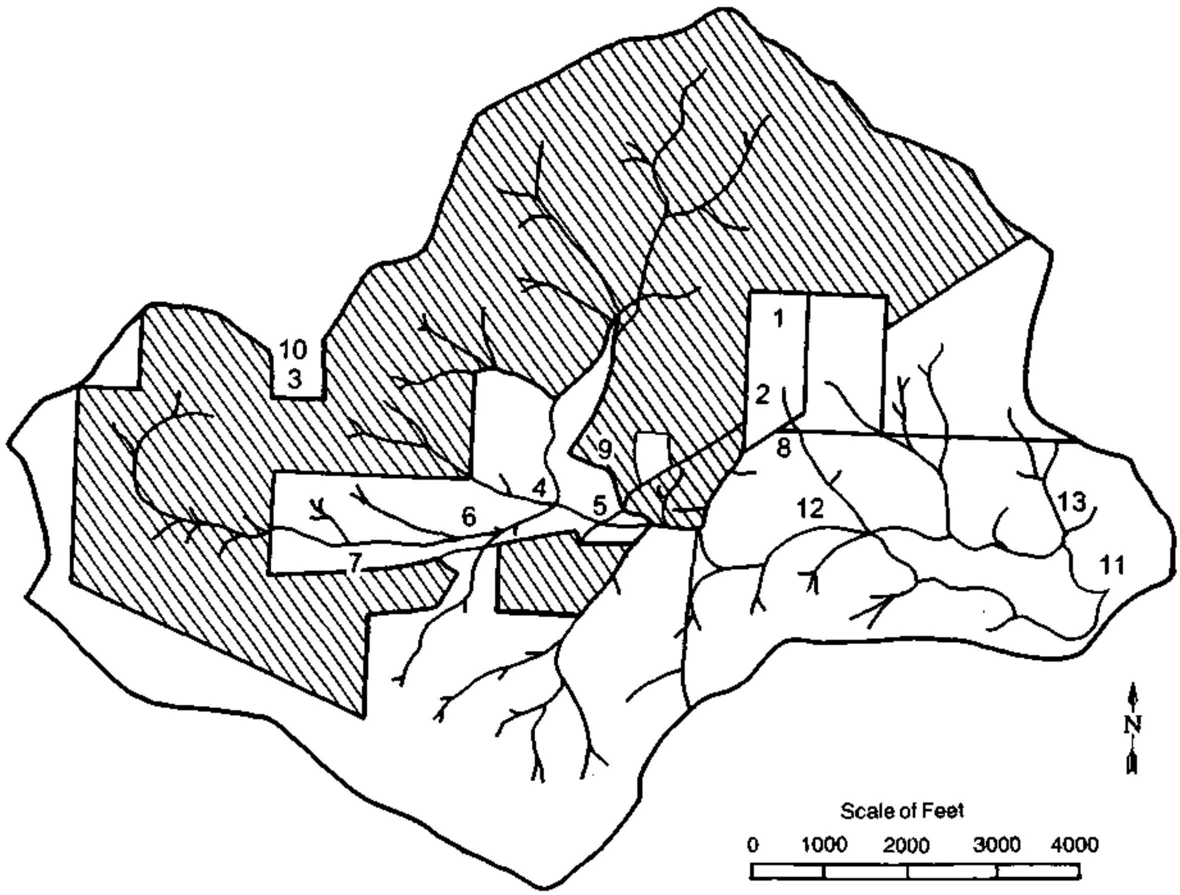
Project	*Federal*	*State*	*Local*	*Total*
National ACP	$38,000	--	$11,400*	$49,400
State ACP	$26,500	--	$7,950*	$34,450
Clean Lakes Program (Initial and Supplemental)	$92,946	$88,146	$4,800*	$185,892
TOTAL	$157,446	$88,146	$24,150*	$269,742

Note:
* Local/Landowner input estimates.
ACP = Agricultural Conservation Program

Source: EPA (1990b)

Table 5. Phase II Implementation of Watershed and Lake Management for Lake Le-Aqua-Na

1984		
		• Conservation tillage project implemented in watershed to reduce sediment yield
		• Critical area stripcropping
1985		
January		• First watershed terracing project completed
May		• Second watershed terracing project completed
		• Critically eroding areas of lake shoreline riprapped
		• Lake drawdown 6 ft for beach construction; remained down 3-7 ft until fall because of drought
July		• Terraces installed to protect beach
	8-10	• Macrophyte harvesting
	16	• Destratifier began operation
August		• Sedimentation basin installed in watershed
	7	• $CuSQ_4$+ citric acid applied - algal control
	8	• $KMnO_4$ applied to reduce BOD caused by decaying algae
October		• Lake returned to normal level with fall rain
		• Destratifier gear box failed, destratifier off
November	mid	• Destratifier gear box replaced and began operation in upflow mode
December	mid	• Destratifier gear box failed again (wrong gear) and replaced under warranty
1986		
January		• Destratifier back on
April		• During iceout, the destratifier anchor dislodged; anchor ropes and electrical cables become wrapped around blades
May	20	• Destratifier operational in downflow mode
	27-30	• Weeds harvested from headwater area of lake
August	16	• Lightning knocks out power to destratifier, repaired immediately with new fuses
November		• Sprocket and chain drive break repaired by November



National ACP Special

Particpating in conservation tillage project (1984)

Initial Clean Lakes Phase 2

1 Terracing (1985)
2 Terracing (1985)
3 Stripcropping (1984)

State ACP Special

4 Streambank protection (1985)
5 Sediment basin (1985)
6 Streambank protection (1985)
7 Terraces, strips, waterways, sediment basin (1985-86)

Supplemental Clean Lakes Phase 2

8 Tile outlet dam (1985)
9 Tile outlet dams (1985)
10 Terraces and tile outlet dams (1985)
11 Terracing of 17 acres of state park property above the beach area
12,13 Streambank and gully mitigation in areas on state park land (source: IEPA(1990)

Figure 3. Conservation tillage participation and land treatment

installed. These projects were completed in January and May of 1985. Additionally, critical area #3 was strip-cropped at no cost to the project.

Subsequent field investigations of the entire watershed revealed that additional watershed protection was required. Therefore, an application for State ACP special funds in the amount of $26,500 was submitted. The application was approved and grant funds were awarded in January 1985. Funds were used to install various practices in areas #4 - #7 of figure 3, including eight water and sediment control basins, 30 acres (12.1 ha) of contour strip cropping, 11 acres (4.5 ha) of contour farming, one grass waterway (all in area #7), a sediment basin in area #5, and streambank protection including livestock exclusion in areas #4 and #6.

Supplemental Clean Lakes Phase II funding was applied for and received in May 1985 in the amount of $36,465. Funds were utilized to finalize necessary watershed work in areas #8 - #12 (see figure 3) and to support water quality monitoring efforts. Practices implemented included terracing of approximately 50 acres of land and tile outlet dams (area #10), terracing of 17 acres of state park property above the beach area (area #11), and streambank and gully mitigation in areas on state park land (areas #12 and #13).

In-Lake Treatments

Destratification

An axial flow mechanical destratifier (similar to that described by Quintero and Garton, 1973), fabricated by J. Garton at Oklahoma State University in Stillwater, Oklahoma, was installed at the deepest point of Lake Le-Aqua-Na (figure 4). The destratifier consisted of a 6-foot-diameter (72R622 aerovent) propeller with an orifice ring and six variable-pitch symmetrical blades mounted on a vertical shaft driven by a 1.5-horsepower (230-volt, single phase, 1725-rpm) electric motor through a system comprising a gear reduction box and V-belt and sheave arrangement. The system was mounted on an anchored, floating wooden platform, such that the propeller was located approximately 5 feet below the water surface. The unit was purchased and installed for $7,830. The square redwood raft was surrounded by a wire mesh enclosure and anchored with four plastic-coated wire cables. Type U electric wire was installed underground and on the lake bottom with a ground fault breaker.

The pitch of individual blades on the destratifier can be set at any desired angle within the range of 14 to 30 degrees. The blades are symmetrical; therefore, the pumping efficiency will remain the same whether lake water is pumped from the surface toward the bottom or vice versa. A reversible switch in the system permits the direction of motor rotation and, consequently, the direction of propeller rotation to be reversed with ease.

The destratifier began operation on July 16, 1985, in downflow mode and remained on until October 1985, when the destratifier gear box failed. The gear box was replaced and the destratifier began operating in upflow mode in mid-November 1985. Operation ceased again in mid-December 1985, because the gear box failed due to an incorrect gear. The gear box was replaced under warranty and the destratifier again became operational in upflow mode during January 1986. During an ice storm in April 1986, the anchors holding the destratifier dislodged and the anchor ropes and electrical cables wrapped around the blades. After being rewired, reanchored, and moved slightly, the destratifier was again operational in upflow mode on May 20, 1986. It went off briefly on August 6, 1986, due to a power outage caused by lightning, but began operating again after a fuse was replaced. The sprocket and chain drive broke in October, but the destratifier was repaired and back in service by November 1986.

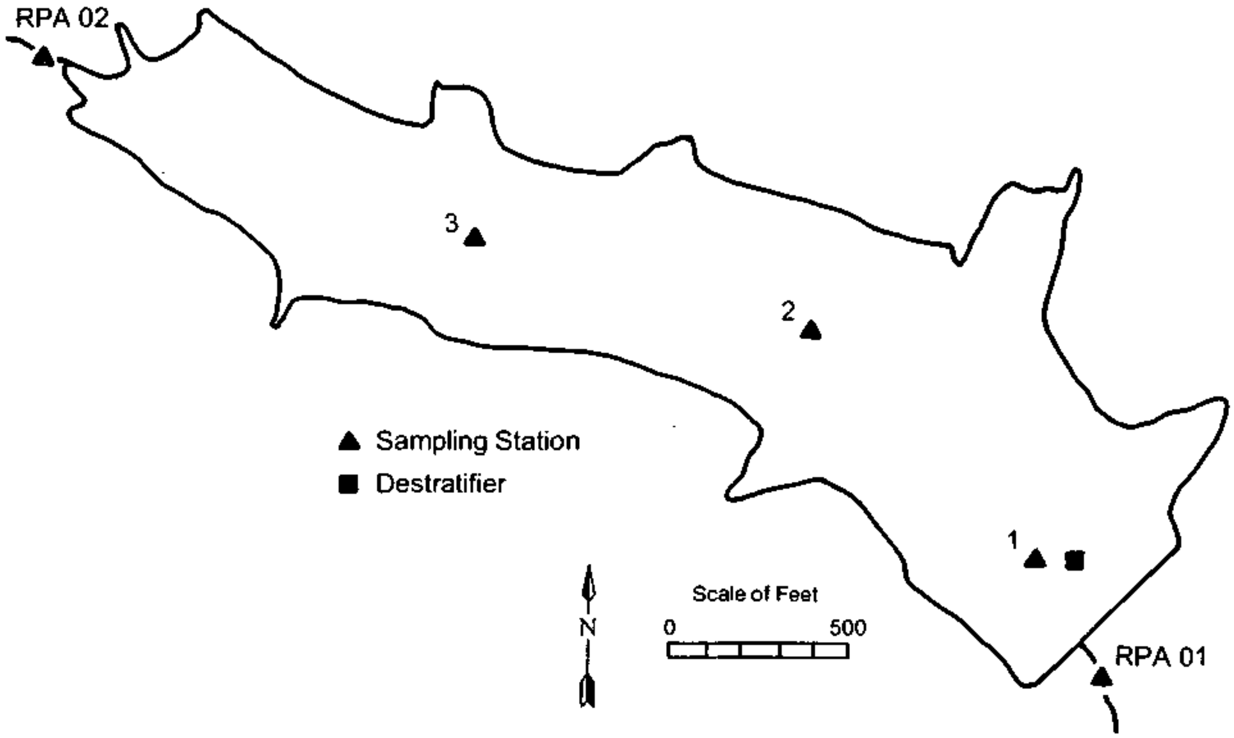


Figure 4. Sampling stations for Lake Le-Aqua-Na

An estimate of the cost of operating the destratifier was not available because the electricity to the destratifier was not metered.

Macrophyte Harvesting and Algal Control

Seventeen truckloads of macrophytes were harvested July 8-10, 1985, and more were removed May 27-30, 1986. The lake was treated with 200 pounds (lb) (91 kg) of copper sulfate on August 7, 1985, with a follow-up treatment of 62 lb (28 kg) of potassium permanganate on August 8, 1985.

Results of Phase II Implementation

The IEPA Lake and Watershed Unit, Planning Section, Division of Water Pollution Control, reported the results of post-implementation monitoring of Lake Le-Aqua-Na based on intensive monitoring of the lake during 1986 (IEPA, 1990b). Their general conclusions were:

1. Implementation of conservation practices in the Lake Le-Aqua-Na watershed was highly successful. Gross erosion and sediment yields were reduced by 57 percent from pre- to post-implementation periods. Streambank erosion was additionally reduced by 600-1,000 tons annually. By 1986, sediment, in the form of total suspended solids, had been reduced to 11.2 percent of the 1981 load, nearly an order of magnitude less than pre-implementation conditions. The goal of reducing soil erosion in the watershed to the maximum practicable extent had been achieved.

2. Success of the watershed implementation program was also supported by reductions in total phosphorus loads transported to the lake. Total phosphorus loads were down to 13.6 percent of the 1981 pre-implementation conditions. With respect to total phosphorus, the goal of reducing nutrient loading to the maximum practicable extent had been achieved.

3. Implementation of watershed practices did not have an effect on the total nitrogen load entering the lake. Pre- and post-implementation total loads were similar. However, a significant shift in the nitrogen form did occur from pre- to post-conditions. During 1981, the majority of nitrogen entering the lake was in the form of total kjeldahl nitrogen (TKN), while in 1986, most was in the form of nitrate. The application of terrace systems and water and sediment control structures, which utilize subsurface tile outlet drains, may have accounted for this observation. With respect to total nitrogen, the goal of reducing nutrient loading to the maximum practicable extent had not been achieved.

4. Under similar hydrologic conditions, average summer Secchi transparency was 39 inches in 1986 as compared to 37 inches in 1981. Although this difference was statistically insignificant, it did appear that watershed best management practices contributed to the maintenance of, if not a slight improvement in, Secchi transparency. However, the goal of attaining Secchi transparencies of not less than 4 feet during the summer months had not been achieved.

5. As is typical for Illinois lakes, Lake Le-Aqua-Na thermally stratifies in the summer and winter seasons into layers, with a minimum interchange of water between the layers. Prior to installation of the destratifier, waters below 7 to 10 feet were typically devoid of oxygen during the summer months, although surface waters usually maintained dissolved oxygen (DO) concentrations above the 5 mg/L standard. In 1986, when the destratifier was operational during critical periods, oxygen concentrations throughout most of the lake were at or above the 5 mg/L standard. Anoxic conditions were never observed in the bottom waters. Therefore, the project goal of maintaining DO concentrations of at least 5 mg/L throughout the lake had been achieved.

6. Average total phosphorus concentrations in the surface water at spring turnover (late April-May) were below the 0.05 mg/L standard during the post-implementation period, unlike pre-implementation conditions (1981) during which the standard was regularly exceeded. This reduction was not believed to be due to operation of the destratifier, but may have been due in part to watershed best management practices. Therefore, the goal of reducing total phosphorus concentrations to less than 0.05 mg/L at spring turnover had been achieved. In addition, average summer total and dissolved phosphorus concentrations in bottom water samples were significantly lower in 1986 than during the pre-implementation period. This reduction could be directly attributed to operation of the destratifier.

7. Destratification had a significant effect on summer concentrations of ammonia and TKN in the bottom waters. Summer average values were down significantly (p>05) from pre-implementation conditions.

8. No nuisance algal blooms were reported in the post-implementation period. Destratification had significantly reduced the potential for algal bloom formation.

9. The benthic macroinvertebrate community was markedly changed by the destratification of the lake. Population densities were much lower at all sites during the post-implementation period, although the population structure had shifted and diversity had increased slightly.

10. Trophic state did not change (nor was it expected to change) from pre-implementation conditions. The lake continued to be eutrophic.

LIMNOLOGICAL ASSESSMENT

Materials and Methods

To assess the long-term post-restoration conditions of the lake, certain physical, chemical, and biological characteristics were monitored from April 1992 to March 1995. Table 6 provides the dates and types of sampling, which included water quality, chlorophyll, phyto- and zooplankton, macrophytes, and sediment organics and metals determinations. Figure 4 shows sampling locations for the lake. Determinations for water quality, chlorophyll, phyto- and zooplankton, and sediment organics and metals were made at station 1, whereas only water quality and chlorophyll determinations were made at station 2 of the lake. For station 3, in addition to water quality and chlorophyll, sediment organics and metals determinations were also made.

All the sample collections (except for aquatic macrophyte) listed in table 6 were made by IEPA field personnel. Samples were collected according to the quality assurance/quality control (QA/QC) procedures found in the 1987 IEPA field methods guide. They were transported to and analyzed by IEPA laboratories using approved methods shown in table 7, with the exception of identification and enumeration of algae samples that were performed by the ISWS. Macrophyte assessments were also made by ISWS staff. All the data were entered into the USEPA STORET database and checked for accuracy and internal consistency by IEPA personnel.

Data collected and analyzed in the field included DO, temperature, pH, conductivity, Secchi transparency, water depth, and total and phenolphthalein alkalinities. Field observations were also recorded, including weather information (wind speed and direction, wave height, cloud cover, and precipitation) and qualitative assessment of lake conditions (water color, amount of suspended solids and algae, aquatic macrophytes, water level, odor, and general lake use).

Table 6. Sampling Dates and Types of Samples for Lake Le-Aqua-Na

Dates	*Water quality*	*Chlorophyll*	*Phyto-and zooplankton*	*Macrophytes*	*Sediment organics and metals*
4/27/92	X	X	X		
5/19/92	X	X	X		
5/29/92	X				
6/10/92				X	
6/16/92	X	X	X		
6/23/92	X				
7/14/92	X	X	X		X
7/29/92	X				
8/24/92	X				
8/25/92	X	X	X		
9/16/92	X	X	X		
9/23/92	X				
10/05/92	X	X			
11/18/92	X	X			
1/26/93	X				
2/24/93	X				
4/28/93	X	X	X		
5/18-20/93				X	
5/27/93	X	X	X		
6/30/93	X	X	X		
7/21/93	X	X	X		
8/31/93	X	X	X		X
9/28/93	X	X	X		
10/20/93	X	X			
11/23/93	X	X			
1/04/94	X				
1/26/94	X				
3/02/94	X	X			
3/29/94	X	X			
5/04/94	X	X	X		
5/18-19/94				X	
5/24/94	X	X	X		
6/23/94	X		X		
7/21/94		X	X		
8/25/94	X	X	X		
10/06/94	X		X		
11/30/94	X				
1/31/95	X				
3/09/95	X				

Table 7. Analytical Procedures

Parameter	*Method of analysis (reference)*	*Unit of measure*	*Detection limit*	*General use standard*
Temperature (Temp)	In-situ determination using Hydrolab 4041 or Yellow Springs Instruments (YSI) model 57 dissolved oxygen meter	°C	0.1°	
Dissolved Oxygen (DO)	In-situ determination using Hydrolab 4041 or 8000 or YSI model 57 DO meter	mg/L O_2	0.1 mg/L	not 5 mg/L
Transparency	Secchi disc	inches	1 inch	
Total suspended solids (TSS)	Filtration on glass fiber filter, determination of increase in weight upon drying at 103-105°C	mg/L TSS	1 mg/L	
Volatile suspended solids (VSS)	Loss in weight of TSS filter upon ignition at 550°C	mg/L VSS	1 mg/L	
Turbidity (Turb)	Nephelometric use of Hach model 2100A turbidimeter	NTU	0.1	
Conductivity (Cond)	YSI model 33 S-C-T conductivity meter or electrolytic conductivity measuring set, model MC-1	umho/cm	1 umho/cm	
Alkalinity (Alk)	Titration of 10 mL sample 0.02 N H_2SO_4 to phenolphthalein and brom cresol green-methyl red end points	mg/L $CaCO_3$	1 mg/L	
pH	Sargent-Welch model PBL pH meter, calibrated in field or Hydrolab 4041 or 8000	units	0.1 units	6.5-9.0 range
Nitrate-Nitrite-N (NO_3+NO_2-N)	Cadmium reduction method on Technicon Auto-Analyzer	mg/L N	0.01 mg/L	
Ammonia-N (NH3-N)	Phenate method on Technicon Auto-Analyzer	mg/L N	0.01 mg/L	1.5 mg/L

Table 7. Concluded

Parameter	*Method of analysis (reference)*	*Unit of measure*	*Detection limit*	*General use standard*
Total kjeldahl-N (TKN)	Digestion at 370°C followed by determination of ammonia as above	mg/L N	0.1 mg/L	
Total phosphorus (TP)	Digestion to convert all phosphorus forms to orthophosphate followed by determination using ascorbic acid reduction method using Technicon Auto-Analyzer	mg/L P	0.001 mg/L	0.05 mg/L
Total dissolved phosphorus (DP)	Field filtration followed by TP analysis as above	mg/L P	0.001 mg/L	
Chemical oxygen demand (COD)	Titrimetric, low-level method sample refluxed with a sulfuric acid, potassium dichromatic, mercuric sulfate, and silver sulfate solution; treated with standard ferrous ammonium	mg/L	1 mg/L	
Chlorophyll (ChL)	Concentration by filtration, extraction with acetone, determination of optical density and calculation of concentration by standard formulae	µg/L	1 µg/L	

DO, temperature, pH, and conductivity were measured *in-situ* using a Hydrolab 4041 or Surveyor II with a 50-foot cable or, if necessary, using separate meters (table 7). DO and temperature measurements were taken at the water surface, at a depth of 1 foot, and at 2-foot intervals to 2 feet above the bottom of the water column. Conductivity and pH were measured at depths 1 foot below the surface and 2 feet above the bottom of station 1.

Secchi disc transparencies were measured using an 8-inch-diameter Secchi disc, which was lowered until it disappeared from view, and the depth noted. The disc was lowered further and slowly raised until it reappeared. This depth was also noted, and the average of the two depths was recorded. Site depth was measured using a weighted line calibrated in feet.

Samples for water chemistry were collected using a 4.2-liter (L) plastic Kemmerer bottle. Near-surface (1 foot below surface) water samples were collected from all the sites, while near-bottom (2 feet above the bottom) samples were collected only at station 1. Total alkalinity and phenolphthalein alkalinity were measured in the field on these samples using Hach alkalinity kits. Sample bottles were filled and sent to the IEPA laboratory for additional analyses. Samples for dissolved phosphorus were filtered in the field through 0.45-micrometer (µm) pore size type MF-Millipore filters. All samples destined for the laboratory were stored on ice during transport and kept refrigerated until processed.

Vertically integrated samples for chlorophyll and phytoplankton were collected using a weighted bottle sampler with a half-gallon plastic bottle. The sampler was lowered at a constant rate to a depth twice the Secchi depth, or to near the lake bottom, and raised at a constant rate to the surface. Chlorophyll samples were transferred to a foil-wrapped quart sample bottle and filtered through microfiber filters. The chlorophyll filters were then wrapped in aluminum foil and the filtrate volume measured using a graduated cylinder. Filters were kept frozen in the laboratory until analyzed. For algal identification and enumeration, 380-milliliter (mL) water subsamples were taken, preserved with 20 mL of formalin at the time of collection, and stored at room temperature until they could be examined.

Also, vertically integrated 10-L samples were collected for zooplankton identification and enumeration. The samples were filtered through a Wisconsin net, and the collected zooplankton were placed in a 250-mL bottle with 10 mL of ethyl alcohol and 190 mL of deionized water. In the laboratory, each sample was filtered through a 0.45-um filter. The organisms were resuspended in 10 mL of deionized water. A 1-mL sample was placed in a Sedgwick Rafter Cell and examined using a differential contrast microscope at 100X magnification. Organisms in the five widths of the cell were counted and recorded.

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, 20X or 100X objective, and a Whipple disc was used for identification and counting purposes. Five short strips were counted. The algae species were identified and were classified into five main groups: blue-greens, greens, diatoms, flagellates, and others. For enumeration, blue-green algae were counted by trichomes. Green algae were counted by individual cells 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.

The macrophyte survey of the lake was done in two stages. A reconnaissance survey of the macrophyte beds was always carried out prior to macrophyte sample collections, using a boat and a detailed lake bathymetric map. The macrophyte beds were probed thoroughly with a garden rake to determine the presence/absence of macrophytes, type and qualitative assessment of vegetation densities (dense, medium, sparse, etc.), and so forth. The reconnaissance survey enabled the delineation of the areal extent and abundance of macrophytes in the lake and the tentative selection of sites for quantitative sampling of macrophytes.

Subsequent to the reconnaissance survey, macrophyte samples were collected at several locations with the aid of two scuba divers, using 18- or 20-inch quadrats depending on whether the site had sparse or dense growth. Observations were made at each sampling site and recorded for water depth, plant length, depth, and character of sediments, etc. All the plants within the quadrat were collected with roots intact and placed in plastic bags, which were then sealed. These samples were then examined with a stereo microscope and identified. Subsequently, the plants from each site were air-dried, then dried at 105 degrees Celsius (°C) in an oven to constant weight, and finally weighed to determine biomass.

Staff gages were installed for measuring the depth of flows in the tributary upstream and downstream of the lake. Daily stage readings were recorded with the help of a private citizen who was compensated for her efforts.

Also, a Sigma portable liquid sampler, model Streamline 800 SL, was installed in the tributary upstream and close to the lake (station RPA 02, figure 4) to monitor the storm events. The sampler was initially programmed to collect three storm event samples in the 30 minutes following initiation of event sampling to delineate first flush characteristics. Thereafter, the sampler was programmed to collect samples after a predetermined volume of flow. Actual streamflow measurements were made using a Marsh-McBirney current meter to establish stage-discharge relationships for different discharge levels. Stage velocity measurements were made during storm events for the rising and falling limbs of the hydrographs by the ISWS staff members.

An automatic recording raingage was installed in the watershed for the duration of this investigation. Rainwater samples collected in the gage were examined periodically for nitrogen and phosphorus content.

All the data gathered for Lake Le-Aqua-Na - physical, chemical, and biological - have been entered into USEPA's STORET system and are readily accessible.

Chemical data obtained from this and previous studies were subjected to statistical analysis. Data from the 1981 Phase I study describe the pre-implementation period. Phase II implementation began in 1984 and continued through 1985. Data collected during 1986 represent the post-implementation period, while data collected in 1992, 1993, and 1994 for the Phase HI study reflect the long-term effects of project implementation. Data pertaining to the calendar year in each of these seven years (1981, 1984, 1985, 1986, 1992, 1993, and 1994) and those pertaining to the warm weather period in each year were analyzed separately. A warm weather (summer) period is defined by the IEPA as from May through October.

Data for Secchi transparency, turbidity, and total and volatile suspended solids (TSS and VSS) were evaluated both with arithmetic means and geometric means. Data for other parameters were evaluated with arithmetic means. In order to determine any differences among the means, two-way analysis of variance, i.e., an F-test (Dixon and Massey, 1957), was used for 7-year data collected at four locations (station 1 - surface and bottom, and stations 2 and 3). If there were differences among the means of a station, further statistical analysis with Duncan's multiple range test (Duncan, 1955; Federer, 1955) was performed to define their differences. For a given parameter, when the number of samples collected each year differed, i.e., if the rth and jth categories had different numbers of observations, the standard error of difference between the rth and jth means was (Carmer and Walker, 1985):

$$Sd(i,j) = (s^2/n_i + s^2/n_j)^{1/2}$$

where s^2 is the estimated error variance (or mean square of within-groups) and n_i and n_j are the number of observations for the ith and jth categories. Sd *(i,j)* was calculated in a form of matrix and then multiplied by a significant range value for a 5 percent level obtained from Duncan's table (Duncan, 1955) or by interpolation from the table as a calculated range. All calculations were performed with Lotus 123 worksheets.

In-Lake Water Quality Characteristics

Most physical and chemical data obtained during the study were plotted to show their temporal variation. For comparison, refer to the temporal variation figures for each parameter for previous years (1981, 1984, 1985, and 1986) in the Phase II report for Lake Le-Aqua-Na (IEPA, 1990b).

As stated previously, statistical analyses for differences of means were performed for both summer and annual data. Tables 8 and 9 show the parameters and corresponding mean values that were not statistically different from each other, for each station. If there were significant differences, the results are depicted as graphical arrays later in this report. In addition, a summary of water quality characteristics observed for the lake during 1992 to 1994 is presented in appendix A-l through A-5.

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 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. Shortly after the temperature variation in water comes 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 (epilimnion) is isolated from the lower layer of water (hypolimnion) by a temperature gradient (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 thermal stratification is established, the lake enters the summer stagnation period, so named because the hypolimnion becomes stagnant.

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 wind.

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

Table 8. Summer Means with No Significant Difference for Lake Le-Aqua-Na

	1981	*1984*	*1985*	*1986*	*1992*	*1993*	*1994*
Station 1 - Surface							
Secchi trans., inches	39	47	27	41	34	45	70
Turbidity, NTU	6.4	4.3	6.5	15.1	8.8	23.0	5.5
TSS,mg/L	11.6	9.9	8.3	19.8	12.9	20.2	5.0
VSS,mg/L	8.0	8.7	6.8	7.9	4.0	5.0	4.3
Ammonia-N, mg/L	0.36	0.26	0.30	0.21	0.16	0.26	0.16
Station 1 - Bottom							
Turbidity, NTU	18.8	3.5	6.6	23.2	10.0	81.2	9.2
TSS,mg/L	24.3	7.9	7.8	10.8	7.0	86.3	12.2
VSS,mg/L	11.3	6.3	6.5	9.1	5.5	14.2	11.6
COD, mg/L		25	21	17	27	28	
T. alk., mg/L as $CaCO_3$	252	222	221	227	249	228	190
Station 2 - Surface							
Secchi trans., inches		45	27	36	38	41	69
Turbidity, NTU		4.5	6.9	17.6	8.4	27.2	6.6
TSS,mg/L		8.4	9.1	16.8	14.7	23.7	7.3
VSS,mg/L		6.6	8.3	7.6	8.3	5.2	5.8
Conductivity, μmhos/cm		375	411	382	385	433	414
Dissolved P, mg/L		0.050	0.187	0.094	0.019	0.090	0.041
Ammonia-N, mg/L		0.24	0.29	0.21	0.16	0.25	0.15
Station 3 - Surface							
Secchi trans., inches		30	22	33	29	36	31
Turbidity, NTU		4.7		7.4	9.4	22.2	7.0
TSS,mg/L		8.7		10.3	18.0	208	6.4
VSS,mg/L		5.6		7.1	11.0	4.2	4.5
Conductivity, umhos/cm		381		402	395	422	421
COD, mg/L		26		18	28	18	
Total P, mg/L		0.128		0.144	0.088	0.147	0.086
Dissolved P, mg/L		0.061		0.082	0.021	0.090	0.024
Ammonia-N, mg/L		0.31		0.15	0.13	0.23	0.13

Table 9. Annual Means with No Significant Difference for Lake Le-Aqua-Na

	1981	*1984*	*1985*	*1986*	*1992*	*1993*	*1994*
Station 1 - Surface							
Secchi trans., inches	52	45	28	45	37	48	61
Turbidity, NTU	5.1	5.9	5.5	11.0	7.4	18.0	8.5
TSS,mg/L	9.2	11.7	8.6	15.1	12.1	16.5	6.5
VSS,mg/L	6.5	7.5	6.7	6.3	4.1	4.6	4.0
Nitrate/nitrite-N, mg/L		0.82	0.94	1.56	0.50	1.61	1.11
Dissolved P, mg/L	0.085	0.074	0.177	0.103	0.022	0.079	0.110
Station 1 - Bottom							
Turbidity, NTU	14.7	4.9	6.0	18.8	8.6	62.4	8.6
TSS,mg/L	21.9	7.6	6.7	8.5	7.0	66.9	9.5
VSS,mg/L	10.4	5.9	5.8	7.5	5.1	11.4	8.6
COD, mg/L		23	18	15	26	27	
T. alk., mg/L as $CaCO_3$	250	216	218	237	237	238	213
Nitrate/nitrite-N, mg/L		0.69	0.94	1.59	0.55	1.49	0.74
Station 2 - Surface							
Secchi trans., inches	43	27	40	29	30	49	61
Turbidity, NTU		6.6	5.5	12.8	6.6	17.9	8.2
TSS,mg/L		10.4	8.8	12.8	13.0	15.4	7.0
VSS,mg/L		6.2	6.9	6.3	7.6	3.7	4.6
T. alk, mg/L as $CaCO_3$		184	202	222	182	209	218
Conductivity, umhos/cm		375	411	382	385	433	413
Dissolved P, mg/L		0.078	0.158	0.088	0.034	0.118	0.086
Ammonia-N, mg/L		0.31	0.25	0.17	0.16	0.79	0.29
Station 3 - Surface							
Turbidity, NTU		65.7	3.5	5.9	8.1	16.3	9.4
TSS,mg/L		10.6		7.7	16.4	11.4	7.0
VSS,mg/L		5.6		5.1	9.9	3.2	4.0
T. alk., mg/L as $CaCO_3$		183		227	189	207	221
Conductivity, umhos/cm		393		434	312	395	452
Total P, mg/L		0.136		0.135	0.082	0.185	0.150
Dissolved P, mg/L		0.067		0.076	0.033	0.117	0.091
Nitrate/nitrite-N, mg/L		0.83		1.65	0.86	2.06	1.06

temperature of the surface water rises. The lake temperature again becomes uniform, and 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 anoxic or devoid of oxygen because of the increased content of highly oxidizable material and because of its isolation from the atmosphere. When oxygen is absent, 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 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. 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.

IEPA (1990b) reported that the temperature regimes were changed drastically by the installation and operation of the destratifier. Prior to the installation of the destratifier, thermal stratification began in late May and continued until mid-September. Temperatures of the top and bottom waters of the deep station differed by as much as 17°C. During spring and fall, the temperatures were uniform after the spring and fall turnovers. A dramatic difference in the temperature profiles for July 15, 1985, and July 16, 1985, was noted after installation of the destratifier on July 15. No evidence of stratification was present until mid-December when the destratifier failed and the lake exhibited winter stratification. The destratifier operated without any extended periods of breakdowns during the critical summer period (table 5) of 1986, and consequently isothermal conditions prevailed throughout the lake that year during intense monitoring of post-implementation effects.

Figure 5 shows isothermal plots for the bottom station during Phase III monitoring of the lake for 1992, 1993, and 1994. Vertical temperature profiles and DO profiles for stations 2 and 3 are shown in figures 6 and 7, respectively.

The lake exhibited stratification throughout the summer of 1992. The maximum observed temperature difference between the surface and near-bottom waters of station 1 occurred on July 25 with a value of 12.3°C (figure 5). Even though this was not as high as the values observed prior to the installation of the destratifier, the thermal regime in the lake was unlike that of 1986, the full calendar year after installation of the destratifier. The lake exhibited distinct thermal stratification. In all likelihood, the destratifier was inoperative during this period. There was no written record of the status of the operating conditions of the destratifier, and it was too late and futile to assess such information from interviewing the site personnel. Appendix B-l shows the destratifier operating details for the period July 1985 to December 1987. The lake exhibited isothermal conditions in early October after the fall turnover.

Isopleth plots for 1993 indicate that there was an onset of lake stratification until mid-June. There were temperature differences between the surface and bottom waters of 8.9°C on April 28 and 9.2°C on May 27. These differences decreased gradually to 4.0°C, 1.8°C, 0.2°C, and 0.1°C, respectively, on June 30, July 21, August 31, and September 28. It is not certain whether this gradual reduction in the intensity of thermal stratification was due to the destratifier or to the extremely wet weather conditions that prevailed that year (table 3), with storm events occurring almost continuously from June 7 through the end of the month. If the former was the

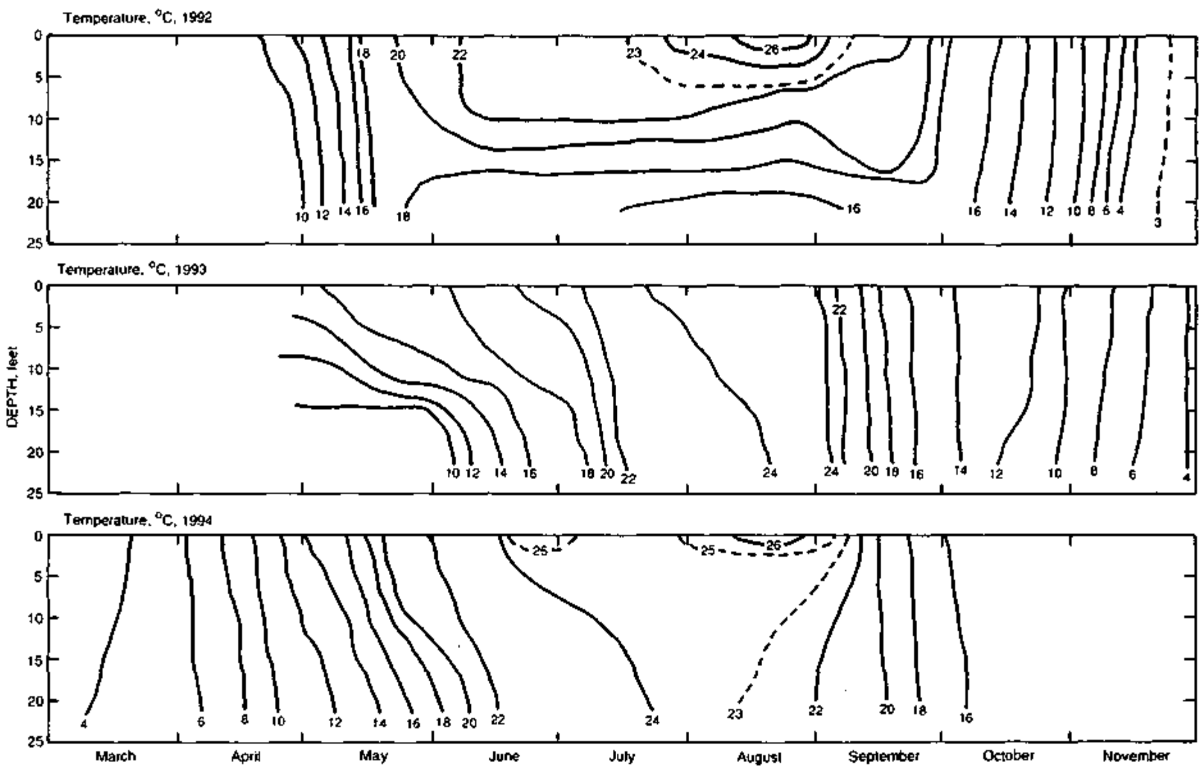


Figure 5. Isothermal plots for the deep station, station 1

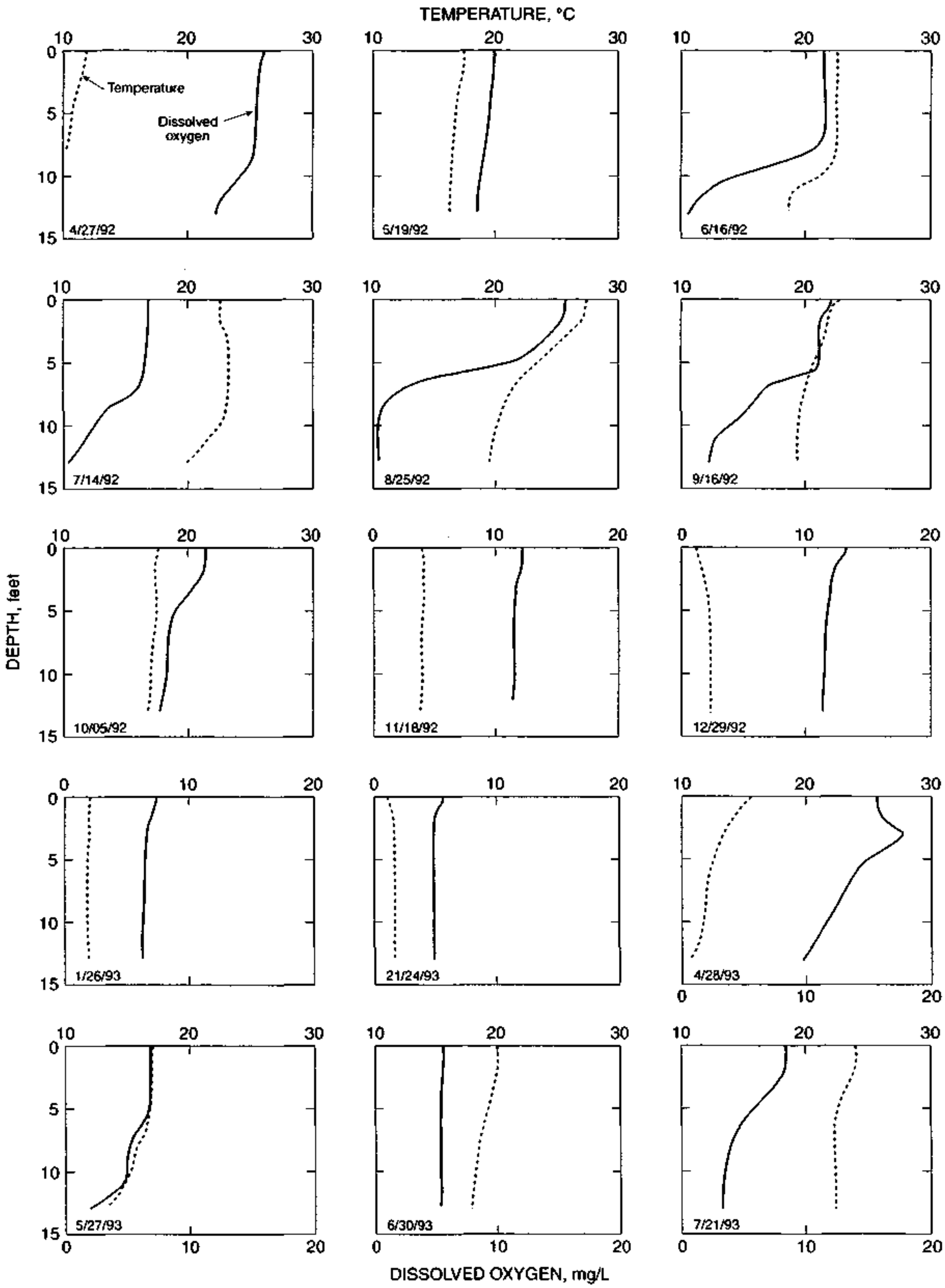


Figure 6. Temperature and dissolved oxygen profiles, station 2

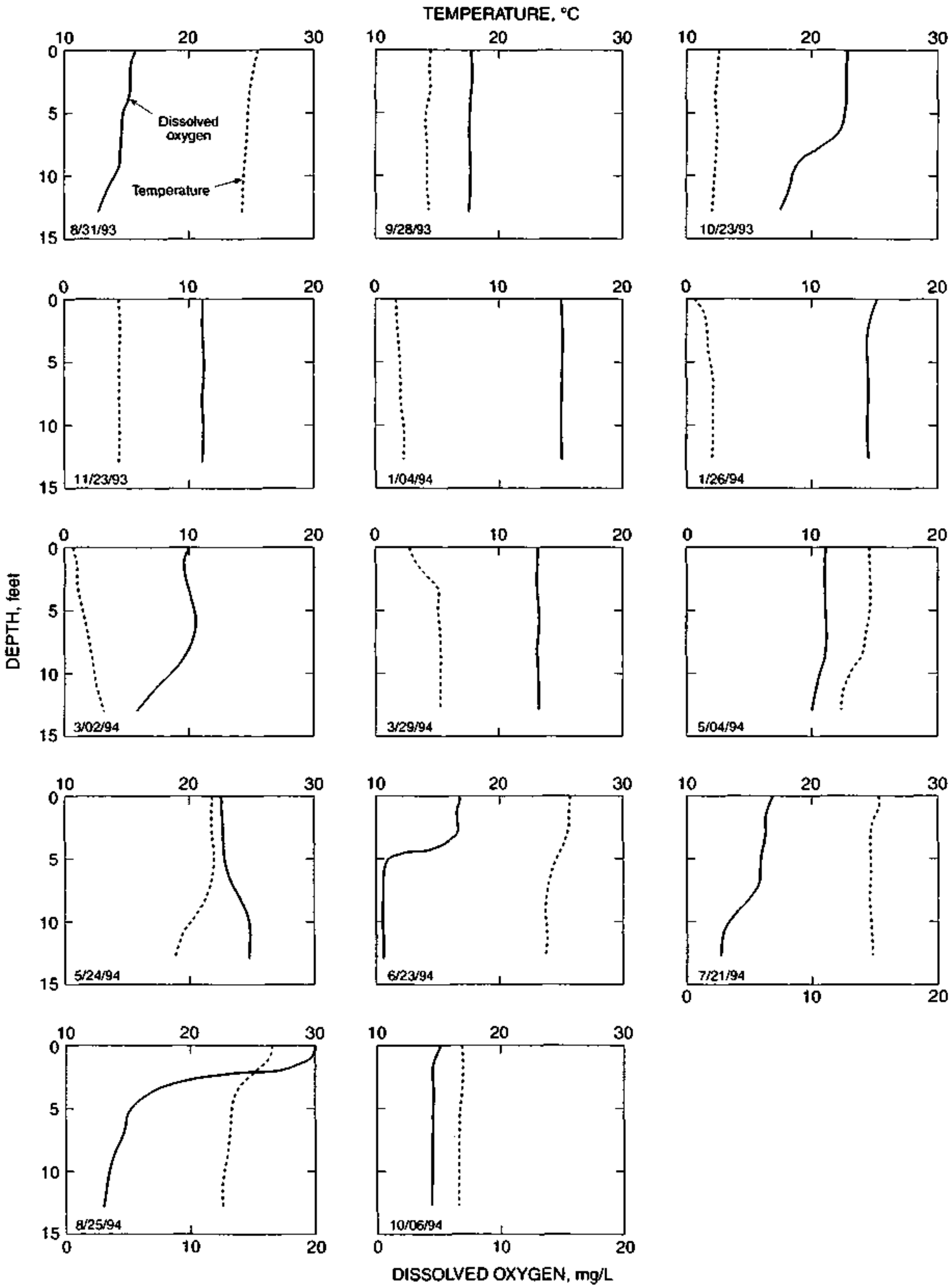


Figure 6. Concluded

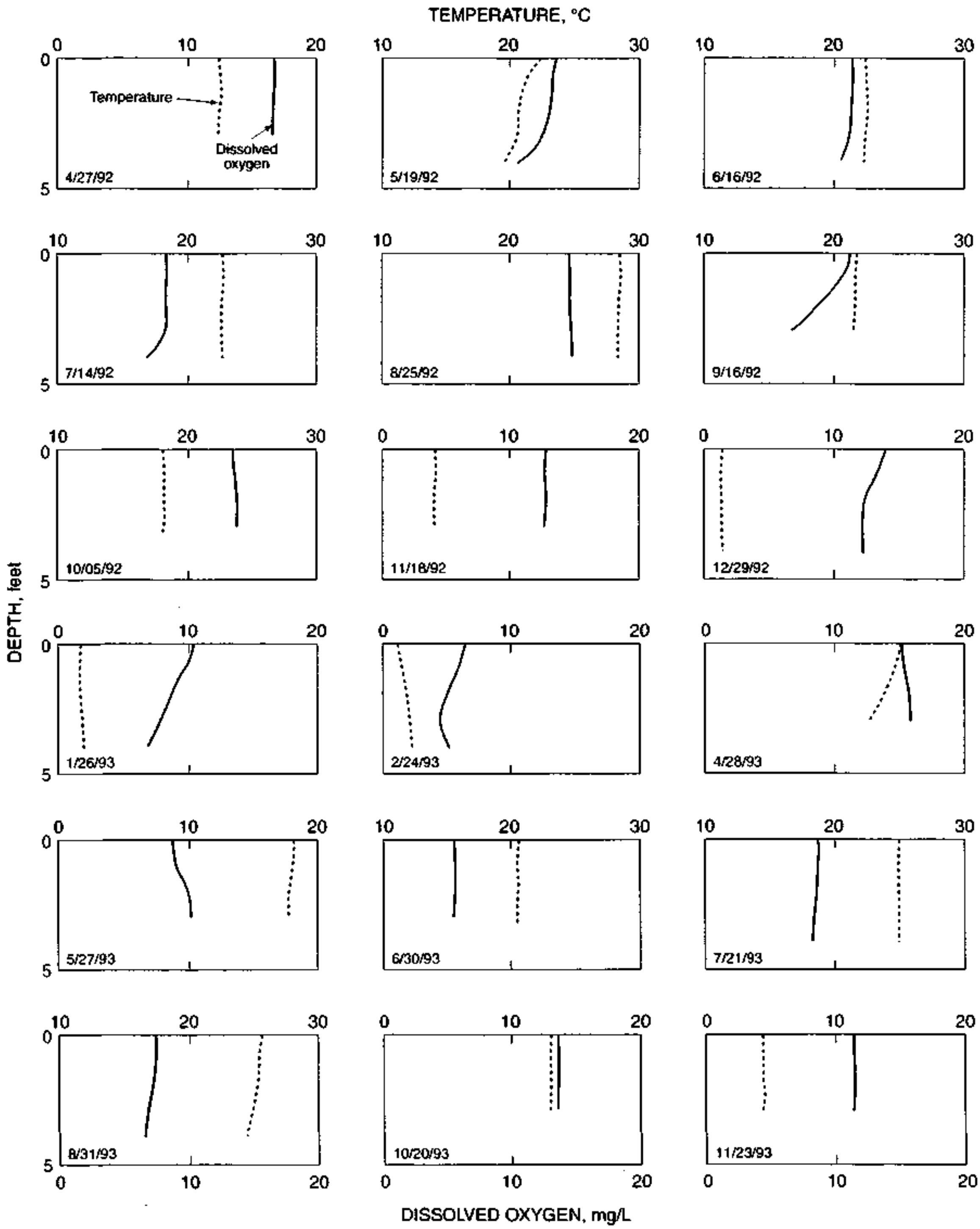


Figure 7. Temperature and dissolved oxygen profiles, station 3

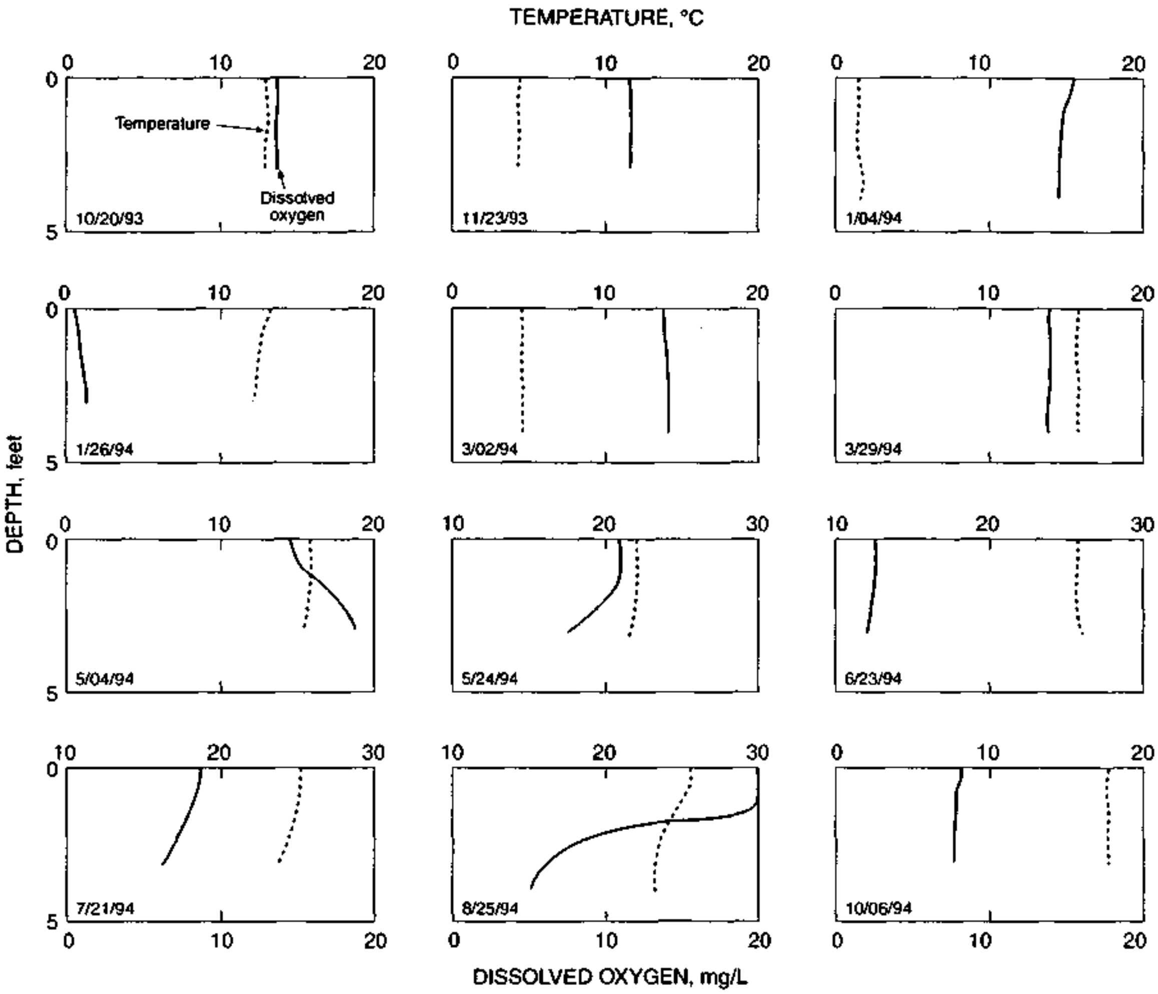


Figure 7. Concluded

case, the temperature would have been more uniform as was observed on July 16, 1985, and during 1986. Increased rainfall-runoff results in decreased hydraulic retention time, more lake natural mixing, and less intense stratification.

The lake did not stratify in 1994 as it did in 1992; however it exhibited a temperature gradient as high as 6.4°C on May 24, 1994, and somewhat lower on other dates. Generally, isothermal conditions observed in 1986 were not observed during the Phase III monitoring period.

Station 2, with a water depth of 14 feet, also exhibited large temperature gradients, very significantly so in 1992 (figure 6). The maximum difference in temperature between the surface and bottom waters was 7.6°C on August 25, 1992. Station 3, being shallow (water depth of 4 feet), was well mixed and did not exhibit any significant temperature gradients in its temperature profiles (figure 7).

It is common knowledge that the impoundment of water alters its physical, chemical, and biological characteristics. The literature is replete with detailed reports about 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, thermal stratification acts as an effective barrier for the wind-induced mixing of the hypolimnetic zone. Oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanism.

During the period of summer stagnation and increasing water temperature, the bacterial decomposition of the bottom organic sediments exerts a high rate of oxygen demand on the overlying waters. When this rate of demand exceeds the oxygen replenishment by molecular diffusion, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom. Hypolimnetic zones of artificial impoundments were also found to be anaerobic within a year of their formation (Kothandaraman and Evans, 1975). However, the IEPA (1990b) reported that in 1986, with the destratifier operating during most of the critical summer period, the concentration of DO at the deep station never dropped to the low levels observed before installation of the destratifier.

DO gradients were minimal during 1986, although the bottom waters had somewhat lower concentrations of DO than the surface waters, With the exception of a period during late June and early July, the lake usually maintained oxygen levels above 5 mg/L throughout the lake, and anoxic conditions were never observed in the bottom waters.

On the other hand, observations in 1981 and 1984 prior to the installation and operation of the destratifier indicated that during the winter and early spring, the entire water column was oxygenated, and DO concentrations were well above the 5 mg/L standard. The lake began to thermally stratify in early to mid-May, and anoxic conditions of the hypolimnion soon followed. During summer months, the waters below 7 to 10 feet of the surface were devoid of oxygen. Anoxic conditions continued until the lake turned over in the fall. The surface waters, on the other hand, usually maintained DO concentrations above the 5 mg/L standard. During fall turnover or periods during which the epilimnion deepened (storm events), DO concentrations were sometimes reduced to levels below 5 mg/L. The DO concentrations usually recovered soon after these events, returning to higher concentrations.

Figure 8 shows the DO isopleths for the bottom station for 1992, 1993, and 1994. Observed vertical DO profiles and temperature profiles for stations 2 and 3 are shown, respectively, in figures 6 and 7.

DO depletion at the bottom station was more severe in 1992 and almost paralleled the predestratification periods. Oxygen depletion began to occur in early June. Waters at depths

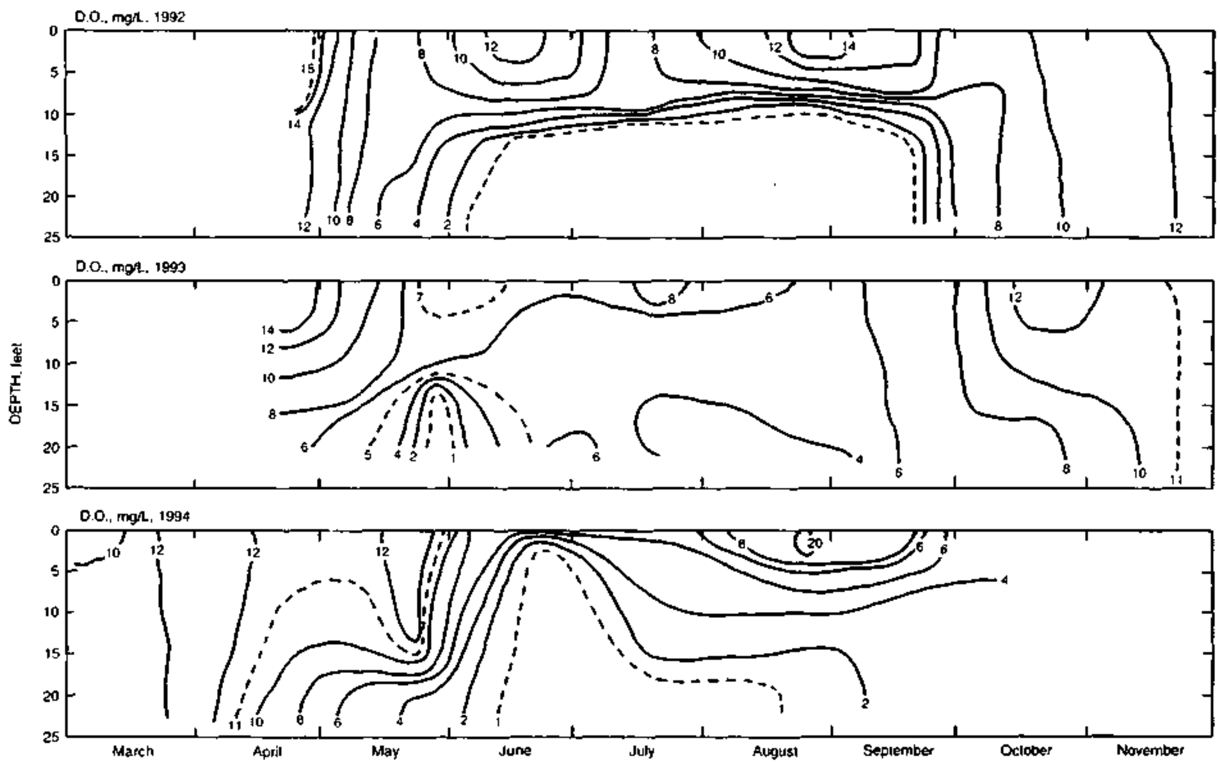


Figure 8. Iso-dissolved oxygen plots for the deep station, station 1

below 10 feet from the surface remained anoxic during summer months, and DO conditions recovered in mid-September probably due to the fall turnover. The severity of oxygen depletion at the bottom station in 1992 indicates that the destratifier might not have been Sanctioning in 1992. The highest surface DO measured at station 1 in 1992 was 15.2 mg/L, or 187.7 percent saturation, on August 25.

Anoxic conditions were not observed at the bottom station during 1993. The lowest DO measured in the near-bottom waters was 3.9 mg/L on August 31. The highest surface DO observed during the summer period (June to August) was 8.1 mg/L, or 95.3 percent saturation, on July 21. This is probably attributable again to numerous storm events that occurred during the summer of 1993. Supersaturated conditions were never observed at the bottom station during that summer period.

The DO depletion at the deep station was not as severe in 1994 as it was in 1992. However, it was very intense on June 23, 1994, when DO concentrations at 3 feet and farther below the surface were 0.5 mg/L and less. Excluding these observations, however, poor oxygen conditions existed in the lake only at depths below 15 feet from the surface during the summer.

Station 2, with a water depth of 14 feet, had significant oxygen depletion near the bottom during summer months, even though typical thermal layering of the waters did not occur at this site. On several occasions during the Phase III monitoring - June 16, 1992; July 24, 1992; August 25, 1992; and June 23, 1994 - the DO concentrations were near zero above the lake bottom up to 1 to 4 feet (figure 6). Anoxic conditions were never encountered at station 3, and the DO conditions were above the standard of 5 mg/L except for the observations on June 23, 1994, when DO levels at this site were much below the standard (figure 7).

The DO and temperature data for the Phase III monitoring bear out the fact that proper maintenance and operation of the destratifier is imperative. Although significant improvements in lake watershed management have taken place over the past decade, hypolimnetic oxygen resources cannot be improved without adequately sized and properly maintained aeration systems in Illinois lakes. This is primarily because most of these lakes are formed on nutrient- and organic-rich lake bottoms. At least for Illinois lakes, aeration/destratification is an essential lake management tool, not a palliative measure.

Secchi Disc Transparency. Secchi disc visibility is a measure of a lake's water transparency, which suggests the depth of light penetration into a body of water (its ability to allow sunlight penetration). Even though Secchi disc transparency is not an actual quantitative indication of light transmission, it provides an index for comparing similar bodies of water or the same body of water at different times. Since changes in water color and turbidity in deep lakes are generally caused by aquatic flora and fauna, transparency is related to these entities. The euphotic zone or region of a lake where enough sunlight penetrates to allow photosynthetic production of oxygen by algae and aquatic plants is taken as two to three times the Secchi disc depth (USEPA, 1980).

Suspended algae, microscopic aquatic animals, suspended matter (silt, clay, and organic matter), and water color are factors that interfere with light penetration into the water column and reduce Secchi disc transparency. Combined with other field observations, Secchi disc readings may furnish information on 1) suitable habitat for fish and other aquatic life, 2) the lake's water quality and aesthetics, 3) the state of the lake's nutrient enrichment, and 4) problems with and potential solutions for the lake's water quality and recreational use impairment.

Figure 9a shows the temporal variations in Secchi disc transparency at station 1 (the deepest location of the lake). An examination of figure 9a and figure 13 of the Phase II study (IEP A, 1990b) reveals that higher transparency occurred in May of each year and during the cold

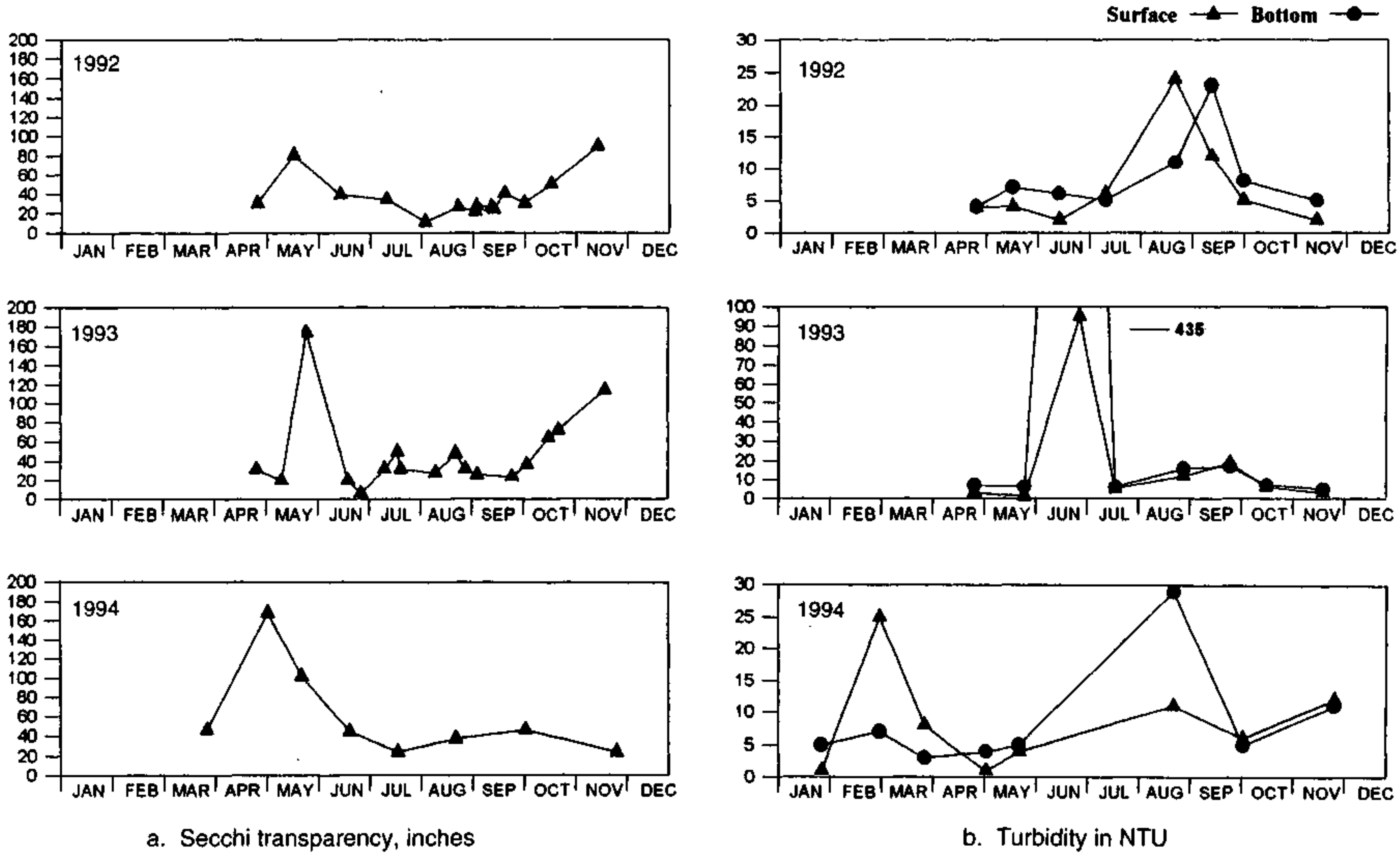
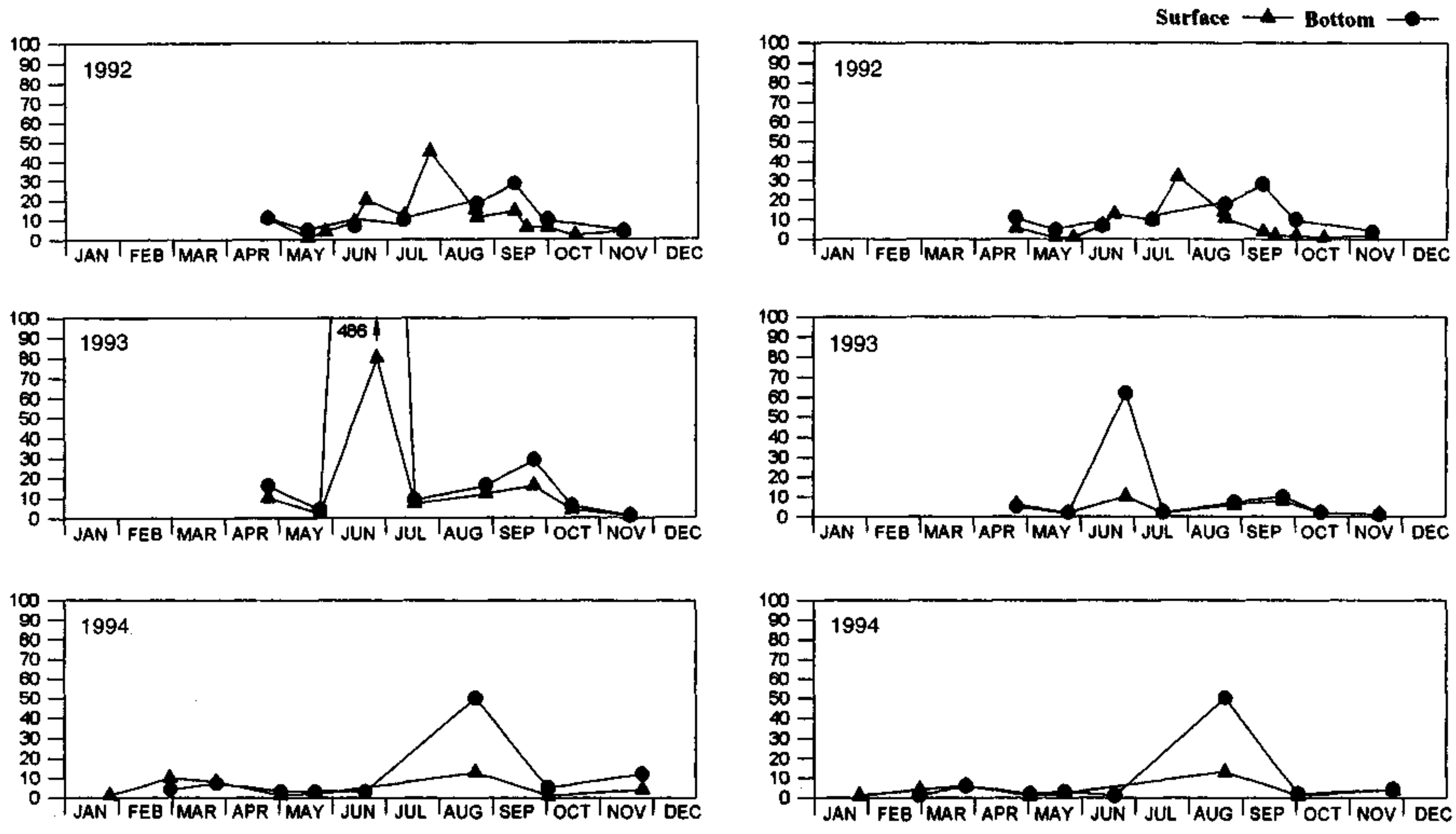


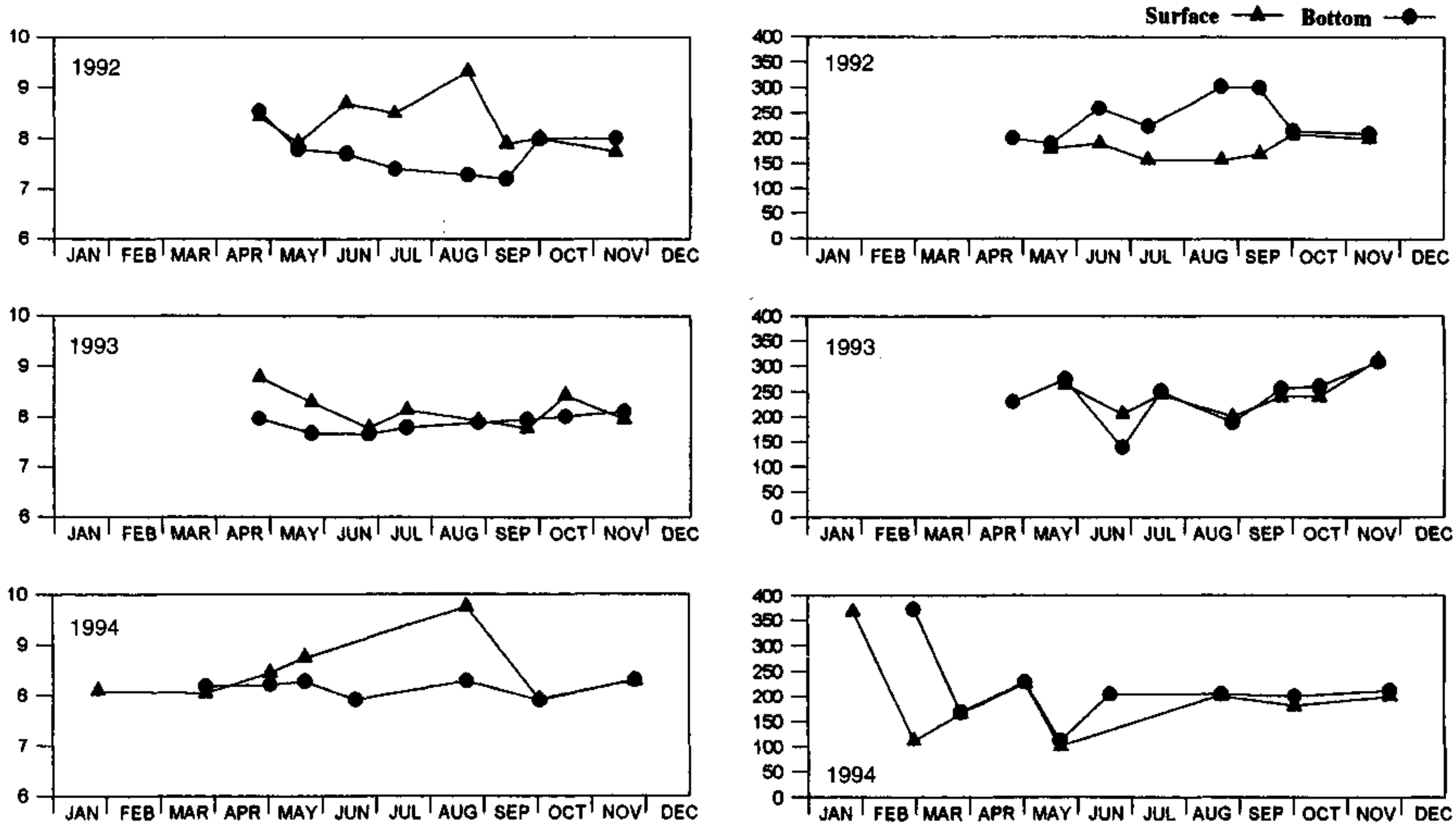
Figure 9. Temporal variation in various parameters at station 1



c. Suspended soilds, mg/L

d. Volatile suspended solids, mg/L

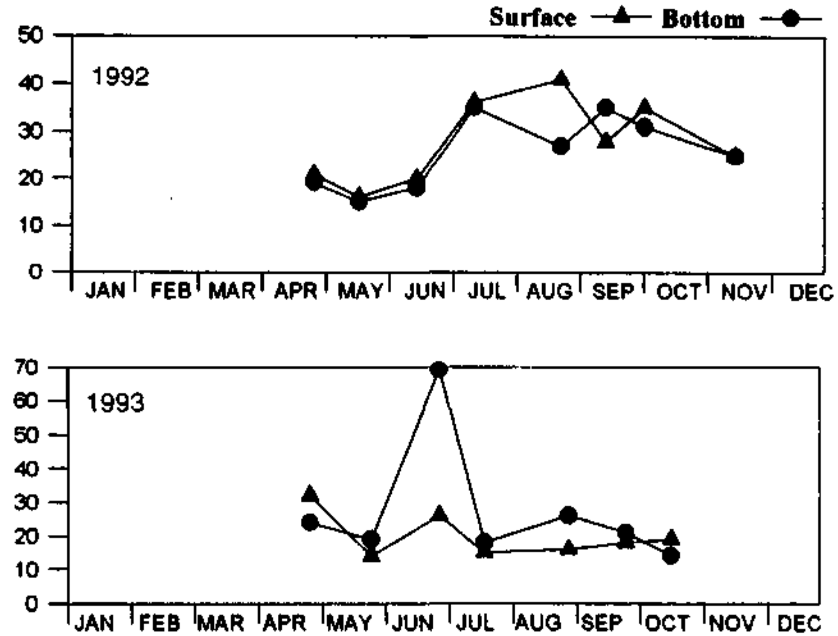
Figure 9. Continued



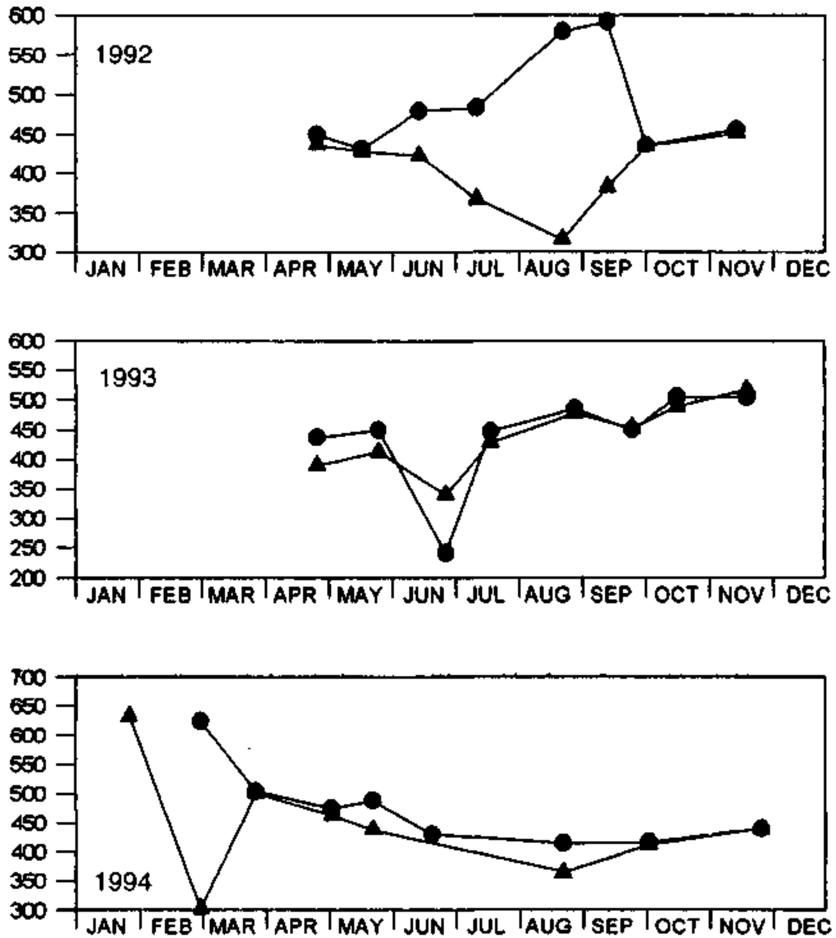
e. pH

f. Total alkalinity, mg/L

Figure 9. Continued

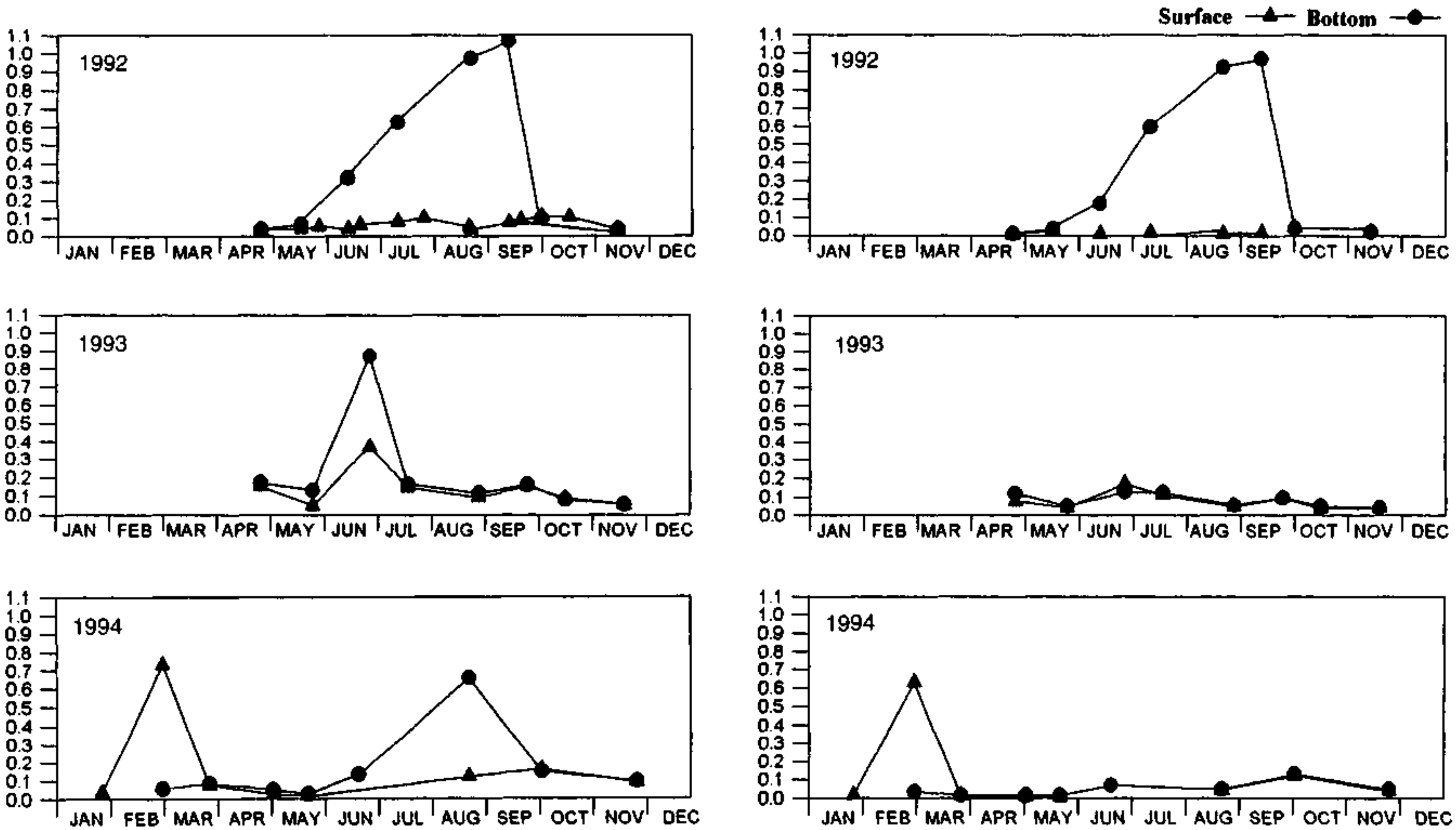


h. COD, mg/L



g. Conductivity, micromhos/cm

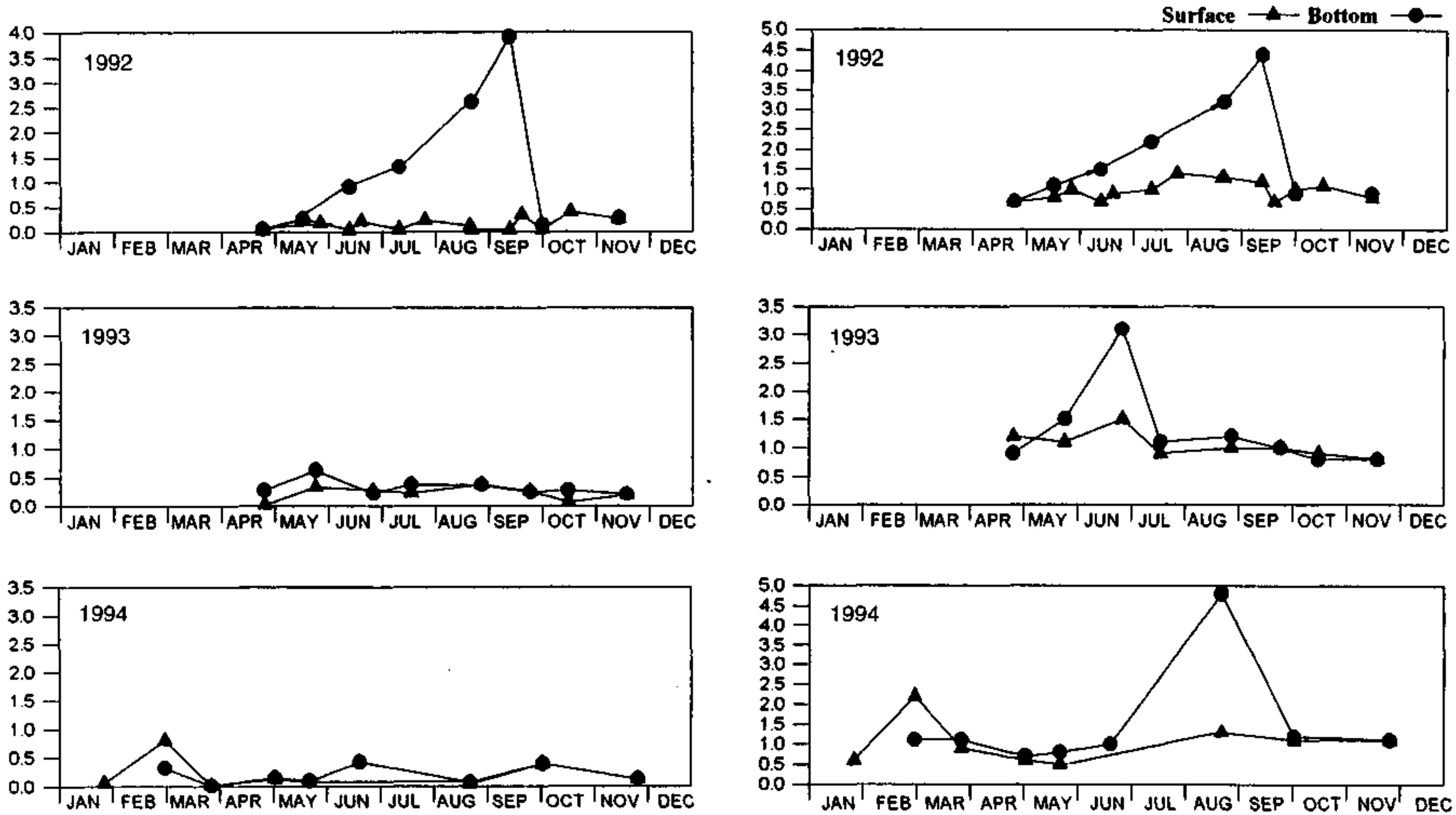
Figure 9. Continued



i. Total phosphorus, mg/L

j. Dissolved phosphorus, mg/L

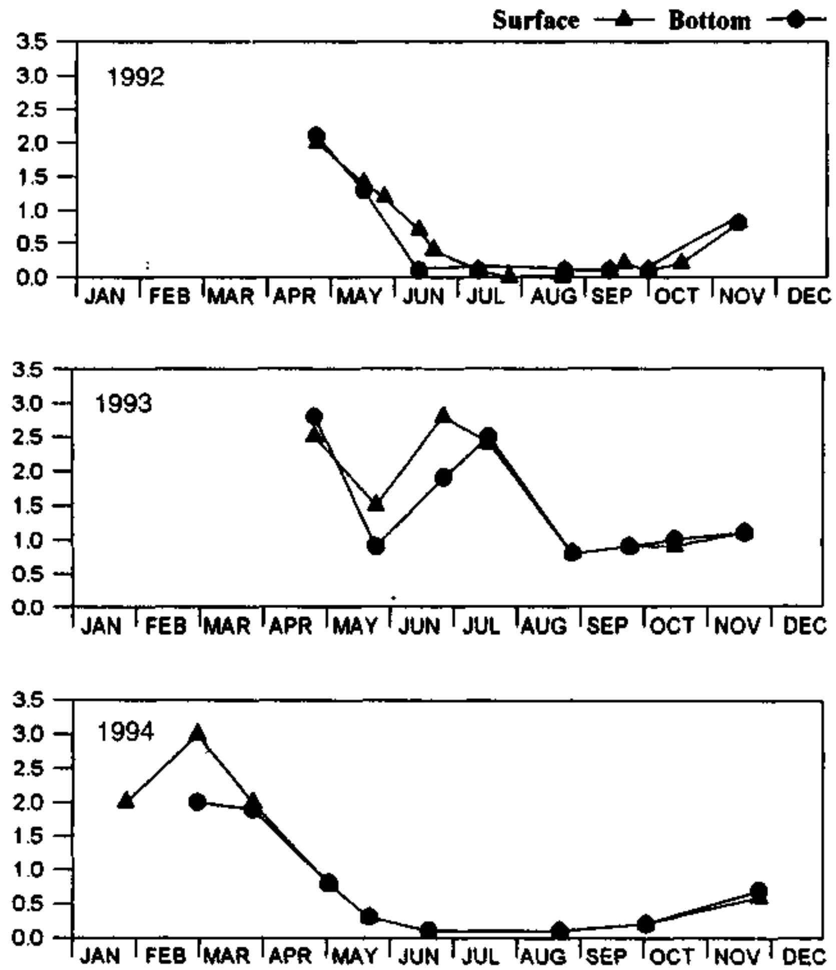
Figure 9. Continued



k. Ammonia nitrogen, mg/L

l. Total kjeldahl nitrogen, mg/L

Figure 9. Continued



m. Nitrate/nitrite nitrogen, mg/L

Figure 9. Concluded

weather period in 1981. This was the same as for cases observed for Wolf Lake in northeastern Illinois - northwestern Indiana (Lin *et al.,* 1996). Overall, the two highest observed transparencies at the station were 174 and 168 inches on May 27, 1993, and May 4, 1994, respectively. The lowest Secchi transparency observed at station 1 was 4 inches on September 25, 1986. Transparency at station 1 was found to fluctuate more in 1985 and 1986 than in other years.

Similarly, for station 2, the highest transparency (156 inches) and the lowest transparency (4 inches) occurred on the same dates as for station 1. The low transparency was caused by high TSS and turbidity.

At station 3, relatively high transparency did not occur in 1993 and 1994 compared to the other years. However, on the two aforementioned dates, transparency for station 3 was the same, (48 inches). The highest transparency observed at station 3 was 78 inches on May 29, 1984, and May 8, 1986. The lowest transparency observed was 2 inches observed on April 17, 1985, and September 23, 1992.

Tables 8 and 9 show, respectively the average values of water quality parameters for the summer and annual periods that showed no statistical differences. For summer transparency, the means ranged from 27 to 47 inches, 27 to 69 inches, and 22 to 36 inches, respectively, for stations 1, 2, and 3 (table 8). The annual means ranged from 28 to 61 inches, 27 to 61 inches (table 9), and 21 to 40 inches (figure 10) for stations 1, 2, and 3, respectively. Based on 1993 and 1994 data, water clarity at station 2 was better than at stations 1 and 3.

Statistical analyses used both the arithmetic and geometric means of transparency, turbidity, TSS, and VSS. The results were found to be similar. Thus, average values were used in this report. Only yearly means for station 3 exhibited statistical differences. Figure 10 suggests that annual means for 1986, 1993, and 1994 were significantly higher than the annual mean for 1985, with a 95 percent confidence level. These show an improvement of water clarity at station 3 only. There were no differences among 1986, 1993, 1994, 1984, and 1992 means, nor among 1984, 1992, and 1995 values. However, on the basis of summer values, there were no statistical differences among the six summer means.

The IEPA's Lake Assessment Criteria state that Secchi depths less than 18 inches indicate substantial lake use impairment and depths between 18 and 48 inches indicate moderate lake use impairment (IEPA, 1978). The minimum recommended Secchi transparency set by the Illinois Department of Pubic Health for bathing beaches is 48 inches. Nevertheless, a lake that does not meet the transparency criteria does not necessarily constitute a public health hazard, as long as it is not used for swimming.

Only summer mean transparencies at stations 1 and 2 in 1994 were greater than 48 inches (table 8), the limit for bathing beaches. Annual means in 1993 and 1994 for both stations 1 and 2 were equal to or greater than 48 inches, as was the case in 1981 at station 1 (table 9).

Conventionally, the deepest location of a lake (such as station 1), whether right or wrong, is considered representative of water quality for that lake. An examination of transparency data at station 1 showed that the value exceeded 48 inches during the summer period (May through October) 18 percent (2 out of 11 samples, 2/11), 30 percent (7/23), 5 percent (1/21), 36 percent (4/11), 14 percent (2/14), 35 percent (6/17), and 50 percent (3/6), respectively, for 1981, 1984, 1985, 1986, 1992, 1993, and 1994. Most of the high transparencies occurred in May and October, not during the swimming period of June through August.

Turbidity. Turbidity is an expression of the property of water that causes light to be scattered and absorbed by a turbidimeter, and it is expressed as nephelometric turbidity units

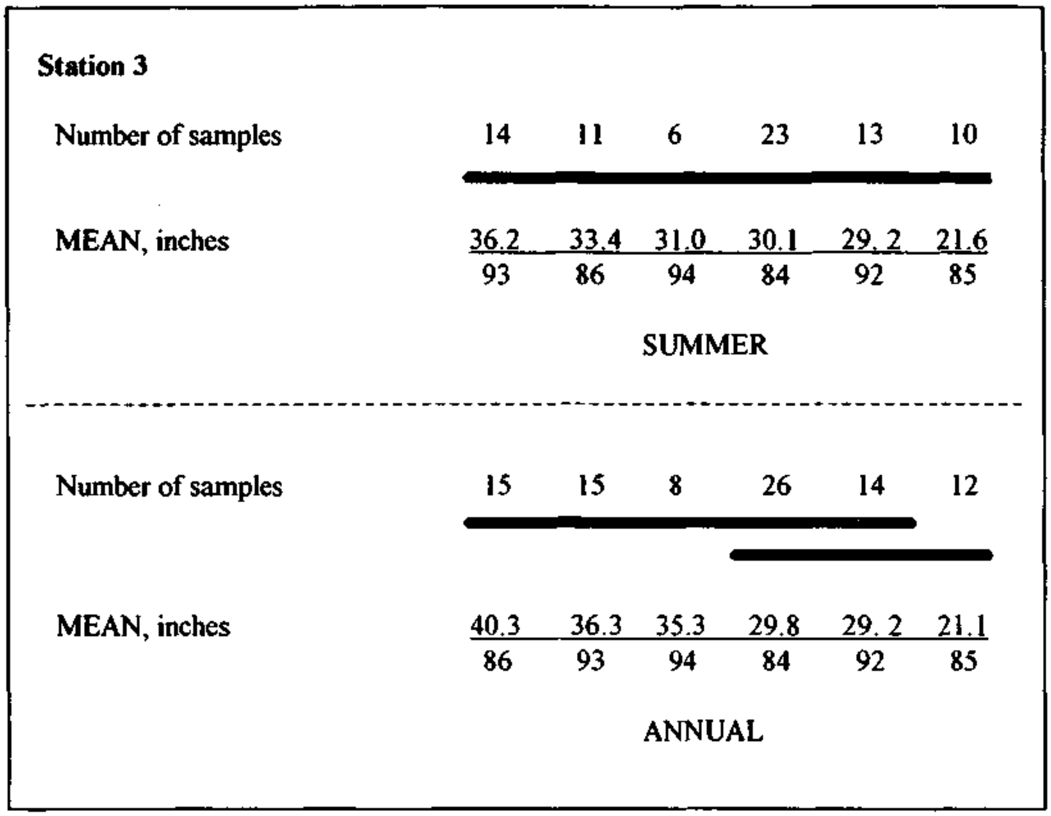


Figure 10. Graphical array and statistical analyses
of Secchi transparency data at Station 3

(NTU). Turbidity in water is caused by colloidal and suspended matter, such as silt, clay, finely divided inorganic and organic materials, soluble colored organic compounds, and plankton and other microorganisms. Generally, turbidity in lake waters is influenced by sediment in runoff from the lake's watershed, shoreline erosion, algae in the water column, and resuspension of lake bottom sediments by wind or wave action or by bottom-feeding fish. Elevated turbidity values give the lake a less pleasing appearance from an aesthetic standpoint.

During the seven-year monitoring period, very high turbidity values occurred in the lake water on September 25, 1986, and June 30, 1993. On September 25, turbidity at station 1-surface (1S), station 1-bottom (1B), station 2, and station 3 was, respectively, 110, 170, 72, and 15 NTU. Turbidity at stations 1S, 1B, 2, and 3 on June 30, 1993, was 95, 435, 125, and 85 NTU, respectively. The cause of high turbidity in the latter case was almost a week of continuous precipitation prior to these data. The recorded average inflow at Waddams Creek was 5.6, 10.8, 7.2, 10.4, 8.6, and 16.8 cubic feet per second (cfs) from June 24-30, 1993, respectively. The dry weather flow at the creek is approximately 1 to 2 cfs.

Examination of the turbidity values obtained during the seven years under review indicates that most turbidity values were less than 20 NTU at all four sampling stations and that turbidity varied without any trend. Temporal variation in turbidity at station 1 is depicted in figure 9b.

The ranges of 7-year summer turbidity means at stations 1S, 1B, 2, and 3 were, respectively, 4.3 to 23.0, 3.5 to 81.2, 4.5 to 27.2, and 4.7 to 22.2 NTU (table 8). The ranges of 7-year annual means were 5.1 to 18.0, 6.7 to 66.9, 5.5 to 17.9, and 7.0 to 16.4 NTU, respectively (table 9). The results of statistical analyses showed that both summer and annual means were not significantly different.

Chemical Characteristics

Total Suspended Solids. Total suspended solids (TSS) are the portion of total solids retained by a filter ≤ 2.0 urn pore size. Total solids is the term applied to the material residue left in the vessel after a sample is evaporated and then dried in an oven at 103 to 105°C. Total solids include TSS and total dissolved solids, the portion that passes through the filter (APHA *et ai*, 1992).

Total suspended solids represent the amount of all inorganic and organic materials suspended in the water column. Typical inorganic components originate from the weathering and erosion of rocks and soils in a lake's watershed and from resuspension of lake sediments. Organic components are derived from a variety of biological origins, but in a lacustrine environment are mainly composed of algae and resuspended plant and animal material from the lake bottom.

Generally, the higher the TSS concentration, the lower the Secchi disc reading. A high TSS concentration results in decreased water transparency, which can reduce photosynthetic activities beyond a certain depth in the lake and subsequently decrease the amount of oxygen produced by algae, possibly creating anoxic conditions. Anaerobic water may limit fish habitats and potentially cause taste and odor problems by releasing noxious substances such as hydrogen sulfide, ammonia, iron, and manganese from the lake bottom sediments. A high concentration of TSS may also cause aesthetic problems in the lake.

The amount of suspended solids found in impounded waters is small compared with the amount found in streams because solids tend to settle to the bottom in lakes. However, in shallow lakes, this aspect is greatly modified by wind and wave actions and by the type and intensity of uses to which these lakes are subjected.

Very high concentrations of TSS were recorded on September 25, 1986, and June 30, 1993: 145, 238, and 96 mg/L, respectively, at stations 1S, 1B, and 2 on September 25, 1986 (no sample was taken at station 3 on that date); and 80, 486, 102, and 65 mg/L at stations 1S, 1B, 2, and 3, respectively, on June 30, 1993. The maximum TSS concentrations observed in 1992 occurred on July 29, with TSS at stations 1S, 2, and 3 of 45, 57, and 94 mg/L, respectively. No sample was collected from station 1B on that date.

Temporal variations in TSS at station 1 are plotted in figure 9c. Inspection of this figure and figure 14 of the Phase II study report (IEPA, 1990b), shows that TSS peaks occurred mostly in the warm summer period. At all stations most TSS values were less than 20 mg/L. This was especially true in 1985, with a maximum TSS observed value of 19 mg/L. Bottom TSS were higher than surface TSS during each peak.

Summer mean TSS values ranged from 5.0 to 20.2, 7.0 to 86.3, 7.3 to 23.7, and 6.4 to 20.8 mg/L at stations 1S, 1B, 2, and 3, respectively (table 8). Annual means were 6.5 to 16.5, 7.0 to 66.9, 7.0 to 15.4, and 7.0 to 11.4 mg/L at stations 1S, 1B, 2, and 3, respectively (table 9). Lowest means generally occurred in 1994. No statistical differences were found among summer means and annual means, although TSS appear to have increased somewhat following rain events.

On the basis of Illinois Lake Assessment Criteria (IEPA, 1978), water with TSS > 25 mg/L is classified as high lake-use impairment, while TSS between 15 and 25 mg/L indicates moderate use impairment. Water with TSS < 15 mg/L is considered to have minimal impairment. Except for 1993 means, the lake surface water can be classified as minimally impaired based on both summer and annual means.

Volatile Suspended Solids. Volatile suspended solids (VSS) are the portion of TSS lost to ignition at 500 ± 50°C. VSS represent the organic portion of TSS, such as phytoplankton, zooplankton, other biological organisms, and other suspended organic detritus. Resuspended sediments and other plant and animal matter originating from the lake bottom either by bottom-feeding fish or by wind action can be major contributors of VSS and TSS.

An examination of figure 15 of the Phase II study (IEPA, 1990b) and figure 9d of this study indicates that bottom VSS are generally higher than surface VSS for stations 1S and 1B. During high TSS periods after storm events, such as samples collected on September 25, 1986, and June 30, 1993, VSS increased substantially. However, VSS values were usually less than 20 percent of TSS values. Thus, the majority of suspended solids introduced to the lake during storm events were inorganic in nature. High organic portions (VSS/TSS) were observed during warm weather periods in 1992 and 1993, possibly contributed by algae (figures 9c and 9d).

The mean summer VSS for stations 1S, 1B, 2, and 3 ranged from 5.0 to 20.2, 6.5 to 14.2, 5.2 to 8.3, and 4.2 to 11.0 mg/L, respectively (table 8). Annual means for VSS varied, respectively, from 4.0 to 7.5, 5.1 to 11.4, 7.0 to 15.4, and 3.2 to 9.9 mg/L (table 9). However, no statistical differences existed among the 7-year data for summer or annual means.

pH. The pH value, or hydrogen ion concentration, is a measure of the acidity of water: values less than 7.0 indicate acidic water, and values above 7.0 indicate basic (or alkaline) water. A pH of 7.0 is exactly "neutral". pH values are influenced by the concentration of carbonate in water. One species of carbonate, carbonic acid, which forms as a result of dissolved carbon dioxide, usually controls pH to a great extent. Carbonic acid is also consumed by photosynthetic activity of algae and other aquatic plants after the free carbon dioxide in water has been used up. A rise in pH can occur due to photosynthetic uptake of carbonic acid, causing water to become more basic. Decomposition and respiration of biota tend to reduce pH and increase bicarbonates.

It is generally considered that pH values above 8.0 in natural waters are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition (Mackenthun, 1969). Although rainwater in Illinois is acidic (pH about 4.4), most lakes offset this acidic input by an abundance of natural buffering compounds in the lake water and the watershed. Most Illinois lakes have a pH between 6.5 and 9.0. The Illinois Pollution Control Board (IPCB, 1990) general-use water quality standard for pH is also in a range between 6.5 and 9.0, except for natural causes.

Inspection of the data depicted in figure 11 of the Phase II study (IEPA, 1990b) and figure 9e of this study indicates that summer pH values for station 1S were generally greater than those for station 1B due to summer stratification. Elevated pH is attributable to photosynthesis during times of heavy algal activity. Less summer pH deviation at these two stations occurred in 1986 and 1993, perhaps due to successful destratification in 1986 and higher than normal precipitation in 1993.

The lowest pH values were between 6.8 and 7.0 for all four sampling sites throughout the entire monitoring period; i.e., no sample had a pH value less than IEPA's minimum limit of 6.5. pH values exceeding 9.0 occurred during May through August 1981, on August 25, 1992, and August 25, 1994, for station 1S; on August 25, 1992 and 1994, for stations 2 and 3; and on July 15 and 17, 1985, for station 2. The highest pH value, 9.72, was measured at station 2 on August 25, 1994. However, the majority of samples had pH values in the range (6.5 to 9.0) stipulated in the IPCB's general-use quality standards. All samples taken from station 1B had pH values in this range.

Summer mean pH values were between 7.78 and 9.04, 7.27 and 8.36, 7.81 and 8.70, and 7.97 and 8.83, respectively, at stations 1S, 1B, 2, and 3. Annual means were, respectively, between 7.76 and 8.72, 6.87 and 8.32, 7.76 and 8.47, and 7.88 and 8.55 (figure 11). Both summer and annual means showed statistical differences at all four stations. The bar graphs of figure 11a show that at station 1S, the summer mean pH in 1981 was significantly greater than in other years except for 1994; the summer mean pH in 1994 was greater than that in 1986 ($p < 0.05$); and there were no differences among mean pH values of 1992, 1984, 1985, 1993, and 1986. For annual mean pH values, the trend is the same as for the summer means, except that there was no difference between 1981 and 1992 as well.

Figure 11b indicates that summer mean pH values at station 1B were significantly higher during 1994 than during the other six years studied and that the summer mean pH values of 1993 and 1981 were higher than those in 1984 to 1986. Annual mean pH at station 1B was significantly less in 1986 than in other years. During 1984 and 1985, the annual mean was less than during 1981 and 1983; and during 1981 and 1992, it was less than during 1994.

At station 2, summer mean pH values during 1994, 1992, 1984, and 1985 were significantly greater than during 1986 (figure 11c). However, annual mean pH values during 1994, 1992, and 1985 were greater than during 1986.

Summer mean pH at station 3 during 1994 was higher than during 1993 and 1986; and during 1992 was higher than during 1986 (figure 11d). However, annual mean pH at station 3 during 1992 was higher than during 1993 and 1986, and the annual mean during 1994 was also higher than during 1986.

In general, both summer and annual mean pH values during this study were greater than during 1986. This is probably a good indication that more algal productivity occurred in the lake during recent years than immediately after implementation in 1986.

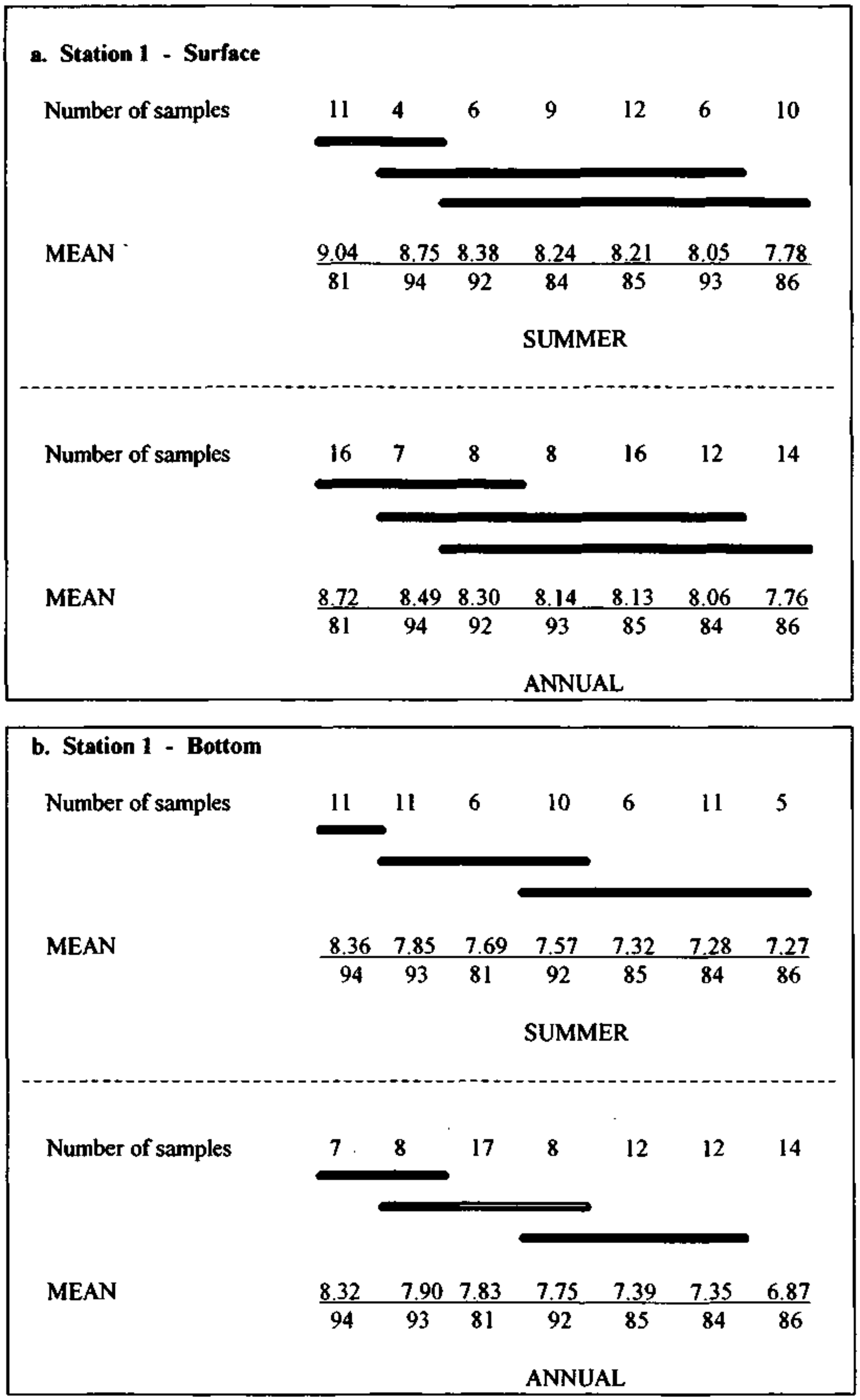


Figure 11. Graphical array and statistical analysis of pH in Lake Le-Aqua-Na

c. Station 2 - Surface

Number of samples	5	5	8	11	6	10
MEAN	8.70	8.58	8.44	8.35	8.05	7.81
	94	92	84	85	93	86

SUMMER

Number of samples	9	8	14	11	10	14
MEAN	8.47	8.34	8.25	8.23	7.91	7.76
	94	92	85	84	93	86

ANNUAL

d. Station 3 - Surface

Number of samples	9	4	5	9	5
MEAN	8.83	8.67	8.34	8.15	7.97
	94	92	84	93	86

SUMMER

Number of samples	7	8	12	9	13
MEAN	8.55	8.51	8.20	7.96	7.88
	92	94	84	93	86

ANNUAL

Figure 11. Concluded

Alkalinity. The alkalinity of a water is its capacity to accept protons, and it is generally imparted by bicarbonate, carbonate, and hydroxile components. The species makeup of alkalinity is a function of pH and mineral composition. The carbonate equilibrium, in which carbonate and bicarbonate ions and carbonic acid are in equilibrium, is the chemical system present in natural waters.

Alkalinity is a measure of water's acid-neutralizing capacity. It is expressed in terms of an equivalent amount of calcium carbonate ($CaCO_3$). Total alkalinity is defined as the amount of acid required to bring water to a pH of 4.5, and phenolphthalein alkalinity is measured by the amount of acid needed to bring water to a pH of 8.3 (APHA *et al.,* 1992).

Lakes with low alkalinity are, or have the potential to be, susceptible to acid rain damage. However, Midwestern lakes usually have high alkalinity and thus are well buffered from the impacts of acid rain. Natural waters generally have a total alkalinity from 20 to 200 mg/L (APHA *et al,* 1992).

At station 1, vertical variations in total alkalinity occurred in 1981, 1984 (figure 10 of the Phase II study, IEPA, 1990b), and 1992 (figure 9f of this study). These were due to summer stratifications, or surface alkalinity decreases due to photosynthetic activity. As expected, surface waters had lower alkalinity than bottom waters during stratified periods. There was essentially no variation in the total alkalinity of the water column at station 1 during 1985, 1986, 1993, and 1994. The destratifier near station 1 was generally in operation in 1985 and 1986. Summer 1993 experienced extremely wet weather conditions from storm events, with more natural mixing and less stratification. Stratification in 1994 was not pronounced. For all the stations during the seven-year monitoring period, total alkalinity in most samples ranged from 150 to 300 mg/L as $CaCO_3$

Figure 12 and tables 8 and 9 show that summer means of total alkalinity at stations 1S, 1B, 2, and 3 ranged, respectively, from 174 to 233, 190 to 252, 163 to 218, and 178 to 222 mg/L as $CaCO_3$. Annual means ranged between 180 and 237, 213 and 250, 182 and 222, and 183 and 227 mg/L as $CaCO_3$. Statistical analyses show no differences in summer mean alkalinity at station 1B, and in annual mean alkalinity at stations 1B, 2, and 3.

Figure 12a suggests that both summer and annual mean alkalinity values at station 1S were significantly higher during 1993 than during 1985, 1984, 1992, 1994, and 1981 ($p < 0.05$); summer surface alkalinity values were significantly greater during 1986 than during 1984, 1992, 1994, and 1981; and annual mean alkalinity for 1986 was significantly higher than that for 1992, 1994, and 1981. There were no differences in summer and annual means during 1985, 1984, 1992, 1994, and 1981.

Total alkalinity values at stations 2 and 3 showed different trends than those at station 1S and were lower during 1984 and 1992. Figure 12b indicates that summer alkalinity means at station 2 were significantly higher during 1993 and 1986 than during 1984 and 1992. Summer means at station 3 were significantly higher during 1986 than during 1984 and 1992 (figure 12c). For purposes of comparison, the annual means for total alkalinity at stations 2 and 3 showing no statistical differences are also plotted in figures 12b and 12c.

Conductivity. Specific conductance provides a measure of a water's capacity to convey electric current and is used as an estimate of the dissolved mineral quality of water. This property is related to the total concentration of ionized substances in water and the temperature at which the measurement is made. Specific conductance is affected by factors such as the nature of dissolved substances, their relative concentrations, and the ionic strength of the water sample. The geochemistry of soils in the drainage basin is the major factor determining the chemical constituents in water. The higher the conductivity reading, the higher the concentration of

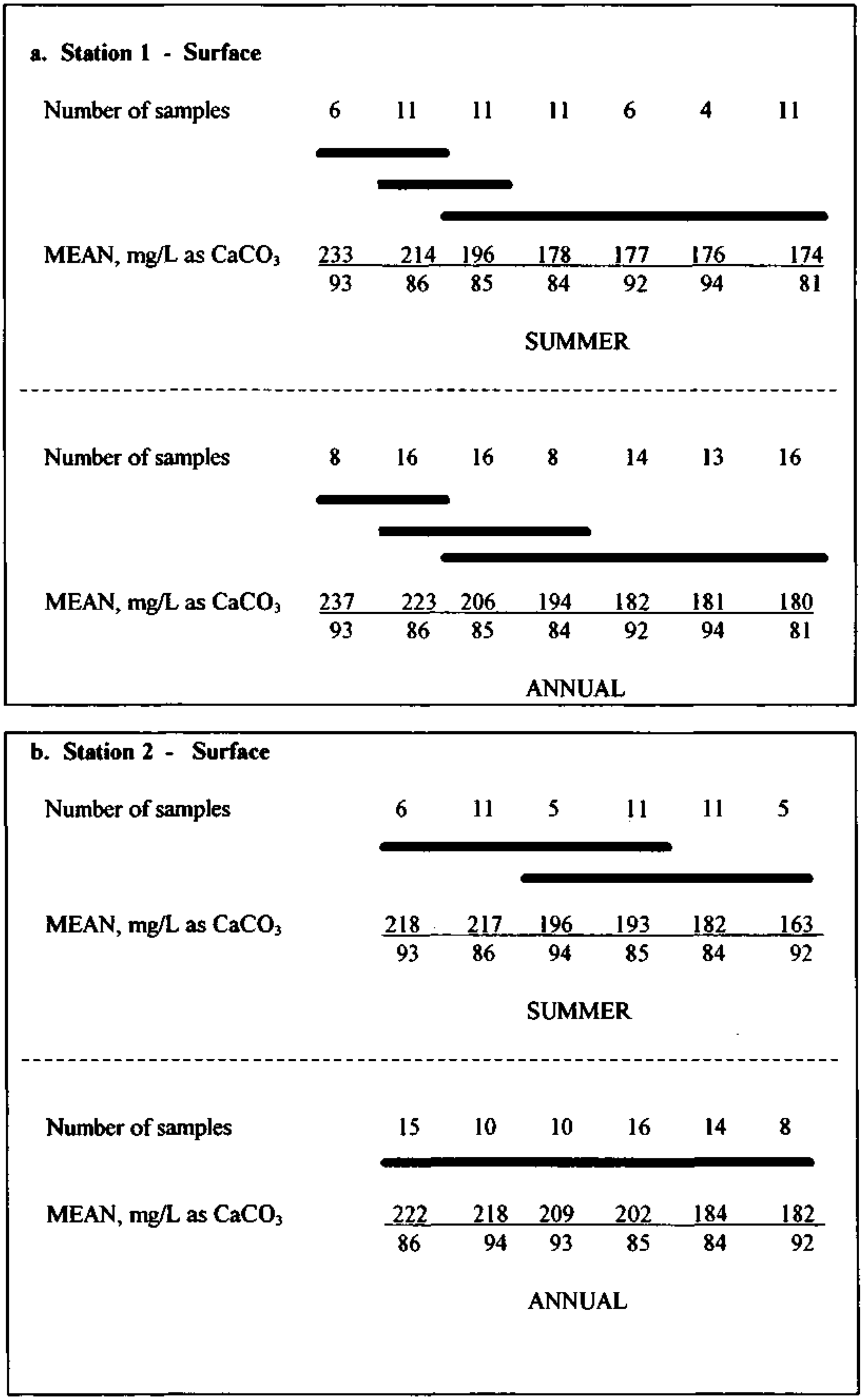


Figure 12. Graphical array and statistical analyses of
total alkalinity in Lake Le-Aqua-Na

c. Station 3 - Surface

Number of samples	10	5	4	11	5
MEAN, mg/L as $CaCO_3$	$\frac{221}{86}$	$\frac{206}{93}$	$\frac{192}{94}$	$\frac{182}{84}$	$\frac{178}{92}$

SUMMER

Number of samples	14	9	9	8	14
MEAN, mg/L as $CaCO_3$	$\frac{227}{86}$	$\frac{221}{94}$	$\frac{207}{93}$	$\frac{189}{92}$	$\frac{183}{84}$

ANNUAL

Figure 12. Concluded

dissolved minerals in the lake water. Practical applications of conductivity measurements include determination of the purity of distilled or deionized water, quick determination of the variations in dissolved mineral concentrations in water samples, and estimation of dissolved ionic matter in water samples.

Comparisons of temporal variations in conductivity at station 1 for the Phase II study (figure 12, IEPA, 1990b) and Phase III monitoring period (figure 9g of this study) reveal that similar values were observed during 1984 and 1992. Conductivity of bottom waters was much greater than surface water during these two summers, due to lower pH. Under acidic conditions, conductivity increases due to higher solubility. The highest conductivity values observed at station 1B were 655 and 592 micromhos per centimeter (umhos/cm) on September 12, 1984, and September 16, 1992, respectively. For the other five study years, the differences between surface and bottom conductivity were not substantial, with most values in the range of 300 to 500 umhos/cm.

Summer mean conductivity values for stations 1S, 1B, 2, and 3 ranged, respectively, from 331 to 434, 410 to 520, 375 to 433, and 381 to 422 umhos/cm (figure 13, table 8); while annual means ranged from 314 to 444, 379 to 496, 375 to 433, and 312 to 452 µmhos/cm (figure 13, table 9).

As shown in tables 8 and 9, no statistical differences in summer and annual means of conductivity existed at stations 2 and 3. At station 1S, the summer mean conductivity in 1981 was significantly less than that of the other six years, and that in 1984 was less than that of 1993, 1994, 1985, 1986, and 1992. Also, the annual mean in 1981 was less than that of the other six years. At station 1B, the summer mean conductivity in 1984 was significantly higher than that of the other years except 1992, and that of 1992 was higher than that of 1981. Annual mean conductivity values in 1984, 1992, 1994, 1986, and 1995 were significantly higher than that of 1981.

Chemical Oxygen Demand. The chemical oxygen demand (COD) is a measure of the oxygen requirement of the organic content of a water sample that is susceptible to oxidation by a strong chemical oxidant. The COD test is less time-consuming than the biochemical oxygen demand (BOD) test and can be related empirically to BOD. BOD is related biological processes that occur when bacteria feeding on dead animal and plant matter and animal wastes consume oxygen during the decomposition process. COD results are typically slightly greater than those for the BOD test, because the COD test includes some materials that are not readily biologically degradable. Domestic and industrial wastewaters usually have high COD levels.

Figure 9h presents the temporal variation in COD at stations 1S and 1B during 1992 and 1993. No COD tests were performed in 1994. On the whole, high COD concentrations occurred during summers due to decaying aquatic plants and animals at all four stations. At station 1, COD levels in surface waters during 1984-1986 were generally higher than in bottom waters. This was not the case for 1992 and 1993 data (figure 9h). A high COD concentration of 69 mg/L was observed on June 30, 1993, at station 1B, due to nearly a week of storm events that scoured up the bottom sediments.

Illinois Lake Assessment Criteria (IEPA, 1978) state that COD > 30 mg/L indicates a high degree of organic enrichment from plant and algal material and that COD levels between 20 and 30 mg/L are considered moderate organic enrichment. For station 1S, 36 percent (5 of 14 samples), 13 percent (2/16), 6 percent (1/16), 38 percent (3/8), and 14 percent (1/7) of samples had COD exceeding 30 mg/L, respectively, during 1984, 1985, 1986, 1992, and 1993. COD concentrations between 20 and 30 mg/L accounted for 36 percent (5/14), 25 percent (4/16), 19 percent (3/16), 50 percent (4/8), and 29 percent (2/7), respectively, of samples.

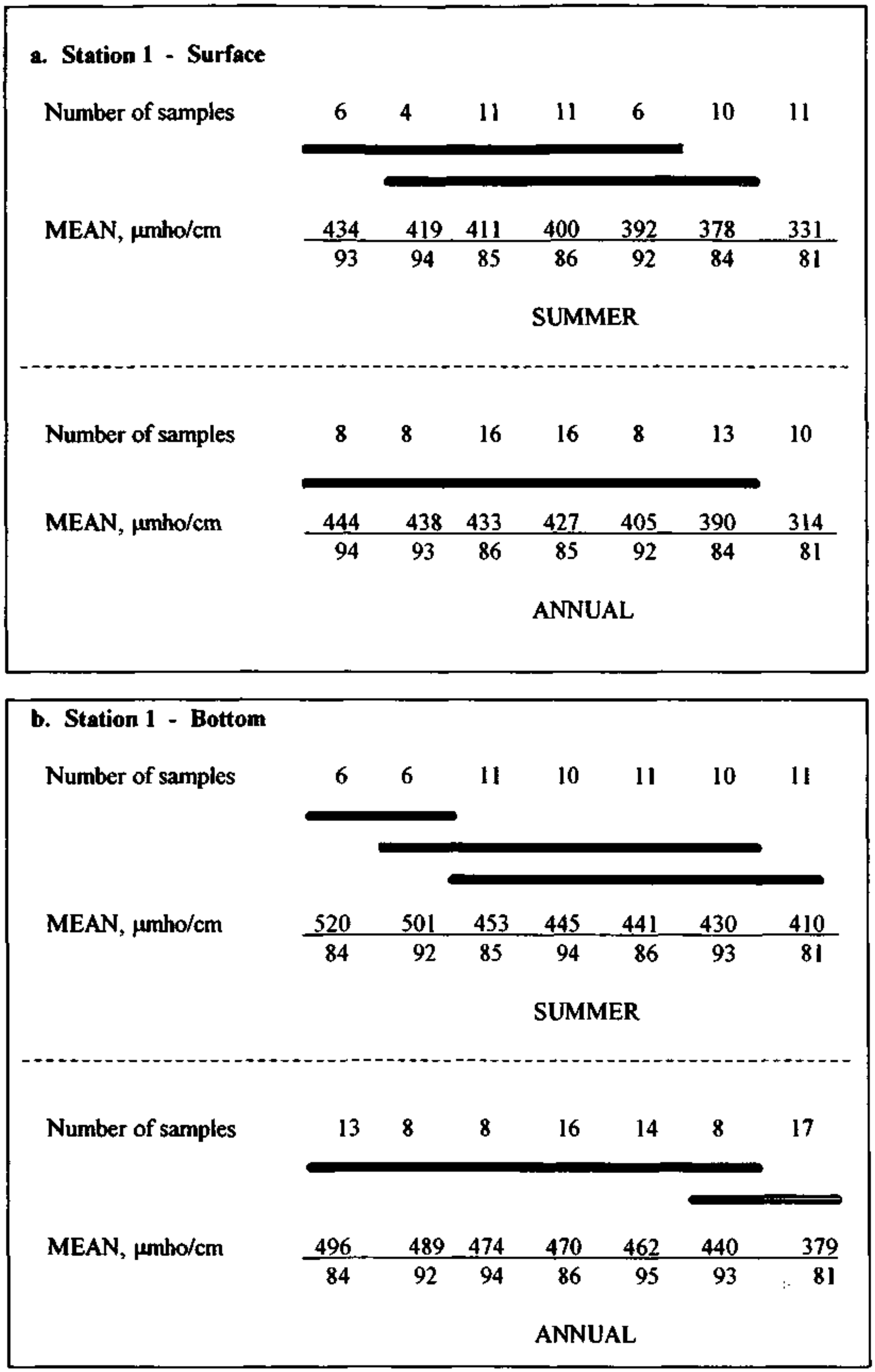


Figure 13. Graphical array and statistical analyses of conductivity in Lake Le-Aqua-Na

Summer mean COD concentrations at stations 1S, 1B, 2, and 3 ranged from 18.0 to 29.9, 17 to 27, 16.6 to 31.5, and 17.5 to 27.8 mg/L, respectively (figure 14, table 8). Annual mean COD levels, respectively, ranged from 17 to 27.8, 15 to 27, 15.3 to 29.7, and 15.4 to 26.5 mg/L. There was no difference in summer and annual COD means at station 1B.

As shown in figure 14a, summer mean COD during 1984 was significantly higher than during 1985, 1986, and 1993; and summer mean COD during 1992 was higher than during 1986 and 1993. Annual mean COD concentrations showed a different trend: 1992 and 1984 COD means were significantly greater than the 1986 mean.

At station 2, summer mean COD in 1984 was significantly greater than that in 1993 and 1986 (figure 14b). Annual mean COD in 1984 was higher than in 1985, 1993, and 1986; and the mean COD in 1992 was higher than the 1986 mean.

At station 3, there were no statistical differences among the four summer COD means (figure 14c). However, annual COD means during 1992 and 1984 were significantly greater than the 1986 annual mean COD.

Phosphorus. Total phosphorus (TP) represents all forms of phosphorus in water, both particulate and dissolved forms, and includes three chemical types: reactive, acid-hydrolyzed, and organic. Dissolved phosphorus (DP) is the soluble form of TP (filtration through a 0.45-µm filter).

Phosphorus as phosphate may occur in surface water or ground water as a result of leaching from minerals or ores, natural processes of degradation, or agricultural drainage. Phosphorus is an essential nutrient for plant and animal growth and, like nitrogen, it passes through cycles of decomposition and photosynthesis.

Because phosphorus is essential to the plant growth process, it has become the focus of attention in the entire eutrophication issue. With phosphorus being singled out as probably the most limiting nutrient and the one most easily controlled by removal techniques, various facets of phosphorus chemistry and biology have been extensively studied in the natural environment.

In any ecosystem, the two aspects of interest for phosphorus dynamics are phosphorus concentration and phosphorus flux (concentration times flow rate) as functions of time and distance. The concentration alone indicates the possible limitation that this nutrient can place on vegetative growth in the water. Phosphorus flux is a measure of the phosphorus transport rate at any point in flowing water.

Unlike nitrate-nitrogen, phosphorus applied to the land as a fertilizer is held tightly to the soil. Most of the phosphorus carried into streams and lakes from runoff over cropland will be in the particulate form adsorbed to soil particles. On the other hand, the major portion of phosphate-phosphorus emitted from municipal sewer systems is in a dissolved form. This is true of phosphorus generated from anaerobic degradation of organic matter in the lake bottom. Consequently, the form of phosphorus, namely particulate or dissolved, is indicative of its source to a certain extent. Other sources of DP in lake water include algae cell decomposition and grass carp excrement. Dissolved phosphorus is readily available for algae and macrophyte growth. However, DP concentrations can vary widely over short periods of time, as plants take up and release this nutrient. Therefore, TP in lake water is the more commonly used indicator of a lake's nutrient status.

From his experience with Wisconsin lakes, Sawyer (1952) concluded that aquatic blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus exceed 0.3 and 0.01 mg/L, respectively. These critical levels for

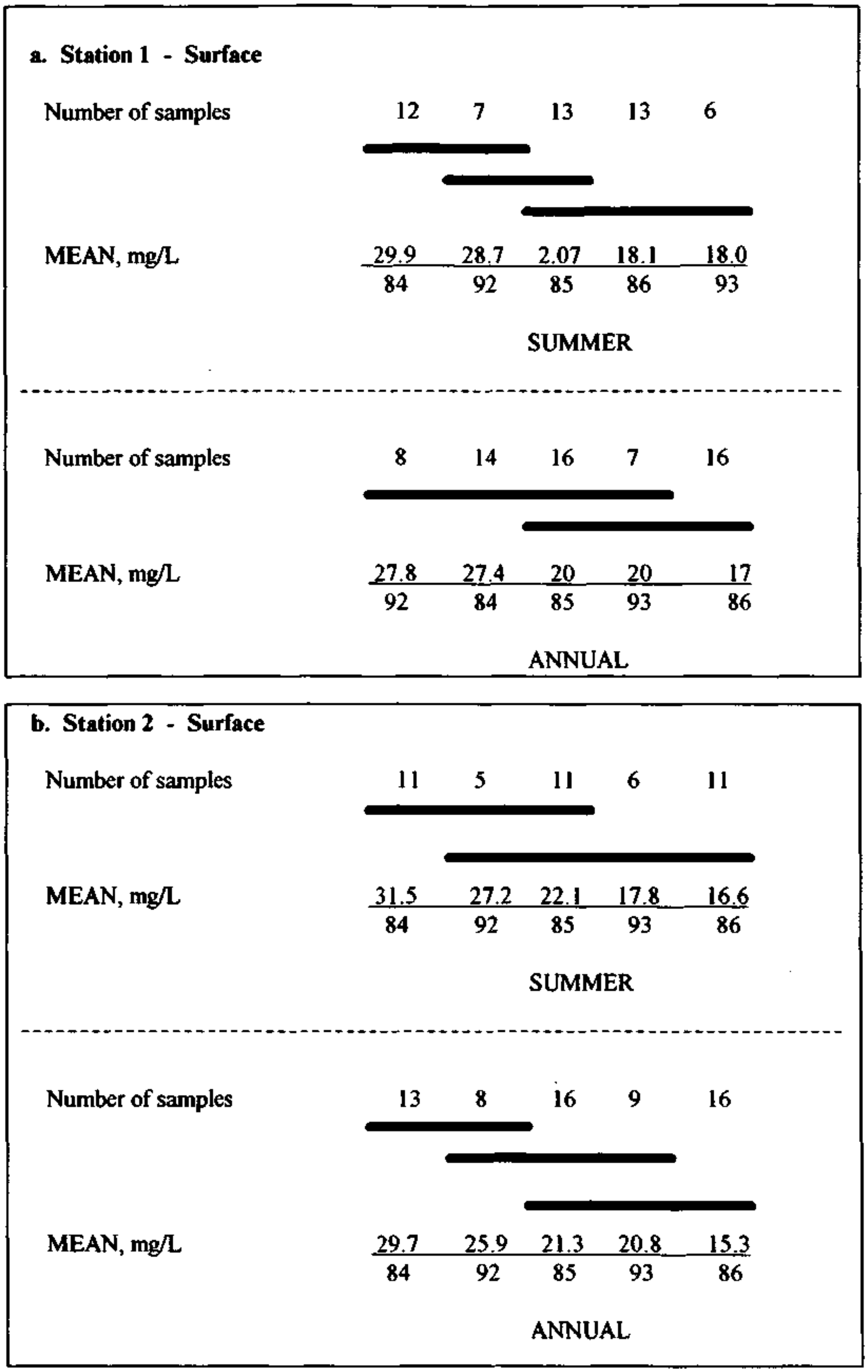


Figure 14. Graphical array and statistical analyses of chemical oxygen demand in Lake Le-Aqua-Na

c. Station 3 - Surface

Number of samples	5	11	5	10
MEAN, mg/L	27.8	26.3	17.6	17.5
	92	84	93	86

SUMMER

Number of samples	8	14	8	15
MEAN, mg/L	26.5	25.4	23.8	15.4
	92	84	93	86

ANNUAL

Figure 14. Concluded

nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature.

Total Phosphorus. The temporal variations in total and dissolved phosphorus at stations 1S and 1B are depicted in figures 9i and 9j, respectively. Examination of figure 9i and figure 16 of the Phase II study (IEPA, 1990b) indicates that the TP concentrations of the bottom waters were generally much higher than those of the surface waters, especially during warm weather periods. During the summers of 1981, 1984, 1992, and 1994, TP levels typically increased due to anoxic conditions resulting from lake stratification. In 1985 and 1986, TP levels in surface and bottom waters were almost identical and without substantial increases during the summers. Destratification greatly reduced phosphorus levels in bottom waters, due to the operation of the destratifier. A TP increase on June 30, 1993, was caused by a week of storm events. Fall turnover in Lake Le-Aqua-Na usually occurred in late September to early October. The data gathered indicate that there were no increases of TP or DP during or after fall turnover. This was the case for spring turnover as well.

To prevent biological nuisance, the IEPA (1990a) stipulates, "Phosphorus as P shall not exceed 0.05 mg/L in any reservoir or lake with a surface area of 8.1 hectares (20 acres) or more or in any stream at the point where it enters any reservoir or lake." At station 1S, all 63 surface water samples collected in 1981, 1984, 1985, and 1986 exceeded 0.05 mg/L of TP; 64 percent (9/14), 100 percent (8/8), and 63 percent (5/8) of samples collected, respectively, during 1992, 1993, and 1994 had TP concentrations exceeding 0.05 mg/L. Similar observations were also made for the surface waters at station 2. For station 3, 93 percent (13/14), 100 percent (2/2), 87 percent (13/15), 57 percent (8/14), 100 percent (9/9), and 89 percent (8/9) of samples, respectively, obtained during 1984, 1985, 1986, 1992, 1993, and 1994 exceeded 0.05 mg/L of TP.

Figure 15 shows mean values of TP at stations 1S, 1B, and 2. Values for station 3 are listed in tables 8 and 9. Summer mean TP levels at stations 1S, 1B, 2, and 3 ranged from 0.070 to 0.301, 0.202 to 0.829, 0.066 to 0.305, and 0.086 to 0.147 mg/L, respectively; while annual means ranged, respectively, from 0.065 to 0.257, 0.155 to 0.601, 0.070 to 0.262, and 0.082 to 0.185 mg/L. Both summer and annual mean TP concentrations were found to be different for stations 1S, 1B, and 2.

Figure 15a indicates that both summer and annual mean TP in 1985 was significantly greater than during the other years. As shown in figure 15b, differences for summer and annual mean TP levels at station 1B were similar. The mean TP value in 1981 was higher than in 1985, 1993, 1986, and 1994. Also, mean TP in 1984 was significantly greater than in 1986 and 1994. For station 2, figure 15c suggests that summer mean TP in 1985 was significantly higher than in the other years. Different trends were found for annual means. Annual mean TP in 1985 was greater than in 1984, 1986, 1994, and 1992; and annual mean TP values in 1993 and 1984 were higher than in 1992. Mean TP concentrations at each station had a different trend.

Dissolved Phosphorus. The ratio of DP to TP generally varied widely between 20 and 90 percent; and most DP/TP ratios were greater than 50 percent. Temporal variations of DP at station 1S were similar to those for TP, except during the summers of 1993 and 1994 (figure 9j).

Summer mean DP concentrations at stations 1S, 1B, 2, and 3 were, respectively, between 0.023 and 0.205, 0.054 and 0.568, 0.019 and 0.187, and 0.021 and 0.090 mg/L (figure 16 and table 8); while annual mean DP values were, respectively, between 0.065 and 0.257, 0.046 and 0.440, 0.078 and 0.158, and 0.033 and 0.117 mg/L. Only summer mean DP values at stations 1S and 1B and annual DP means at station 1B were statistically different.

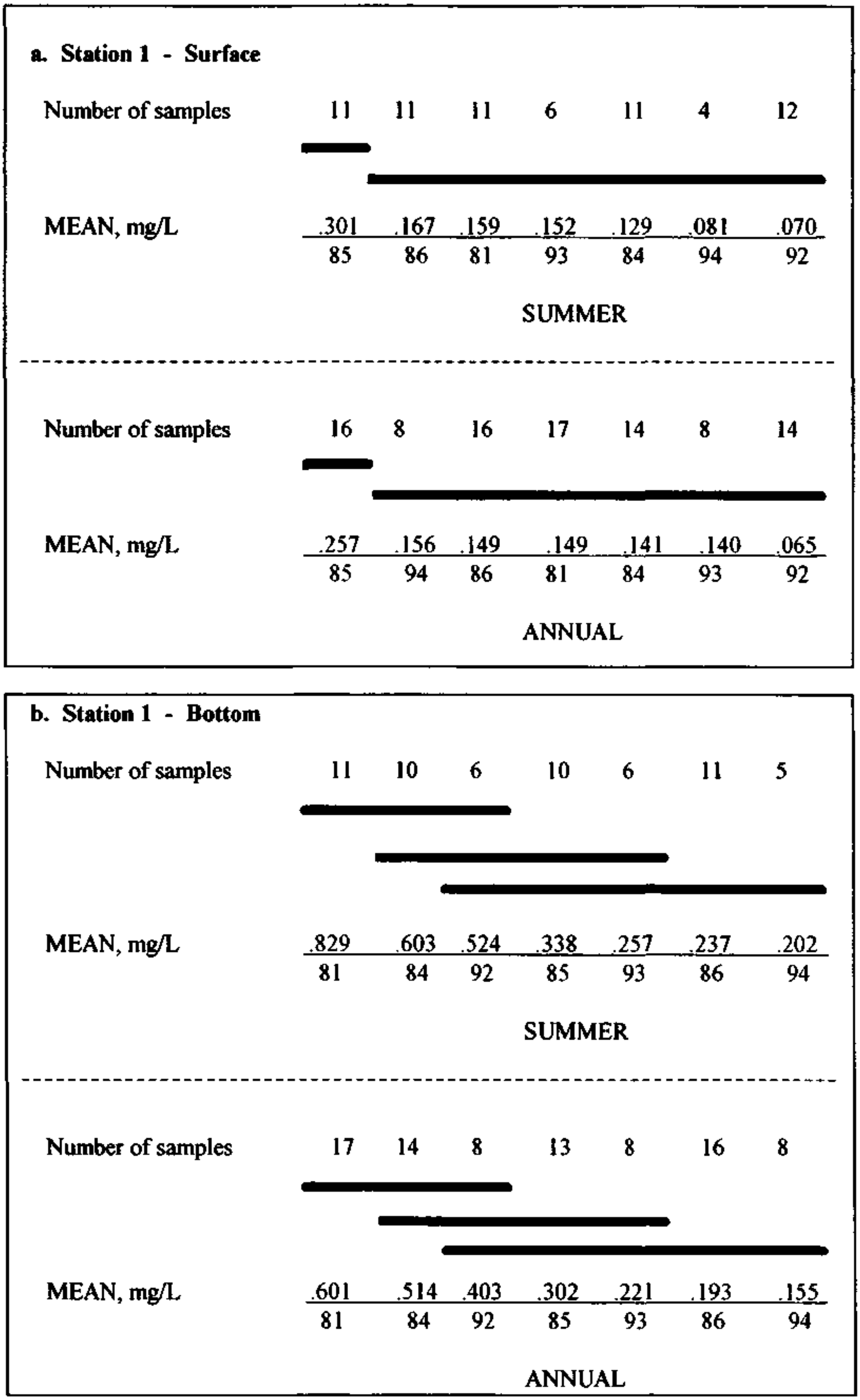


Figure 15. Graphical array and statistical analyses of total phosphorus in Lake Le-Aqua-Na

c. Station 2 - Surface

Number of samples	11	6	11	11	5	6
MEAN, mg/L	.305	.159	.157	.149	.100	.066
	85	93	86	84	94	92

SUMMER

Number of samples	16	10	14	16	10	14
MEAN, mg/L	.262	.174	.161	.145	.141	.070
	85	93	84	86	94	92

ANNUAL

Figure 15. Concluded

Figure 16a indicates that summer mean DP in 1985 was significantly higher than in 1993, 1981, 1984, 1994, and 1992 at station 1S ($p \leq 0.05$). For station 1B (figure 16b), summer mean DP in 1981 was significantly higher than in 1985, 1986, 1993, and 1994; summer mean DP in 1984 was greater than those in 1993 and 1994; and summer mean DP in 1992 was higher than in 1994. There were no significant differences among summer mean DP levels in 1985, 1986, 1993, and 1994. At station 1B, annual mean values in 1981 and 1984 were found to be significantly higher than in 1993, 1986, and 1994 (figure 16b).

Nitrogen. Nitrogen is generally found in surface waters in the form of ammonia (NH3), nitrite (NO_2), nitrate (NO_3), and organic nitrogen. Organic nitrogen is determined by subtracting NH3 nitrogen from the total kjeldahl nitrogen (TKN) measurements. Organic nitrogen can indicate the relative abundance of organic matter (algae and other vegetation) in water, but has not been shown to be directly used as a growth nutrient by planktonic algae (Vollenweider, 1968). Total nitrogen is the sum of nitrite, nitrate, and TKN. Nitrogen is an essential nutrient for plant and animal growth, but it can cause algal blooms in surface waters and create public health problems at high concentrations. The IPCB (1990) has stipulated that nitrate not exceed 10 mg/L nitrate as nitrogen or 1 mg/L nitrite as nitrogen for public water-supply and food processing waters.

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, 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 lakes.

The concerns about nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because traditional water treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/L in public water supplies. Second, a concentration in excess of 0.3 mg/L is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1952). The IEPA (1990) stipulates that ammonia-nitrogen and nitrate plus nitrite as nitrogen should not exceed 1.5 and 10.0 mg/L, respectively.

Nitrogen is one of the principal elemental constituents of amino acids, peptides, 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.

Vollenweider (1968) reports that in laboratory tests, the two inorganic forms of ammonia and nitrate are, as a general rule, used by planktonic algae to roughly the same extent. However, Wang *et al.* (1973) reported that during periods of maximum algal growth under laboratory conditions, ammonium-nitrogen was the source of nitrogen preferred by planktons. In the case of higher initial concentrations of ammonium salts, yields were noted to be lower than with equivalent concentrations of nitrates (Vollenweider, 1968). This was attributed to the toxic effects of ammonium salts. The use of nitrogenous organic compounds has been noted by several investigators, according to Hutchinson (1957). However, Vollenweider (1968) cautioned that the direct use of organic nitrogen by planktons has not been definitely established, citing that not one of 12 amino acids tested with green algae and diatoms was a source of nitrogen when bacteria-free cultures were used. But the amino acids were completely used up after a few days when the cultures were inoculated with a mixture of bacteria isolated from water. He opined that in view of the fact that there are always bacterial fauna active in nature, the use of organic nitrogen sources is of more interest to physiology than to ecology.

a. Station 1 - Surface

Number of samples	9	10	6	11	10	4	6
MEAN, mg/L	.205	.117	.085	.080	.058	.045	.023
	85	86	93	81	84	94	92

SUMMER

Number of samples	16	8	16	17	14	8	14
MEAN, mg/L	.257	.156	.149	.148	.141	.140	.065
	85	94	86	81	84	93	92

ANNUAL

b. Station 1 - Bottom

Number of samples	11	10	6	6	8	6	5
MEAN, mg/L	.568	.502	.457	.204	.161	.084	.054
	81	84	92	85	86	93	94

SUMMER

Number of samples	12	17	8	7	11	8	8
MEAN, mg/L	.440	.408	.347	.197	.132	.083	.046
	81	84	92	85	93	86	94

ANNUAL

Figure 16. Graphical array and statistical analyses of dissolved phosphorus in Lake Le-Aqua-Na

Ammonia Nitrogen. Temporal variations of ammonia nitrogen in Lake Le-Aqua-Na at station 1 are shown in figure 9k and figure 18 of the Phase II study (IEPA, 1990b). It can be seen from these figures that ammonia-nitrogen in the surface waters was fairly stable throughout the years; while that in the bottom waters tended to increase during the summer months, especially in 1981, 1984, and 1992. Levels began to rise soon after the onset of summer stratification. The major source was probably lake sediments, however, sources of ammonia in the Lake Le-Aqua-Na watershed include livestock manure, commercial fertilizers, domestic waste, and natural sources (IEPA, 1900b).

The Illinois general-use water quality standards for NH_3-N vary according to water temperature and pH value, with the allowable concentration of NH_3-N decreasing as temperature and pH rise. High water temperatures and higher pH of water increase the toxicity of NH_3-N for fish and other aquatic organisms. The allowable concentration of NH_3-N varies from 1.5 (mostly) to 13.0 mg/L, depending on temperature and pH (IEPA, 1990a). Review of data obtained for surface waters at stations 1, 2, and 3 shows that no water sample exceeded 1.5 mg/L of NH_3-N. The maximum value of NH_3-N, 1.0 mg/L, was found at station 1 on June 24, 1981.

Summer mean NH_3-N values in the lake at stations 1S, 1B, 2, and 3 ranged from 0.16 to 0.36, 0.22 to 3.74, 0.15 to 0.29, and 0.13 to 0.31 mg/L, respectively (figure 17, table 8); while annual mean NH_3-N concentrations ranged from 0.16 to 0.36, 0.20 to 3.08, 0.13 to 0.36, and 0.83 to 2.06 mg/L, respectively (figure 17, table 9). At station 1S, summer NH_3-N means were not statistically different; but annual mean concentrations during 1981 and 1984 were significantly greater than those during 1986 and 1992 (figure 17a).

The mean NH_3-N concentrations at station 1B were completely different from those at station 1S. Figure 17b shows that summer means during 1984 and 1981 were not different from each other; the summer mean NH_3-N in 1984 was higher than in 1992, 1985, 1986, 1993, and 1994; and the summer mean in 1981 was significantly higher than in 1985, 1986, 1993, and 1994. Annual mean NH_3-N concentrations had exactly the same trends as summer means.

For station 2, there were no statistical differences among the six summer means; however, the annual mean NH_3-N concentration in 1984 was significantly greater than in 1994, 1992, and 1986. One can conclude that ammonia concentrations in the lake significantly decreased following implementation of measures (1986, 1992 to 1994) compared with the pre-implementation periods (1981 and 1984).

Total Kjeldahl Nitrogen. Temporal variations of TKN at station 1S during the seven study years were similar to NH_3-N (figures 9k and 91 of this study, figures 18 and 19 of the Phase II study, IEPA, 1990b). Both NH_3-N and TKN concentrations in bottom waters (station 1B) increased after spring turnover, and increased substantially immediately after lake stratification, especially during 1981, 1984, and 1992. The major source of this nitrogen was lake sediments under anoxic conditions. Since NH_3-N is the inorganic portion of TKN, increased TKN is considered mainly to come from inorganic matter. Both NH_3-N and TKN levels in the surface waters at station 1 were relatively constant year-round. In near-bottom waters, after the fall turnover, both NH_3-N and TKN decreased, showing no difference between surface and bottom waters.

As shown in figure 18, summer mean TKN concentrations at stations 1S, 1B, 2, and 3 ranged between 0.88 and 2.18, 1.45 and 4.76, 1.04 and 2.15, and 1.08 and 1.88 mg/L, respectively; while annual means ranged, respectively, between 0.97 and 2.06, 1.20 and 3.72, 0.98 and 2.06, and 0.93 and 1.86 mg/L. Both summer and annual TKN means exhibited differences at all stations during the monitoring.

a. Station 1 - Surface

Number of samples	11	11	6	11	11	12	7
MEAN, mg/L	.365	.298	.260	.255	.208	.164	.158
	81	85	93	84	86	92	94

SUMMER

Number of samples	17	14	16	8	8	16	14
MEAN, mg/L	.360	.339	.259	.223	.203	.170	.161
	81	84	85	93	94	86	92

ANNUAL

b. Station 1 - Bottom

Number of samples	11	11	6	10	11	6	5
MEAN, mg/L	3.74	3.49	1.52	.882	.451	.360	.224
	84	81	92	85	86	93	94

SUMMER

Number of samples	14	17	8	13	16	8	8
MEAN, mg/L	3.08	2.42	1.18	.771	.368	.331	.198
	84	81	92	85	86	93	94

ANNUAL

Figure 17. Graphical array and statistical analyses of ammonia nitrogen in Lake Le-Aqua-Na

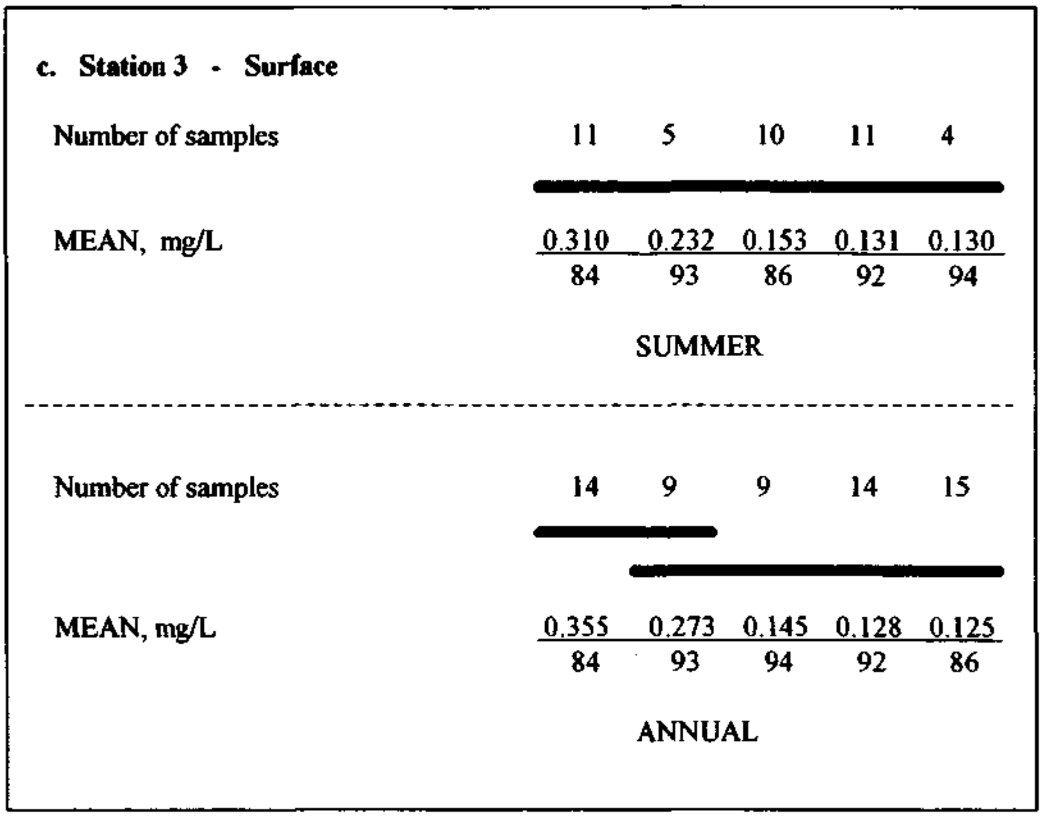


Figure 17. Concluded

a. Station 1 - Surface

Number of samples	11	11	10	11	6	12	4
MEAN, mg/L	2.18	1.85	1.38	1.15	1.07	1.03	0.88
	84	85	81	86	93	92	94

SUMMER

Number of samples	14	16	16	8	8	14	16
MEAN, mg/L	2.06	1.63	1.24	1.05	1.04	0.99	0.97
	81	84	85	93	94	86	92

ANNUAL

b. Station 1 - Bottom

Number of samples	11	11	6	10	5	11	6
MEAN, mg/L	4.76	4.32	2.22	1.95	1.70	1.47	1.45
	81	84	92	85	94	86	93

SUMMER

Number of samples	14	17	13	8	8	8	16
MEAN, mg/L	3.72	3.49	1.75	1.48	1.30	1.25	.120
	84	81	85	94	93	92	86

ANNUAL

Figure 18. Graphical array and statistical analyses of total kjeldahl nitrogen in Lake Le-Aqua-Na

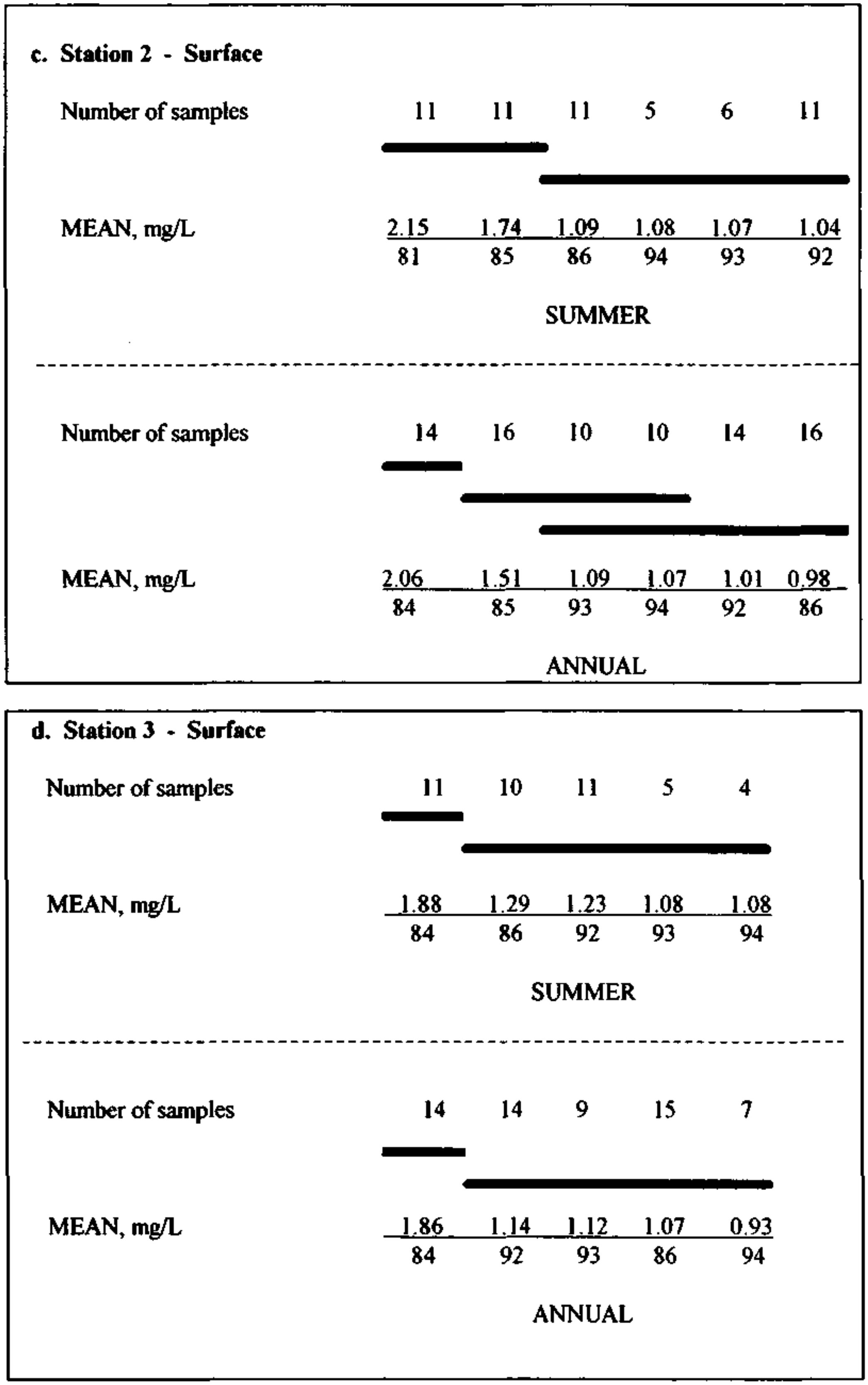


Figure 18. Concluded

For station 1S, figure 18a shows that summer TKN means during 1984 and 1985 were significantly higher than during other years ($p < 0.05$). However, the annual mean TKN during 1981 was higher than during any other year; and the annual mean in 1984 was significantly greater than during the other years (during and after implementation).

Figure 18b indicates that the summer mean for TKN during 1981 at station 1B was significantly greater than in all other years except 1984; while annual mean TKN concentrations during 1984 and 1981 were significantly higher than during the other years.

For station 2 samples, summer mean TKN concentrations during 1981 and 1985 were significantly higher than during other years (figure 18c). The annual mean, in 1984 was significantly higher than in the other years, while the annual mean in 1985 was significantly higher than in 1992 and 1986.

It can be seen in figure 18d that both summer and annual TKN levels at station 3 during 1984 were significantly greater than in the years following implementation (1986, 1992 to 1994). It may be concluded that both NH_3-N and TKN concentrations in surface waters of Lake Le-Aqua-Na significantly decreased after implementation. No TKN observations were reported for 1981.

Nitrate-Nitrite-Nitrogen. An examination of temporal variations in nitrate-nitrite-nitrogen concentrations at station 1 reveals that both surface and bottom waters generally had similar concentrations, high during cold weather periods and low during summers (figure 9m and figure 20 of the Phase II study, IEPA, 1990b). After fall turnovers, NO3/NO2-N increased due to the conversion of ammonia to nitrate during the fall and winter of the following year until summer stratification.

The IPCB (1990) has stipulated that nitrate not exceed 10 mg/L nitrate-nitrogen for general uses or 1 mg/L nitrite-nitrogen for public water-supply and food processing waters. Inspection of appendices A-l through A-5 indicates that none of the samples collected from Lake Le-Aqua-Na had nitrate-N concentrations close to 10.0 mg/L. The highest NO3/NO2-N concentrations were found on February 20, 1986, for all lake stations: 3.9, 4.1, 4.1, and 4.7 mg/L, respectively, for 1S, 1B, 2, and 3.

Figure 19 lists summer and annual mean NO3/NO2-N concentrations at four stations. The summer means at stations 1S, 1B, 2, and 3 ranged from 0.20 to 1.55, 0.19 to 1.33, 0.23 to 1.58, and 0.30 to 1.76 mg/L, respectively. Low NO_3/NO_2-N means occurred in 1985 and 1984, while the highest means occurred in 1993 for all stations. Annual means were, respectively, between 0.50 and 1.61, 0.55 and 1.59, 0.78 and 1.84, and 0.83 and 2.06 mg/L. Low annual mean NO_3/NO_2-N concentrations generally occurred in 1992 or 1994 at all stations; the highest means were found during 1993 or 1986.

As shown in figure 19, there were no statistical differences among the annual mean NO3/NO2-N concentrations for stations 1S, 1B, and 3. At station 2, the annual mean in 1993 was significantly greater than in 1985, 1994, 1984, and 1992 (figure 19c); and the annual mean in 1986 was higher than in 1984 and 1992 ($p < 0.05$). Summer means for all three surface stations (1S, 2, and 3) in 1993 (wet year) were significantly higher than in the other study years (figures 19a, 19c, and 19d). For station 1B, summer mean NO3/NO2-N concentrations during both 1993 and 1986 were significantly greater than during other study years (figure 19b). For station 1S, the 1986 summer mean NO_3/NO_2-N concentration was higher than the 1985 summer mean (figure 19a). At station 2, the 1986 summer mean was higher than that in 1984, 1992, 1994, and 1985; and the 1984 summer mean was higher than the 1985 summer mean (figure 19c).

a. Station 1 - Surface

Number of samples	6	11	11	12	4	11
MEAN, mg/L	1.55	0.89	0.44	0.35	0.33	0.20
	93	86	84	92	94	85

SUMMER

Number of samples	8	16	8	16	14	14
MEAN, mg/L	1.61	1.56	1.11	0.94	0.82	0.50
	93	86	94	85	84	92

ANNUAL

b. Station 1 - Bottom

Number of samples	6	11	11	5	6	10
MEAN, mg/L	1.33	0.94	0.31	0.26	0.25	0.19
	93	86	84	94	92	85

SUMMER

Number of samples	16	6	10	8	14	8
MEAN, mg/L	1.59	1.49	0.94	0.74	0.69	0.55
	86	93	85	94	84	92

ANNUAL

Figure 19. Graphical array and statistical analyses of nitrate/nitrite nitrogen in Lake Le-Aqua-Na

c. Station 2 - Surface

Number of samples	6	11	11	11	5	10
MEAN, mg/L	1.58	0.86	0.45	0.40	0.30	0.23
	93	86	84	92	94	85

SUMMER

Number of samples	10	16	15	10	14	14
MEAN, mg/L	1.84	1.56	1.03	1.03	0.78	0.78
	93	86	85	94	84	92

ANNUAL

d. Station 3 - Surface

Number of samples	5	10	11	11	4
MEAN, mg/L	1.76	0.88	0.49	0.37	0.30
	93	86	84	92	94

SUMMER

Number of samples	9	15	9	14	14
MEAN, mg/L	2.06	1.65	1.06	0.86	0.83
	93	86	94	92	84

ANNUAL

Figure 19. Concluded

Chlorophyll. All green plants contain chlorophyll *a*, which constitutes approximately one to two percent of the dry weight of planktonic algae (APHA *et al.,* 1992). Other pigments that occur in phytoplankton include chlorophyll *b* and c, xanthophylls, phycobilius, and carotenes. The important chlorophyll degradation products in water are the chlorophyllides, pheophorbides, and pheophytines. The concentration of photosynthetic pigments is used extensively to estimate phytoplanktonic biomass. The presence or absence of the various photosynthetic pigments is used, among other features, to identify the major algal groups present in the water body.

Chlorophyll *a* is the primary photosynthetic pigment in all oxygen-evolving photosynthetic organisms. Extraction and quantification of chlorophyll *a* can be used to estimate biomass or the standing crop of planktonic algae present in a body of water. Other algae pigments, particularly chlorophyll *b* and c, can give information on the type of algae present. Blue-green algae (Cyanophyta) contain only chlorophyll *a,* while both the green algae (Chlorophyta) and the euglenoids (Euglenophyta) contain chlorophyll *a* and *c.* Chlorophyll *a* and *c* are also present in the yellow-green and yellow-brown diatoms (Chrysophyta), and dinoflagellates (Pyrrhophyta). These accessory pigments can be used to identify the types of algae present in a lake. Pheophytin *a* results from the breakdown of chlorophyll *a,* and a large amount indicates a stressed algal population or a recent algal die-off. Because direct microscopic examination of water samples was used to identify and enumerate the type and concentrations of algae present in the water, indirect methods of making such assessments were not employed in this investigation.

According to the Phase II study (IEPA, 1990), the average summer chlorophyll *a* concentration for station 1 decreased substantially from the pre-implementation period (1981 and before, 41 mg/L) and 1984-1985 levels (45 to 43 mg/L) to the value recorded during 1986 (31 mg/L). The trend for station 2 was similar. In contrast, chlorophyll *a* at station 3 showed a substantial increase: 34 mg/L during 1981 and before, 58 mg/L during 1984 and 1986. This increase in chlorophyll *a* values in the headwaters of the lake was a result of watershed work that began in 1984. At station 1, the peak chlorophyll concentrations occurred during the springs of 1984 and 1985, as well as during the fall of 1984, likely the results of nutrient increases during lake turnover. The spring peak was absent in 1986, and fewer algal bloom conditions were apparent in the 1986 data than the 1984 and 1985 data. Destratification during 1986 reduced spring, summer, and fall algal blooms by limiting the nutrients entering the water column from the bottom sediments.

The data for all pigments determined using an annual statistical summary are presented in tables 10 to 12. For chlorophyll *a* (corrected) at station 1, the annual mean increased, with values of 31.00, 40.91, and 77.72 µg/L, respectively, for 1992, 1993, and 1994. At stations 2 and 3, the annual mean chlorophyll *a* values were also higher in 1994, but lower in 1993.

Chlorophyll *a* values are routinely corrected for pheophytin *a,* a breakdown product of chlorophyll *a,* to obtain the living algal population. All reported chlorophyll *a* values in this study were corrected for pheophytin *a.* For many samples collected from each station, no pheophytin *a* was observed (tables 10-12).

Chlorophyll *b* and *c* and pheophytin *a* in the lake were generally found to be low. The highest concentrations of chlorophyll *b* and c in the lake both occurred at station 3 and were, respectively, 28.58 mg/L on February 24, 1993, and 24.13 mg/L on May 24, 1994. No algal sample was collected on February 24, 1993. On May 24, 1994, green alga, *Spirogyra communis,* may have been the major contributor of chlorophyll *c.*

Biological Characteristics

Zooplankton. The term "plankton" refers to those microscopic aquatic forms having little or no resistance to currents and living free-floating and suspended in open or pelagic waters

Table 10. Chlorophyll Concentrations in Lake Le-Aqua-Na at RPA-1 (Station 1)

Date	*Sample depth, ft*	*Chlorophyll a, µg/L*	*Chlorophyll a corrected, µg/L*	*Chlorophyll b, µg/L*	*Chlorophyll c, µg/L*	*Pheophytin a, µg/L*
1992						
4/27	5	51.18	51.26	3.18	12.59	0 00
5/19	14	2.46	1.78	0.05	0.77	1 02
6/16	7	20.83	19.87	4.99	0 75	0 99
7/14	6	11.36	13.41	1.20	0.76	0 00
8/25	11	34.54	37.77	2.92	1.66	0 00
9/16	4	56.83	61.94	2.05	5 60	0 00
10/05	5	44.34	46.65	3.89	2 82	0 00
11/18	15	14.18	15.35	0.89	1.62	0.00
Mean		29.47	31.00	2.40	3.32	0 25
σ		20.12	21.35	1.65	4.08	0.47
1993						
4/28	5	160.32	184.76	8.31	12 62	0 00
5/27	19	15.77	17.80	0.45	1.08	0 00
6/30	1	9.17	12.46	0.00	0.00	0 00
7/21	8	21.86	24.03	1.30	0.19	0 00
8/31	5	23.16	21.36	4.06	0.00	2 14
9/28	4	21.80	23.50	1.34	0.08	0 00
10/20	11	39.81	39.16	1.39	1.70	0 00
11/23	19	4.21	4.27	1.30	1.92	0.00
Mean		36.99	40.91	2.27	2 20	0 27
σ		50.95	58.98	2.72	4.28	0.76
1994						
3/2	1	31.74	32.93	1.95	4.83	0 00
3/29	8	59.47	57.98	10.40	3.30	0 23
5/4	18	3.63	3.74	0.10	1.16	0 00
5/24	17	6.55	6.41	4.82	0.00	0 00
7/21	4	85.74	93.98	0.24	3 70	0 00
8/25	6	250.76	271.27	7.84	87.39	0.00
Mean		72.98	77.72	4.22	16 73	0 04
σ		92.60	100.68	4.23	34.66	0.09
1992-1994						
Mean		44.08	47.35	2.85	6.57	0.20
Minimum	1	2.46	1.78	0.00	0 00	0 00
Maximum	19	250.76	271.27	10.40	87.39	2 14
Standard deviation		58.14	64.08	2.90	18.40	0.54

Table 11. Chlorophyll Concentrations in Lake Le-Aqua-Na at RPA-2 (Station 2)

Date	*Sample depth, ft*	*Chlorophyll a, μg/L*	*Chlorophyll a corrected, μg/L*	*Chlorophyll h, μg/L*	*Chlorophyll c, μg/L*	*Pheophytin a, μg/L*
1992						
4/27	5	65.53	69.42	6.52	12.39	0.00
5/19	12	2.07	2.23	0.27	0.41	0.00
6/16	8	21.53	22.59	5.18	0.81	0.00
7/14	5	35.49	40.15	1.52	0.00	0.00
8/25	5	32.70	34.17	2.85	1.81	0.00
9/16	5	41.44	43.85	1.84	4.99	0.00
10/05	5	64.51	68.86	3.83	4.01	0.00
11/18	13	11.29	12.02	1.27	1.80	0.00
Mean		26.95	36.66	2.91	3.28	0.00
σ		20.83	24.41	2.13	4.07	0.00
1993						
1/26	1	1.30	0.00	0.36	1.52	2.20
2/24	1	38.08	42.05	9.12	0.85	0.00
4/28	6	42.68	45.39	3.53	2.32	0.00
5/27	12	2.63	2.67	0.35	0.20	0.00
6/30	2	3.90	6.57	0.00	0.00	0.00
7/21	9	25.21	28.70	1.97	1.81	0.00
8/31	6	17.98	16.23	3.78	0.62	2.36
9/28	4	23.16	23.50	1.53	0.00	0.00
10/20	10	52.29	52.33	2.18	2.77	0.00
11/23	14	4.17	3.81	0.61	1.80	0.46
Mean		24.14	22.13	2.34	1.19	0.50
σ		15.28	19.37	2.72	0.99	0.95
1994						
1/04	1	47.95	50.06	2.40	6.17	0.00
1/26	1	84.64	89.45	2.87	11.95	0.00
3/02	1	20.58	20.29	4.18	7.82	0.00
3/29	8	64.95	63.32	11.21	2.58	0.23
5/04	12	2.51	3.20	0.00	0.16	0.00
5/24	12	5.38	5.87	3.64	3.94	0.00
7/21	4	117.71	123.89	0.00	5.01	0.00
8/25	5	152.53	151.66	3.44	47.94	0.00
Mean		62.03	63.47	3.47	10.70	0.03
a		54.09	54.90	3.51	15.46	0.08
1992-1994						
Mean		35.51	39.32	2.86	4.76	0.20
Minimum	1	1.30	0.00	0.00	0.00	0.00
Maximum	14	152.53	151.66	11.21	47.94	2.20
Standard deviation		37.35	38.12	2.76	9.43	0.62

Table 12. Chlorophyll Concentrations in Lake Le-Aqua-Na at RPA-3 (Station 3)

Date	*Sample depth, ft*	*Chlorophyll a, µg/L*	*Chlorophyll a corrected, µg/L*	*Chlorophyll b, µg/L*	*Chlorophyll c, µg/L*	*Pheophytin a, µg/L*
1992						
4/27	4	43.04	40.58	2.78	8.75	2.03
5/19	4	17.58	16.02	0.00	2.08	1.55
6/16	7	21.71	17.55	5.74	0.97	6.48
7/14	4	37.38	41.84	1.28	0.00	0.00
8/25	5	34.52	38.51	0.41	0.74	0.00
9/16	2	53.29	56.42	0.75	4.07	0.00
10/05	4	52.54	52.73	2.59	2.29	0.00
11/18	2	14.22	14.49	1.50	0.95	0.00
Mean		34.29	34.77	1.88	2.48	1.26
σ		15.22	16.68	1.84	2.82	2.26
1993						
1/26	1	15.47	16.02	1.78	3.13	0.00
2/24	1	90.18	97.46	28.58	2.07	0.00
4/28	2	23.68	25.89	2.34	0.13	0 00
5/27	2	2.83	2.67	0.26	0.18	0.13
6/30	2	4.82	6.68	0.00	0.00	0.00
7/21	4	29.54	32.71	1.51	0.61	0.00
8/31	3	21.42	21.36	5.37	0.53	0.00
9/28	2	18.20	18.16	0.77	0.00	0.00
10/20	3	69.83	68.89	2.16	5.19	0.00
11/23	3	4.75	3.81	1.35	2.67	1.53
Mean		28.07	29.37	4.41	1.45	0.17
σ		29.14	30.68	8.62	1.76	0.48
1994						
1/04	1	44.82	45.39	2.58	4.75	0.00
1/26	1	10.67	9.15	0.88	1.64	2.06
3/02	1	62.55	65.15	9.19	15.12	0.00
3/29	4	46.56	49.59	8.72	3.34	0.00
5/04	2	2.95	2.67	0.11	0.43	0.32
5/24	2	31.52	26.70	17.72	24.13	8.94
7/21	2	109.98	112.14	0.00	3.75	0.00
8/25	4	62.84	68.35	0.06	11.97	0.00
Mean		46.49	46.14	4.19	8.14	1.42
σ		33.73	36.54	6.43	8.23	3.12
1992-1994						
Mean		35.65	36.57.	3.67	3.83	0.89
Minimum	1	2.83	2.67	0.00	0.00	0.00
Maximum	7	109.98	112.14	28.58	24.13	8.94
Standard deviation		27.39	28.81	5.95	5.58	2.14

(APHA *et al.,* 1992). Plankton can be divided into planktonic plants or phytoplankton (microscopic algae) and planktonic animals (zooplankton). The zooplankton in fresh water comprise principally protozoans, rotifers, cladocerans, copepods, and ostracods; a greater variety of organisms occurs in marine waters. Since a Wisconsin plankton net was used for collecting plankton samples, protozoans (microplanktons) were not detected. In this report, protozoans are not included in the discussion of zooplankton.

Zooplankton densities in Lake Le-Aqua-Na are listed in tables 13-15. These tables show that total observed zooplankton densities ranged from 200 to 2,800 counts per liter (cts/L); 100 to 2,100 cts/L; and 200 to 3,400 cts/L at stations 1, 2, and 3, respectively. Generally, high zooplankton densities occurred in early spring (April and May) and in summer (July and August) for all three stations. Highest counts were found in April 1992 and 1993 at station 1, in May 1994 at station 2, and in July 1994 at station 3. The temporal variation of zooplankton communities at each station showed similar trends. For all three stations, the plankton counts were high in 1994 and low in 1993.

At the three sampling stations, 26 zooplankton species were observed during the three-year study period: 11 cladecerans, 2 copepodas, 2 ostracods, and 11 rotiferas. However, the dominant zooplanktons were copepodas, based on their frequency of occurrence and densities. The dominant species for all three stations were *Diaptomus minutus* (71 to 88 percent of occurrence) and *Eucyclops speratus. Daphnia pulex,* a cladocera, was the second most dominant species at stations 1 and 3; this species was one of the dominant zooplankton in found a study of Lake George in northwestern Indiana (Raman *et al.,* 1996). *Cycocpyris forbesi* (an ostracoda), and *Bosmina coregonia* and *B. longirostris* (Cladoceras) were also prevalent at all three stations.

The number of zooplankton species found in the 49 samples collected ranged from one to five (tables 13-15). The majority of samples contained three or four zooplankton species.

Biovolumes of zooplankton found in the samples were computed using the shape and size information provided in table 16, and included in tables 13-15 for stations 1 to 3, respectively. Wide variations of biovolumes were found from sample to sample for each station and from station to station. This was also the case for Lake George (Raman *et al.,* 1996) and Wolf Lake (Lin *et al.,* 1996). Overall, the biovolume of zooplankton in Lake Le-Aqua-Na ranged from a low of 20 cubic millimeters per liter (mm^3/L) on September 16, 1992, to a high of 4,200 mm^3/L on August 25, 1994, at station 1 (table 13); from 0.04 mm^3/L on June 16, 1992, to 2,100 mm^3/L on September 16, 1992 and August 25, 1994, at station 2 (table 14); and from 3.3 mm^3/L on May 24, 1994, to 1,700 mm^3/L on September 16, 1992 and July 21, 1993, at station 3 (table 15). High zooplankton biovolumes were contributed by high densities of the dominant species, such as *Diaptomus minutus* and *Daphnia pulex.*

Phytoplankton. Phytoplanktonic algae form the base of the aquatic food web and provide the primary source of food for fish and other aquatic insects and animals. The algae produce oxygen and remove carbon dioxide from the water through photosynthesis. Nevertheless, excessive growths (blooms) of algae can degrade water quality and cause problems such as bad taste and odor, increased color and turbidity, decreased filter run at a water treatment plant, unsightly surface scums and aesthetic problems, and even oxygen depletion after die-off.

During the Phase I diagnostic-feasibility study in 1981 (Kothandaraman and Evans, 1983), algal counts in Lake Le-Aqua-Na were found to be of bloom proportions from June through September (1,500 to 8,200 cts/L). Blue-green algae (Cyanophyte) dominated (50 to 87 percent) from June through August. The blue-greens created unsightly conditions in the lake by forming algal scum under quiescent lake conditions. Algal biovolume was found to be the highest on June 24, 1981, with concentrations of 99,591 mmVL. A relatively large number of flagellates were

Table 13. Zooplankton Densities in Lake Le-Aqua-Na at Station 1

Species	1992 4/27	1992 5/19	1992 6/16	1992 7/14	1992 8/25	1992 9/16	1993 4/28	1993 5/27	1993 6/20	1993 7/21	1993 8/31	1993 9/28	1994 5/4	1994 5/24	1994 6/23	1994 7/21	1994 8/25	1994 10/6	Percent occurrence
Cladocera																			
Bosmini coregoni	1600	400					400				200							300	31
B. longirostris	900			400	700	300			300	400									38
B. pulex																			
Daphnia ambigus									200					300					13
D. catavila																			
D. dubia																			
D. laevis																	600		6
D. pulex		100						500		200		100	800	200	200		400	100	56
D. rosea																			
Leptodora kindtii																			
Polyphemus pediculus											100								6
Copepoda																			
Diaptomus minutus	300	200		100	200	300	300	200	200	200			1700	1200	200		1100	300	88
Eucyclops speratus							200				100	100		500					25
Ostracoda																			
Cyclocyprisforbes		200		200	300			900		100			300		300				44
Cypris obesa															100				6
Rotifera																			
Ascomorpha sattam																			
Asplanchna priodonta																			
Brachionus rubens																	100	100	13
B. quadridentata																			
Chromogaster ovalis																			
Elose woralli																			
Horaella brehmi										100				200			300		19
Keratella cochlearis																			
K. quadrata		200																	6
K. stipitata																			
Philodina sp.																			
Total density, cts/L	2800	1100	-	700	1200	600	1800	700	900	800	400	200	2800	2400	800	-	2500	800	
Number o f species	3	5		3	3	2	4	2	5	3	3	2	3	5	4		5	4	
Biovolume, mm^3/L	160	450		39	66	20	91	2100	33	860	150	420	3400	3400	860		4200	440	

Note: Bad samples on 6/16/92 and 7/21/94

Table 14. Zooplankton Densities in Lake Le-Aqua-Na at Station 2

	1992						*1993*						*1994*						*Percent*
Species	*4/27*	*5/19*	*6/16*	*7/14*	*8/25*	*9/16*	*4/28*	*5/27*	*6/30*	*7/21*	*8/31*	*9/28*	*5/4*	*5/24*	*6/23*	*7/21*	*8/25*	*10/6*	*occurrence*
Cladocera																			
Bosmini coregoni	1100	400			300	200	300	100						300					41
B. longirostris									100	200						1100			18
B. pulex																			
Daphnia ambigus										100				300	300				18
D. catavila																			
D. dubia																			
D. laevis								400			100								12
D. pulex						500					100	100					500	200	29
D. rosea																			
Leptodora kindtii																			
Polyphemus pediculus																			
Copepoda																			
Diaptomus minutus	400	100	100		200	200	200	200	100				1400		400		700	700	71
Eucyclops speratus											100	100		400		400	300	200	35
Ostracoda																			
Cyclocypris forbesi		100					600							100		100	200	200	35
Cypris obesa																			
Rotifera																			
Ascomorpha sattarn																			
Asplanchna priodonta							100						400						12
Brachionus rubens															200		300		12
B. quadridentata																			
Chromogaster ovalis																			
Elose woralli																			
Horaella brehmi														200	100				12
Keratella cochlearis												100		300					12
K. quadrata		100			200														12
K. stipitata																			
Philodina sp.																			
Total density, cts/L	1500	700	100		700	900	1200	700	200	300	300	300	2100	1300	1000	1600	2000	1300	
Number of species	2	4	1		3	3	4	3	2	2	3	3	3	5	4	3	5	4	
Biovolume, mm^3/L	72	33	0.04		20	2100	88	1700	66	45	840	420	120	130	100	90	2100	860	

Note: Bad sample on 7/14/92

Table 15. Zooplankton Densities in Lake Le-Aqua-Na at Station 3

Species	*1992*						*1993*						*1994*						*Percent*
	4/27	*5/19*	*6/16*	*7/14*	*8/25*	*9/16*	*4/28*	*5/27*	*6/20*	*7/21*	*8/31*	*9/28*	*5/4*	*5/24*	*6/23*	*7/21*	*8/25*	*10/6*	*occurrence*
Cladocera																			
Bosmini coregoni	700							200					300		200			300	29
B. longirostris					300	300		200		300						1900			29
B. pulex																			
Daphnia ambigus																400			6
D. catavila																			
D. dubia																			
D. laevis											100				200				12
D. pulex			200	300			100			400	100		200		100		200		47
D. rosea						400													6
Leptodora kindtii																			
Polyphemus pediculus																			
Copepoda																			
Diaptomus minutus	200		200	600		300	200	400					1100	1300	700	700	900	500	71
Eucyclops speratus					1300			100		200	100			100			400		35
Ostracoda																			
Cyclocyprisforbesi		200		200			200			100			400			400			35
Cypris obesa																			
Rotifera																			
Ascomorpha sattarn																			
Asplanchna priodonta				100	100														12
Brachionus rubens																		400	6
B. quadridentata																			
Chromogaster ovalis																			
Elose woralli																			
Horaella brehm																		200	6
Keratella cochlearis																			
K. quadrata																			
K. stipitata						100													6
Philodina sp.																			
Total density, cts/L	900	200	400	1200	1700	1100	500	900		1000	300	-	2000	1400	1200	3400	1500	1400	
Number o f species	2	1	2	4	3	4	3	4		4	3		4	2	4	4	3	4	
Biovolume, mm^3/L	46	13	840	1300	85	1700	430	29		1700	840		680	3.3	1300	280	850	30	

Note: No sample on 9/28/93

Table 16. Sizes and Shapes of Zooplankton Used in Biovolume Determination

Name	*Shape*	*Size (µm)*
Cladocera (Water Fleas)		
Bosmini coregoni	Spherical	500 diam.
B. longirostris	Spherical	500 diam.
B. pulex	Ovoid	450×340×210
Daphnia ambigas	Ovoid	1,040 × 660 × 460
D.catavila	Ovoid	1,300×550×450
D. dubia	Ovoid	1,600 × 780 × 700
D. laevis	Spherical	2,000 diam.
D. pulex	Spherical	2,000 diam.
D. rosea	Spherical	2,000 diam.
Lepotodora kindtii	Cylindrical	1,500×12,250
Polyphemus pediculus	Ovoid	1500 × 1,000 × 900
Copepoda (Copepods)		
Diaptomus minutus	Cylindrical	100×500
Eucyclops speratus	Cylindrical	200 × 900
Ostracoda (Seed shrimps)		
Cyclocypris forbesi	Spherical	500 diam.
Cypris obesa	Spherical	500 diam.
Rotifera (Rotifers)		
Ascomorpha saltans	Spherical	150 diam.
Asplanchua priodonta	Cylindrical	960×400
Brachionus rubens	Spherical	350 diam.
B. quadridentata	Spherical	350 diam.
Chromogaster ovalis	Ovoid	170×120×120
Elose woralli	Cylindrical	100 × 30
Horaella brehmi	Spherical	200 diam.
Keratella cochlearis	Cylindrical	110 × 70
K. quadrata	Cylindrical	130×85
K.stipitata	Cylindrical	150×80
Philodina sp.	Cylindrical	120×80

found in the water sample on that date. These algae are much larger than the other types of algae found in the lake, accounting for the very large biomass. Chlorophyll *a* was found to peak (93 µg/L) on July 8, 1981. Algal biomass was found to be the highest on June 24, 1981, with a concentration of 99.59 mm^3/L. Apparently, there was no correlation between chlorophyll *a*, biomass, and the algal density in Lake Le-Aqua-Na.

According to the Phase II project report (IEPA, 1990b) prepared after the post-implementation study of 1986, phytoplankton densities at station 1 were lower on all collection dates in 1986 than they had been in 1984. Phytoplankton communities in 1986 were generally dominated by green and blue-green algae, and on May 8, 1986, by flagellates (Cryptophyta). Green algae *(Coelastrum microporum, Micractinium pusillum, Pediastrum* spp., and *Scenedesmus* spp.) dominated from July 24 - September 10, 1986. These green algae are indicators of eutrophic conditions, and none of these species dominated in 1984.

Blue-green algae were present in 1986 in about the same densities as in 1984 and 1985. *Anacystis montana* dominated on most dates. *Aphanizomenon flos-aquae* was abundant on August 6, 1986, and its density was greater than in August 1984 but less than in August 1985. A decline in density of this algae by August 19, 1986, was probably a direct result of the destratifier. Other eutrophic indicator species *{Anabaena spiroides* and *Microcystis aeruginosa)* were found on August 6, 1986, but in densities well below those of 1984 and 1985. These algae did not become as numerous as in earlier years probably because of the continuous operation of the destratifier from May 20 through about September 3, 1986. *Schizothrix calcicola* was not abundant in 1986 despite the reflooding of littoral areas after the drawdown of the lake for beach construction in 1985 (IEPA, 1990b).

Flagellates, such as *Cryptomonas* spp., were never as abundant in 1986 as in 1984 and 1985, but they appeared on comparable dates. Return of the lake to its full level probably eliminated the habitat necessary for development of *Cryptomonas* spp., *Chlamydomonas* sp., and *Phascotus lenticularis* (IEPA 1990b).

During the Phase III study, sampling of plankton (zooplankton and phytoplankton algae) communities was carried out monthly from April through September or October of 1992, 1993, and 1994. Algal densities (standing crops) expressed as the total number of counts per milliliter (cts/mL), frequency of occurrence, species distribution, and biovolume are presented for three stations in Lake Le-Aqua-Na in tables 17-19. Chlorophyll values and biomass are also listed in the tables. Traditionally, two significant digits are used for reporting total algal density. The total number of algae listed in tables 17-19 can be rounded off to two digits to follow this convention.

Annual ranges of algal density for 1992, 1993, and 1994 were respectively, 8 to 9,600, 69 to 4,600, and 500 to 7,900 cts/mL for station 1; 69 to 6,200, 36 to 3,000, and 110 to 6,300 cts/mL for station 2; and 39 to 4400, 70 to 4300, and 69 to 4900 cts/mL for site 3. Algal densities varied in each sample, each year, and for each site. However, in general, the lowest algal densities occurred in May for stations 1 and 2, and in June and April for site 3. High algal densities were observed in August for all sites (though not for each year). This is typical of Illinois lakes, which have high algal densities in early spring and during summer. The impact of aeration/destratification cannot be assessed since a status log was not maintained for the destratifier. DO and temperature data for 1992 indicate that the destratifier was not operational. It did not have a significant impact during the summer of 1993 given heavy precipitation, decreased hydraulic retention, and increased lake mixing. The lake experienced severe anoxic conditions during June and July of 1994.

Between one and nine algal species were found in each of the samples collected from the three different stations in the lake for three years. The number of species per sample was low compared with other Illinois lakes. For example, 15 algal species were observed in a Wolf Lake

Table 17. Types, Densities, and Volume of Algae and Chlorophyll in Lake Le-Aqua-Na at Station 1

Algal species	*1992*						*1993*						*1994*						*Percent*
	4/27	*5/19*	*6/16*	*7/14*	*8/25*	*9/16*	*4/28*	*5/27*	*6/20*	*7/21*	*8/31*	*9/28*	*5/4*	*5/24*	*6/23*	*7/21*	*8/25*	*10/6*	*occurrence*
Blue greens																			
Anabaena spiroides					42	231									92	2741	1439		5
Anacystis cyanea					347														1
A.thermolis				326							1974	1691					189		4
Aphanizomenon flos-aquae					8862	2069				408		294			181	462	473		7
Chroococcus sp.			2531																1
Oscillatoria chlorina																95	662		2
O. sp.																			
Greens																			
Actinastrum hantzchii					53														1
Chlorella pyrenoidosa																			
C. vulgaris													11						1
Coelastrum microporvm			200	630							116	74		17	139	294			7
Oocystis borgei	15		1743	231	21	32					189					138		174	8
Pediastrum duplex			21								242	137		2310			74		5
P. simplex						21													1
Scenedesmus dimorphus																			
Sphaerocystis schroeteri																			
Spirogyra communis																			
Ulothrix variabilis																			
U. zonata																			
Diatoms																			
Asterionella formosa							200	35					15						3
Cacconeis rugosa													21						1
Caloneis amphisbaena																			
Cyclotella meneghiniana																			
C. ocellate																			
Cymbella prostrata													17						1
Diploneis smithii																			
Fragilaria capucina						1061	116												2

Table 17. Concluded

Algal species	1992						1993						1994						Percent
	4/27	*5/19*	*6/16*	*7/14*	*8/25*	*9/16*	*4/28*	*5/27*	*6/20*	*7/21*	*8/31*	*9/28*	*5/4*	*5/24*	*6/23*	*7/21*	*8/25*	*10/6*	*occurrence*
Diatoms																			
Melosira binderana																			
M.granulata					21				107	710		221		17	40				6
Pinnularia candate																			
Stephanodiscus niagarae																21			1
Synedra acus																			
S. ulna																			
Surirella ovata																			
Tabellaria fenestrate	363				179								181						3
T. sp.																			
Flagellates																			
Ceratium hirundinella	11		11	74	32	42			11	127		137			25				9
Dinobryon sertularia							431	21		69			242	103					5
Eurorina elegans				116															
Euglena gracilis												63							1
E. viridis																			
Lepocinclis texta							3790												1
Peridinium cinctum																	5072	806	2
Phacus pleuronectes					11		74									74			3
Svnura uvella				1974															1
Trachenonas crebea		8	32	63	42	42		23						25					7
Desmids																			
Desmidium sp.													8						1
Glenadinium sp.					11											2			2
Staurastrum comutum						21						32			11	4			4
Total algal density, cts/mL	389	8	4538	3414	9621	3519	4611	69	118	1314	2521	2649	495	2472	488	3830	7909	980	
Number o f species	3	1	6	8	1 1	8	5	3	2	4	4	8	7	5	6	9	6	2	
Biomass, mm^3/L	1.47	0.87	16.47	7.40	170	14.50	34.35	0.97	0.77	8.86	3.57	4.49	12.66	7.13	1.70	14.91	230.0	36.90	
Chlorophyll-a, µg/L	51.26	1.78	19.87	13.41	37.77	61.94	184.76	17.80	12.46	24.03	21.36	23.50	3.74	6.41		-93.98	271.27		

Table 18. Types, Densities, and Volume of Algae and Chlorophyll in Lake Le-Aqua-Na at Station 2

Algal species	1992 4/27	5/19	6/16	7/14	8/25	9/16	1993 4/28	5/27	6/20	7/21	8/31	9/28	1994 5/4	5/24	6/23	7/21	8/25	10/6	Percent occurrence
Blue greens																			
Anabaena spiroides					126	284									223	4064			4
Anacystis cyanea					326													82	2
A. thermolis			1271	420							181	401					221		5
Aphanizomenon flos-aquae					2909	2216		69		302					302				5
Chroococcus sp.			2331																1
Oscillatoria chlorina																	105		1
O. sp.																			
Greens																			
Actinastrum hantzchii																			
Chlorella pyrenoidosa																			
C. vulgaris													29						1
Coelastrum microporum		6	347	452		11				27	92	65			82	809	84	23	11
Oocystis borgei		4	1964		63							97				305	179	55	7
Pediastrum duplex			21	42		63				37	29	40		11	15	21			9
P. simplex																			
Scenedesmus dimorphus		11					63							17					3
Sphaerocystis schroeteri														15					1
Spirogyra communis	122														42				2
Ulothrix variabilis			147																1
U. zonata															120				1
Diatoms																			
Asterionella formosa				21			189						17						3
Cacconeis rugosa													48						1
Caloneis amphisbaena																			
Cyclotella meneghiniana																			
C. ocellate		44																	1
Cymbella prostrata																			
Diploneis smithii																			
Fragilaria capucina				116		1407	210	63											4

Table 18. Concluded

Algal species	1992 4/27	1992 5/19	1992 6/16	1992 7/14	1992 8/25	1992 9/16	1993 4/28	1993 5/27	1993 6/20	1993 7/21	1993 8/31	1993 9/28	1994 5/4	1994 5/24	1994 6/23	1994 7/21	1994 8/25	1994 10/6	Percent occurrence
Diatoms																			
Melosira binderana												80							1
M. granulate	25							38	36	1108	63								5
Pinnularia candate													6						1
Stephanodiscus niagarae																			
Synedra acus													11						1
S. ulna																			
Surirella ovata																			
Tabellaria fenestrata					137														1
T. sp.																			
Flagellates																			
Ceratium hirundinella			74	53		189				164	27	288		99	15				8
Dinobryon sertularia							116			95									2
Eurorina elegans				53															1
Euglena gracilis																			
E. viridis																			
Lepocinclis texta							2237												1
Peridinium cinctum																	5733	189	2
Phacus pleuronectes														11					1
Synura uvella				1691															1
Trachenonas crebea	8	4	21		42	32	137	25											7
Desmids																			
Desmidium sp.																			
Glenadinium sp.						116								17					2
Staurastrum comutum											19								1
Total algal density, cts/mL	155	69	6176	2848	3603	4318	2952	195	36	1733	411	971	111	159	799	5199	6322	349	
Number of species	3	5	8	8	6	8	6	4	1	6	6	6	5	5	7	4	5	4	
Biomass, mm^3/L	0.26	0.11	15.61	64.00	5.24	9.78	10.50	0.62	0.24	12.90	1.26	2.29	0.09	6.16	1.35	7.93	260	8.96	
Chlorophyll-a, µg/L	69.422	2.23	22.59	40.15	34.17	43.85	45.39	2.67	6.57	28.70	16.23	23.50	3.20	5.87	-	123.89	151.66	-	

Table 19. Types, Densities, and Volume of Algae and Chlorophyll in Lake Le-Aqua-Na at Station 3

	1992						1993						1994						Percent
Algal species	*4/27*	*5/19*	*6/16*	*7/14*	*8/25*	*9/16*	*4/28*	*5/27*	*6/20*	*7/21*	*8/31*	*9/28*	*5/4*	*5/24*	*6/23*	*7/21*	*8/25*	*10/6*	*occurrence*
Blue greens																			
Anabaena spiroides					137											2489		15	3
Anacystis cyanea					63	74													2
A.thermolis				1187							151						126	11	4
Aphanizomenon flos-aquae					4211	1376		27		504	53			53		1166			7
Chroococcus sp.																			
Oscillatoria chlorina																			
O. sp.						53											73		2
Greens																			
Actinastrum hantzchii																			
Chlorella pyrenoidosa												4064							1
C. *vulgaris*													11						1
Coelastrum microporum		5	170	588							23				50	221	147		7
Oocystis borgei	13		305	32						21						242			5
Pediastrum duplex			11	11		63	8			42	42				15	95	63		9
P. simplex						11													1
Scnedesmus dimorphus							17	19											2
Sphaerocystis schroeteri																			
Spirogyra communis														36					1
Ulothrix variabilis										90									1
U. zonata																641			1
Diatoms																			
Asterionella formosa							52	36					15						3
Cacconeis rugosa																			
Caloneis amphisbaena												32							1
Cyclotella meneghiniana																		13	1
C. ocellate																			
Cymbella prostrata																			
Diploneis smithii													21						1
Fragilaria capucina						924													1

Table 19. Concluded

Algal species	1992 4/27	1992 5/19	1992 6/16	1992 7/14	1992 8/25	1992 9/16	1993 4/28	1993 5/27	1993 6/30	1993 7/21	1993 8/31	1993 9/28	1994 5/4	1994 5/24	1994 6/23	1994 7/21	1994 8/25	1994 10/6	Percent occurrence
Diatoms																			
Melosira binderana																			
M. granulate			29						57	991	50	231							5
Pinnularia caudate																			
Stephanodiscus niagarae																	42		1
Synedra acus													44						1
S. ulna		175																	1
Surirella ovata				11															1
Tabellaria fenestrata									13										1
T. sp.		864																	1
Flagellates																			
Ceratium hirundinella			32	32		42				154				25					5
Dinobryon sertularia								57		53			11						3
Eurorina elegans			191	168															2
Euglena gracilis	15																		1
E. viridis															4				1
Lepocinclis texta																			
Peridinium cinctum																	3161	347	2
Phacus pleuronectes														17					1
Synura uvella				2279															1
Trachenonas crebea	11	37		53	32	11	23				15							27	8
Desmids																			
Desmidium sp.																			
Glenadinium sp.																			
Staurastrum comutum																			
Total algal density, cts/mL	39	1081	738	4361	4443	2554	100	139	70	1855	334	4327	102	131	69	4854	3613	413	
Number of species	3	4	6	9	4	8	4	4	2	7	6	3	5	4	3	6	6	5	
Biomass, mm^3/L	0.13	0.93	8.50	0600	6.18	9.17	0.08	2.47	0.04	4.11	0.45	0.50	0.65	2.04	0.42	6.03	150.0	15.63	
Chlorophyll-a, µg/L	40.58	16.02	17.55	41.84	38.51	56.42	25.89	2.67	6.68	32.71	21.36	18.16	2.67	26.70		-112.40	68.35		
Chlorophyll-b, µg/L																			
Chlorophyll-c, µg/L																			
Pheophytin *a*, µg/L																			
Sample depth, ft	5	14	7	6	11	4													

sample (Lin *et al.,* 1996). There were 31, 34, and 37 different algal species identified at different times during 1992 to 1994 at sites 1, 2, and 3, respectively. A total of 49 different species were found in all of the algal samples examined, including 6 blue-greens (Cyanophytes), 12 greens (nonmobile Chlorophytes), 18 diatoms (Bacillariophytes), 10 flagellates (Euglenophytes), and 3 desmids (tables 17-19). At all three sampling stations, diatoms and green algae were generally the predominant algae, not the problem-causing blue-green algae.

Aphanizomenon flos-aquae was the relatively frequently observed blue-green algae at all three sites. *Coelastrum microporum* (61 percent at site 2), *Pediastrum duplex* (50 percent at site 3) and *Oocystis borgei* (44 percent at site 1) were the most frequently occurring greens at all three sites in the lake. Although 12 species of diatoms were found, they did not occur frequently at any site. Two flagellates, *Ceratium hirundinella* and *Trachemonas crebea,* were observed frequently at all three sites.

Blue-greens were dominant during the summer of 1981 (Kothandaraman and Evans, 1983) and in 1986 (IEPA, 1990b). *Aphanizomenon flos-aquae* were abundant with high density in August and September 1992 at all three stations but were not significant in 1993 and 1994. These algae, which cause taste and odor, also dominated on August 6, 1986 (IEPA, 1990). Very high densities (3,200 to 5,700 cts/mL) of a diatom, *Peridinium cinctum,* were observed on August 25, 1994, at three sites. This species is rare in Illinois lakes, and it did not occur in 1992 and 1993.

Algal biovolumes were calculated for each sample using the size and shape information provided in table 20. The calculated algal biovolume values showed a wide range at all three stations (tables 17 to 19): 0.87 to 7,400, 0.08 to 8,600, and 0.09 to 640 mm^3/L, respectively, for stations 1, 2, and 3. All the highest values at each station occurred on July 14, 1992, mainly the contribution of the flagellates *Synura uvella* (195-mm spherical diameter). At station 1, high biovolumes (170 and 230 mm^3/L) were also observed on August 25, 1992, and on August 25, 1994. At stations 2 and 3, high algal biovolumes were found on August 25, 1994, but not on August 25, 1992. In general, algal biovolumes were: station 1 > station 2 > station 3.

Chlorophyll *a* values for algae sampling dates are also given in tables 17 to 19. In general, for all three sampling stations, chlorophyll *a* values were low in May and high in July and August during 1992 to 1994, except at station 2 in 1993. Examination of tables 17 to 19 indicates no correlation between total algal density and chlorophyll *a* concentration and between algal density and biovolume. This was also the case for Lake George (Raman *et al.,* 1996) and Wolf Lake (Lin *etal.,* 1996).

Macrophytes. Macrophytes are commonly called aquatic vegetation (or weeds). The macrophyton consists principally of aquatic vascular flowering plants, but it also includes the aquatic mosses, liverworts, ferns, and larger macroalgae (APHA *et al.,* 1992). Macrophytes may include submerged, emerged, and floating plants, and filamentous algae. In most lakes and ponds, aquatic vegetation is found that may beneficially and/or adversely impact the natural ecosystem. Reasonable amounts of aquatic vegetation improve water clarity by preventing shoreline erosion, stabilizing sediment, storing nutrients, and providing habitat and hiding places for many small fish (young of the year, bluegill, sunfish, etc.). They also provide food, shade, and oxygen for aquatic organisms; block water movement (wind wave); and utilize nutrients in the water, reducing the excessive growth of phytoplankton.

However, excessive growth of aquatic vegetation generally interferes with recreational activities (fishing, boating, surfing, etc.); adversely affects aquatic life (overpopulation of small fish, benthic invertebrates); causes fish kill; emits taste and odor in water due to decomposition of dense weed beds; blocks water movement and retards heat transfer, creating vertical temperature

Table 20. Sizes and Shapes of Algae Used in Biovolume Computations

Algae	*Shape*	*Size, µm*
Blue greens		
Anabaena spiroides	Spherical, filamentous	10 diam.×100
Anacystis cyanea	Spherical	5.5 diam.
A. thermolis	Spherical, colony	5 diam.
Aphanizomenon flos-aquae	Cylindrical, filamentous	4.5×90
Chroococcus sp.	Cylindrical	5 diam.×35
Oscillatoria chlorina	Cylindrical	8x55
O. sp.		
Greens		
Actinastrum hantzchii	Spherical	42 diam.
Chlorella pyrenoidosa	Spherical	6 diam.
C. vulgaris	Spherical	11 diam.
Coelastrum microporum	Spherical	24 diam.
Oocystis borgei	Spherical	22 diam.
Pediastrum duplex	Cylindrical	3×150
P. simplex	Cylindrical	10×22
Scenedesmus dimorphus	Flat, rectangular	5 × 19
Sphaerocystis schroeteri	Spherical	89 diam.
Spirogyra communis	Spherical	10 diam.
Ulothrix variabilis	Cylindrical, filamentous	5×10, 10
U. zonata	Flat, rectangular	31 × 55
Diatoms		
Asterionella formosa	Flat, rectangular	2 × 125
Cacconeis rugosa	Ovoid	13×21
Caloneis amphisbaena		
Cyclotella meneghiniana	Spherical	21 diam.
C. ocellate	Spherical	11 diam.
Cymbella prostrata	Cylindrical	25×85
Diploneis smithii	Cylindrical	15×8
Fragilaria capucina	Plank	60×10×5
Diatoms		
Melosira binderana	Rod	20×8
M.granulata	Cylindrical	12×60
Pinnularia caudate	Rod	130×17
Stephanodiscus niagarae	Spherical	52 diam.
Synedra acus	Cylindrical	4.5×200
S. ulna	Cylindrical	4.5×200
Surirella ovata	Ovoid	132×84
Tabellaria fenestrata	Cylindrical	6 × 90
T. sp.	Cylindrical	6 × 90

Table 20. Concluded

Algae	*Shape*	*Size, µm*
Flagellates		
Ceratium hirundinella	Triangular	48 × 48 × 200
Dinobryon sertularia	Cylindrical	30 × 60
Eurorina elegans	Flat, rectangular, colony	10×21,135
Euglena gracilis	Cylindrical	6×45
E. viridis	Cylindrical	17×50
Lepocinclis texta	Ovoid	40 × 50
Peridinium cinctum	Spherical	44
Phacuspleuronectes	Cylindrical	40 × 87
Synurauvella	Spherical	195
Trachenonas crebea	Spherical	18diam.
Desmids		
Desmidium sp.	Cylindrical	73 × 36
Glenadinium sp.	Spherical	28
Staurastrum cornutum	Flat, rectangular	18×32

gradients; and destroys aesthetic value to the extent of decreasing the economic values of properties surrounding a lake. Under these circumstances, aquatic plants are often referred to as weeds.

Historical Data. The historical and current data on macrophytes management were obtained from the Park Office of the Lake Le-Aqua-Na State Park, Illinois Department of Natural Resources (formerly Illinois Department of Conservation). Table 21 summarizes the recorded history of weed control in Lake Le-Aqua-Na. During the Phase I diagnostic/feasibility study period, one-third of the lake surface was covered by a dense growth of aquatic macrophytes. The dominant species were American elodea *(Elodea canadensis)* and coontail *{Ceratophyllum demersum)*. On June 4, 1982, a gallon of diquat was applied to control elodea. The results of the treatment lasted until August 1982 when elodea reappeared.

On June 28, 1982, 25 gallons of Aquathol-K was applied to control curlyleaf pondweed *(Potamogeton crispus).* The treatment resulted in excellent control of curlyleaf pondweed. Several species of nontarget weeds, including sago pondweed *{Potamogeton pectinatus),* leafy pondweed *(Potamogeton foliosus),* small pondweed *(Potamogeton pusillus),* coontail, and American elodea, were also reduced. Only coontail reinvaded later at the treated areas.

Thirty gallons of Aquathol-K was used to control curlyleaf pondweed on June 20, 1984, with excellent results, but limited control was observed on sago, small and leafy pondweeds, coontail, and elodea. The lake experienced periodic algal blooms from late June to late September, which limited the regrowth of rooted weeds throughout the remainder of 1984.

On August 7, 1985, 200 pounds of copper sulfate ($CuSO_4$) and 100 pounds of citric acid were applied to control phytoplankton (algae) in the main lake area. Plankton treatment was performed by hanging burlap bags of $CuSO_4$ and citric acid from the four corners of the destratifier and switching the destratifier flow to an upward mode. Sixty-two pounds of potassium permanganate was applied in the same manner on August 8, 1985. Treatment results were striking with the algal bloom disappearing and the lake becoming clear, but the water took on a brownish hue. Prior to the chemical treatment, DO was 10.3 mg/L at the surface and 1.6 mg/L at the bottom. On August 12, 1985, DO was 4.5 mg/L at the surface and 1.2 mg/L at the bottom, due to die-off of algae. The destratifier mode was switched to downward flow on August 10, 1985.

After the watershed treatments in 1985, curlyleaf pondweed and filamentous algae became dominant in the beach area and the boat dock area in late spring 1986. On May 20, 1986, localized treatments with Komeen or Koplex (7.5 gallons at the beach and 12.5 gallons at the boat dock) effectively controlled the weeds in both areas.

In 1987, 35 to 40 percent of the lake was covered with weeds. On May 12, 1987, the same quantity of Komeen was used to control curlyleaf pondweed at the same two areas as in 1986. Although the results of localized treatment were not as effective as before, control in the beach area where the herbicide was directly applied was effective. There was no drift. In the concession bay, control was very slow in appearing and relatively ineffective.

On May 27, 1987, 30 gallons of Aquathol-K was applied in the concession bay and in the upper end of the lake. Control of curlyleaf pondweed in these areas was complete, and the effectiveness extended beyond the treated area. Control was excellent, and no intense bloom followed as of July 8, 1987. Duckweed was not a problem either. Secchi transparencies ranged from 11 to 180 inches with an average of 59 inches during this period at station 1.

Curlyleaf pondweed again dominated the entire north shoreline and the upper end of the lake to a depth of 8 to 12 feet by mid-May 1988. No weed harvesting took place in 1987, so

Table 21. Historical and Current Vegetation Management in Lake Le-Aqua-Na

Date	Target vegetation	Herbicide used: Type	Herbicide used: quantity	Results
6/4/82	American elodea	Diquat	1 gallon	Lasted until August when elodea reinvaded
6/28/82	Curlyleaf pondweed	Aquathol-K	25 gallons	Excellent
6/24/84	Curlyleaf pondweed	Aquathol-K	30 gallons	Excellent
8/7-8/85	Phytoplankton	$CuSO_4$	200lb	Excellent
		Citric acid	100 lb	
		$KMnO_4$	62 lb	
5/20/86	Curlyleaf pondweed	Komeen	7.5 gallons in beach	Effective in both areas
			12.5 gallons dock area	
5/12/87	Curlyleaf pondweed	Komeen	Ditto	Not as effective as 1986
5/27/87	Curlyleaf pondweed	Aquathol-K	30gallons	Completely eradicated curlyleaf pondweed
5/27/88	Curlyleaf pondweed	Aquathol-K	30 gallons	Effective, coontail and duckweed replaced
5/18/90	Filamentous algae	$CuSO_4$	6 lb in beach	Effective, but algae soon returned
	Filamentous algae	$CuSO_4$	25 lb at boat ramp	
	Coontail	Komeen	7.5 gallons in beach	
6/11/90	Filamentous algae	$CuSO_4$	25 1b	Algae became uprooted and floated;
	Coontail	Sonar	1 gallon	weeds were manually removed
5/12/92	Waterlily planted		500 tubers	Successful, 12 patches found 9/16/92
5/19/92	Curlyleaf pondweed, coontail	Komeen	12.5 gallons	Effective, normal algal growth
	Filamentous algae	$CuSO_4$	20 lb	
5/23/95	Curlyleaf pondweed	Aquathol-K	5 gallons	Excellent
	Curlyleaf pondweed	Sonar	1 quart	

treatment with 30 gallons of Aquathol-K was undertaken on July 28, 1988. Coontail and duckweed then replaced the curlyleaf pondweed by the fall, but the coverage was not excessive. Two patches of white waterlily were observed in 1988. During the year, the destratifier operated only nine days due to many mechanical problems.

The lake was dominated by curlyleaf pondweed with large patches of coontail and small pondweed in 1989. By 1990 filamentous algae became the dominant vegetation, increasing along the shoreline and in the concession area, beach area, and the shallow end of the lake. The first treatment in 1990 was carried out on May 18. Thirty-one pounds of $CuSO_4$ was used to control filamentous algae and 7.5 gallons of Komeen to treat coontail. The results were effective by May 21, 1990. However, filamentous algae soon returned, and a second treatment was necessary. On June 11, 1990, 25 pounds of $CuSO_4$ was used in the concession bay and 1 gallon of Sonar was applied on a narrow strip along the north shore to control coontail. Dry conditions resulted in the lake being down 3 feet. Effective results of the vegetation treatment were seen on June 18, 1990. By July following a heavy rain on June 27, the coontail became dislodged and was found floating throughout the lake, making boating difficult in the concession bay. The weeds were manually removed. It is not clear whether the weed treatment or the heavy rains that raised the lake level by 3 feet were responsible for uprooting all coontail in the lake.

Vegetation appeared early in 1991. However, by late spring aquatic vegetation was non-existent, and no herbicide treatment was necessary in 1991. By fall, only small patches of coontail were found in the upper shallow end of the lake.

Current Management. During the Phase III study, 500 waterlily tubers were planted on May 12, 1992. Twelve waterlily patches were seen by September 1992. On May 19, 1992, 12.5 gallons of Komeen were applied in the beach and boat dock areas to control coontail and curlyleaf pondweed. In addition, 20 pounds of $CuSO_4$ also was applied at the boat launch area to control filamentous algae. After a week, the lake level was found to be low, but the lake water was clear. Generally, beneficial results were noticed, although the lake turned green during the remainder of the year. No weed regrowth was seen for the rest of 1992. The green coloration was healthy bloom and not one of visible noxious blue-green algae.

During 1992 and 1994, herbicides were applied, but no records are available.

On May 23, 1995, 5 gallons of Aquathol-K was applied at the concession bay, beach, and a small strip along the north shore to control curlyleaf pondweed. One quart of Sonar also was used in the beach. Treatment results were excellent.

Current Data. The annual macrophyte surveys during the Phase III study were conducted on June 9-11, 1992, May 18-19, 1993, and May 18-19, 1994. Data for the macrophyte surveys in the lake are presented in tables 22-25. These tables include field observations and laboratory analysis results, i.e., water depth at the stations, quadrat size used, plant height, major macrophyte species, bottom sediment characteristics, major species observed in the field, percent species composition, and biomass. Figures 20-22 show the distributions and densities of macrophytes in the lake. The reconnaissance survey determined the areal extent of macrophyte beds and dominant species.

As stated earlier, in late May 1992 before Memorial Day weekend, herbicide was applied to control macrophytes. During the 1992 macrophyte survey, unhealthy plants were observed. Some dead plants and unhealthy fragments were floating on the lake surface. Figure 20 shows the macrophyte map after chemical treatment. Curlyleaf pondweed, coontail, and Eurasian water milfoil *(Myriophyllum spicatum)* were dominant.

Table 22. Data from Macrophyte Survey in Lake Le-Aqua-Na, June 9-10,1992

*Station**	*Location* Bearing degree	*Location* Distance, ft	*Location* Ft from shore	*Location* Water depth, ft	*Location* Plant height, ft	*Genera*	*Percentage*	*Total biomass, g/m²*	*Remarks*
1	(30' SW of deck) near R3		50	6	5	Curlyleaf pondweed	100	84.55	
2	(80' from R7)		60	6	5	Curlyleaf pondweed	100	68.14	12-20' wide strip
3	(80' from R21)		60	6	4-6	Curlyleaf pondweed	100	67.95	
4	265-R9	260	105	4.5	3	Coontail	100	226.14	
5			205	5	3	Curlyleaf pondweed	100	143.88	R11-R12
6	238-R9	351		7	4.5	Coontail	100	348.68	dead CLPW with algal mat
7	170-R11	320		4	4	Coontail	100	1177.88	healthy
8	200-R11	395		5	5	Curlyleaf pondweed Eurasian water milfoil	95 5	395.48	Not healthy
9	140-R11	205		1.5	1.5	Curlyleaf pondweed Eurasian water milfoil	90 10	224.51	duckweed
10	255-R11	265		1.5	1.5	Curlyleaf pondweed Eurasian water milfoil	98 2	261.98	near bird house

Note:
* See figure 20 for station locations.

Table 23. Observations in Lake Le-Aqua-Na during Macrophyte Survey, May 18-20,1993

*Station**	*Location*	*Distance from shore, ft*	*Water depth, ft*	*Plant density*	*Major species*	*Remarks*
1	200' off Rl	20	3	Dense	Curlyleaf pondweed	Soft organic bottom, Secchi = 73"
2A	75' off R19	10	2	Moderate	Curlyleaf pondweed	
2		27	5	Sparse	Curlyleaf pondweed	Soft muck, Secchi = 68"
3A	25' offR3	10	3	Dense	Curlyleaf pondweed	Muck clumps of sago pondweed around this area
3		55	8	Sparse	Coontail	Rocky bottom
4A	150' off R3	28	4	Dense	Curlyleaf pondweed	Muck, sago pondweed
4		54	6	Sparse	Curlyleaf pondweed	Muck
5A	200' offR5	25	3	Dense	Curlyleaf pondweed	Organic muck
5		70	7	Sparse	Small pondweed	Organic muck
6A	From R5	29	3	Moderate	Curlyleaf pondweed	Organic muck
6		66	7	Sparse	Curlyleaf pondweed	Gray-black sediment
7A	1/2 distance between	25	3	Moderate	Coontail	Gray organic muck, with shells
7	R5 and R7	80	7	Sparse	Coontail	Gray organic muck
8A	From R7	20	3	Dense	CLPW, Coontail	Organic muck
8		40	5	Sparse	Coontail	Organic muck
9	100' offR21	70	3	Moderate	Coontail	Black, organic muck
10	175'offR21	150	5	Dense	Coontail	Black, organic muck
11	80' offR22	30	1	Dense	Coontail	Soft muck bottom
12	230' offR22	200	4	Sparse	Coontail	Organic muck
13	275' offRl0	200	3.5	Dense	Curlyleaf pondweed	Organic muck
14	375'offR10	220	4	Very D.	Coontail	Organic muck
15	290' offRl0	90	5.5	Moderate	Coontail	Organic muck
16	280'off R11	235	3	Dense	Curlyleaf pondweed	Soft organic muck

Note:
* See figure 21 for station locations.

Table 24. Percent Composition and Biomass of Macrophytes Collected in Lake Le-Aqua-Na, May 18-20,1993

	Species						
*Sampling station**	*Coontail*	*Curlyleaf pondweed*	*Horned pondweed*	*Small pondweed*	*American elodea*	*Duckweed*	*Biomass, g/m^2*
1	1	90	9				36.9
2	5	95					4.3
2A	2	98					23.5
3	100						0.5
3A	<1	99		<1			111.9
4		100					3.2
4A	<1	97	1		1	<1	109.3
5	2			98			10.4
5A	1	80	1	18			106.4
6	5	95					3.4
6A	<1	99					61.6
7	90	8			2		3.0
7A	95	5					87.2
8	99	<1					7.1
8A	45	50			5		106.8
9	99	<1					52.6
10	99	<1					137.0
11	97	<1			2		254.5
12	85	5			10		6.9
13	2	98					136.7
14	99	<1					382.0
15	99	<1					75.4
16	1	99					107.3

Note:

* See figure 21 for station locations.

Table 25. Data from Macrophyte Survey in Lake Le-Aqua-Na, May 18-19, 1994

*Sampling station**	*Quadrat size, inches*	*Major species*	*Biomass, g/m^2*
1	18	Curlyleaf pondweed, coontail	18.9
2	18	Curlyleaf pondweed, filamentous algae	28.9
2A	12	Curlyleaf pondweed	39.5
3	18	Curlyleaf pondweed	60.0
3A	12	Curlyleaf pondweed, sago pondweed	160.4
4	18	Curlyleaf pondweed, sago pondweed	1.1
4 algae	18	Filamentous algae	28.5
4A	12	Curlyleaf pondweed, filamentous algae	64.9
5	18	Curlyleaf pondweed	16.7
5A	12	Curlyleaf pondweed, filamentous algae	347.4
6	18	Curlyleaf pondweed	41.5
6A	12	Curlyleaf pondweed	180.8
7	18	Curlyleaf pondweed	106.9
7A	12	Duckweed, filamentous algae	84.6
8	18	Curlyleaf pondweed	3.7
8 algae	18	Filamentous algae	46.3
8A	12	Curlyleaf pondweed, coontail	34.7
9	18	Curlyleaf pondweed, coontail	40.2
10	12	Coontail	243.8
11	18	Algae scum	23.6
12	12	Coontail	200.2
13	12	Curlyleaf pondweed	266.7
14	18	Coontail, curlyleaf pondweed	65.7
15	12	Coontail, curlyleaf pondweed	55.1
16	18	Coontail, curlyleaf pondweed	34.7
17	18	Coontail, curlyleaf pondweed	60.7

Note:
* See figure 21 for station locations.

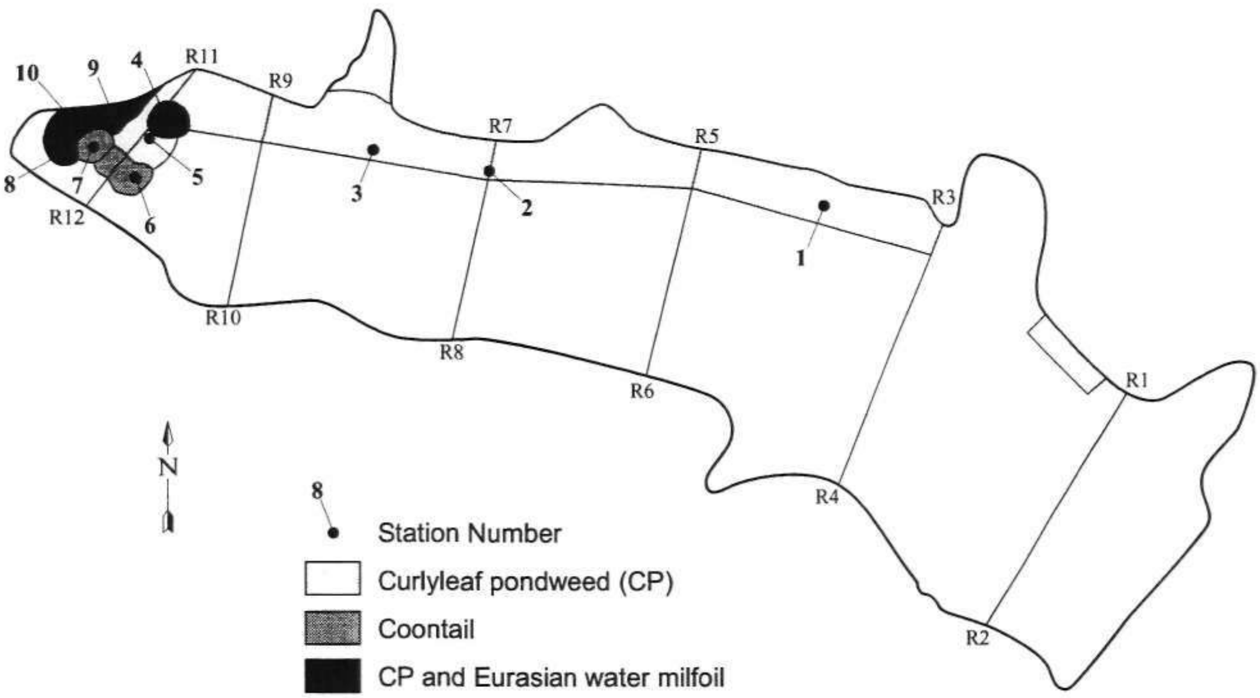


Figure 20. Macrophytes in Lake Le-Aqua-Na, June 9-11, 1992

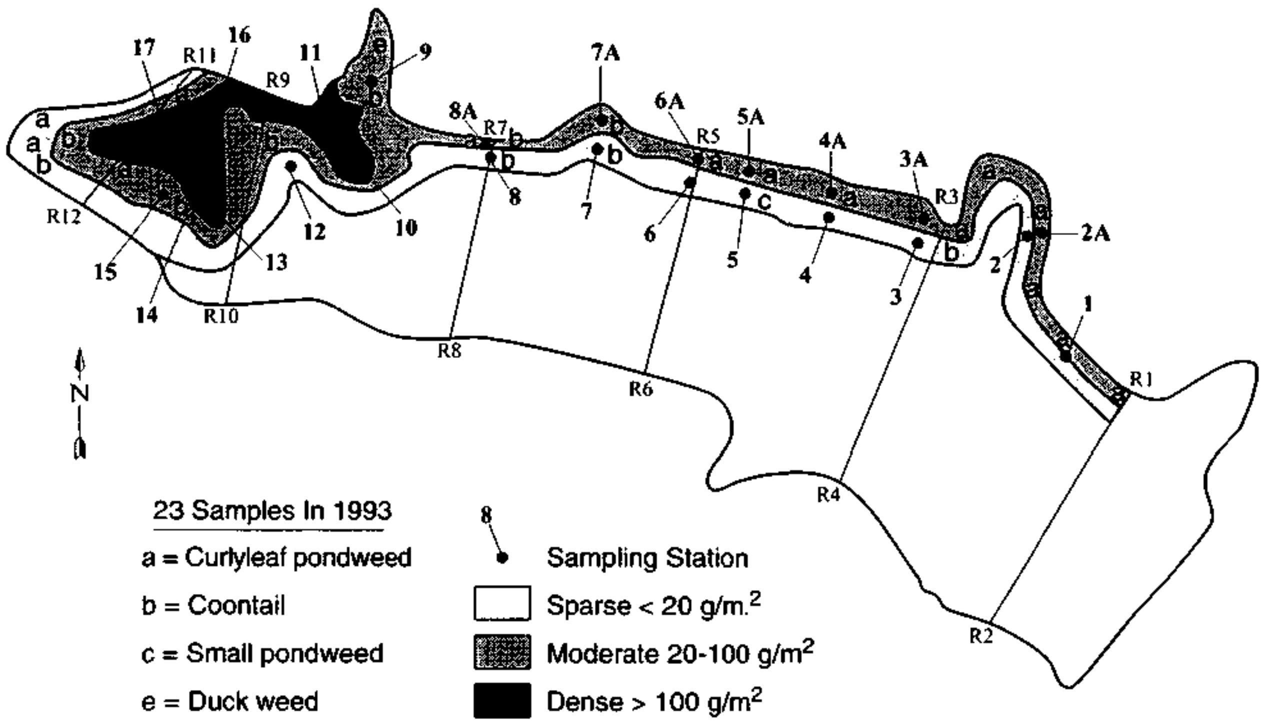


Figure 21. Macrophytes in Lake Le-Aqua-Na, May 18-19, 1993

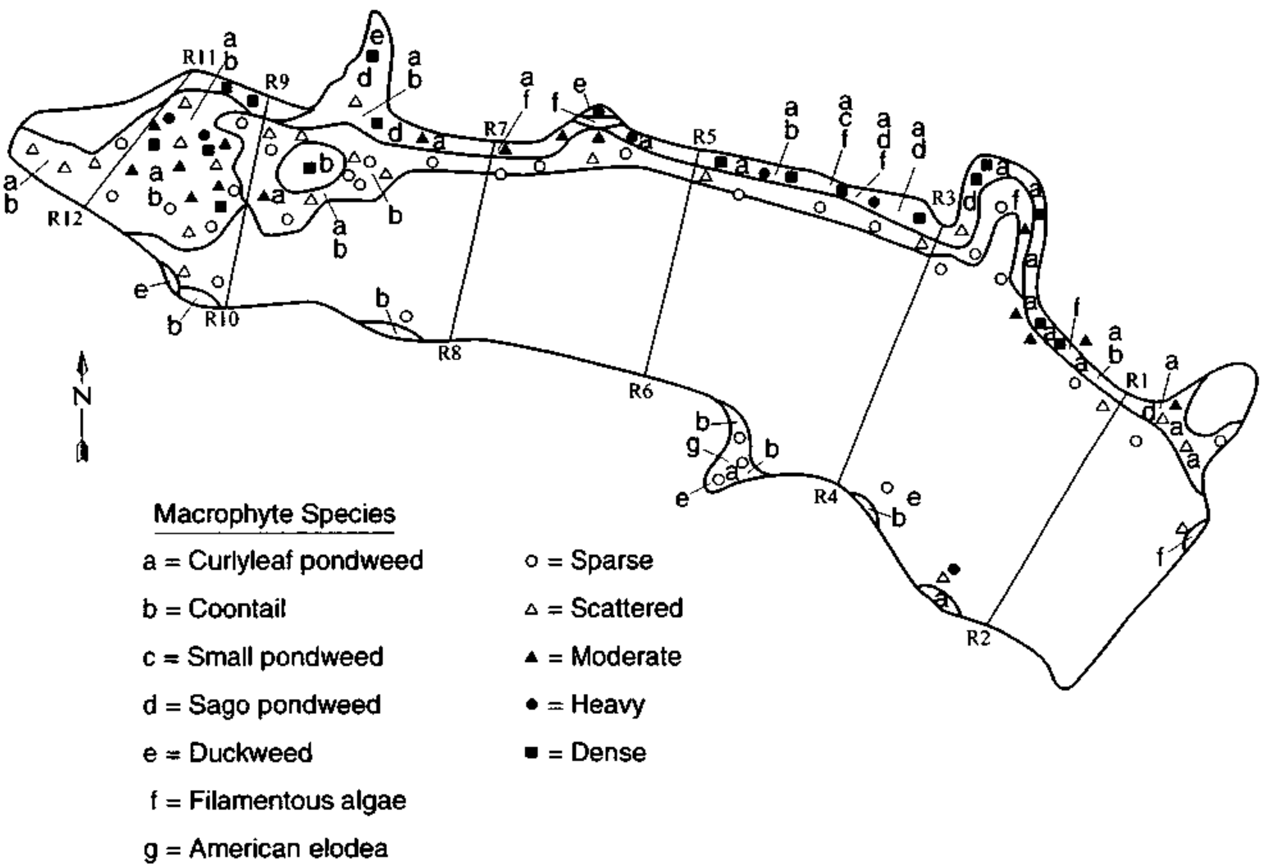


Figure 22. Macrophytes in Lake Le-Aqua-Na, May 18-19, 1994

It should be noted that the sampling locations for 1992 were not the same as in 1993; the sampling locations for 1993 and 1994 were exactly the same. For this reason, station numbers are not depicted in figure 22. Refer to figure 21 for the locations of 1994 sampling stations listed in table 25.

In both 1993 and 1994, macrophyte surveys were performed before the annual herbicide application. Laboratory analysis of macrophyte composition in 1993 showed that either coontail or curlyleaf pondweed dominated the lake (table 24). Curlyleaf pondweed is more common in the northern half of Illinois, while coontail is a common plant throughout Illinois. In Lake Le-Aqua-Na, small pondweed was dominant only at station 5. American elodea and duckweed were also observed but were not significant. As shown in table 24, biomass ranged from 0.5 grams per square meter (g/m^2) at station 3 to 382 g/m^2 at station 14.

Schloesser and Manny (1984) provided guidances for defining denseness of macrophyte growth in lakes. They considered growths of 20 to 80 g/m^2 to be low density, 60 to 160 g/m^2 medium density, and 150 to 220 g/m^2 high density. In the 1993 survey, stations 11 and 14 could be classified as high density stations, with macrophytes over 220 g/m^2. For the 1994 survey, stations 3A, 5A, 6A, 10, 12, and 13 could be considered high density (table 25). The maximum density (347.4 g/m^2) was found at station 5, which was dominated by curlyleaf pondweed and filamentous algae. The algal species were not determined.

For the 1994 macrophyte survey, percent compositions of macrophytes collected were determined, but the data was lost due to personnel relocation. Only dominant species from field observations are presented in table 25. As in the previous years, curlyleaf pondweed and coontail were dominant in the lake.

Eurasian water milfoil was found in the 1992 survey. Fortunately, it was not observed in the 1993 and 1994 surveys (tables 22, 24, and 25). Eurasian water milfoil is a non-native aquatic plant that has become a widespread problem throughout North America.

Inspection of figures 20-22 indicates that macrophyte growths generally occur along the north bank of Lake Le-Aqua-Na and in the shallow end of the lake. No macrophytes were observed on the south shore in 1992 and 1993 due to its short and steep littoral zone. However, some aquatic plants were observed at certain locations of the south bank with sparse or scattered distribution in 1994. The areal extent and densities of macrophytes seem to have increased in the lake over the years. Up to two feet of soft, organic-rich sediment in the shallow west end of the lake is covered every year with dense aquatic vegetation.

Fisheries

Creel Survey. Creel surveys were conducted on Lake Le-Aqua-Na in 1989, 1994, and 1995 by the Illinois Natural History Survey, Champaign, Illinois. A summary of survey results is presented in tables 26 and 27a-27c. Inspection of table 26 reveals that there was no shore fishing during the ice fishing period (January 1, 1994, to March 14, 1994). It was all coded as boat fishing, on the assumption that most ice fishing occurs offshore. Comparing creel data for 1989 and 1994-1995, shows that angler hours and hours per acre of boat fishing were almost identical. However, angler hours and hours per acre of shore fishing both increased during the 1994-1995 period.

In table 26, "percent effort interviewed" is the percentage of the estimated total effort actually accounted for by angler interviews. The number was calculated by summing the total hours of fishing reported from each stratum (i.e., day period-year period-weekday/weekend-boat/shore combination) and dividing the sum by the estimated total effort (calculated from

Table 26. Results of Creel Survey in Lake Le-Aqua-Na

	Survey period		
	1/1/89-11/15/89	*1/1/94-3/14/94*	*4/9/94-3/14/95*
Acreage	43.0	41.5	41.5
Sampling ratio	333/957(34.7%)	93/219(42.4%)	376/882(42.6%)
Ratio of effort hours interviewed	863/27790(21.09%)	857/2565(33.4%)	7125/30782(23.14%)
Number of interviews	1964	238	2125
Boat fishing			
Angler hours			
Weekdays	4801	1285	3994
Weekend/holiday	5502	1277	6075
Total	10303	2562	10069
Hours per acre			
Weekdays	112	31	96
Weekend/holiday	128	31	146
Total	240	62	243
Percent effort interviewed			
Weekdays	9.40	20.43	19.16
Weekend/holiday	29.66	46.55	36.56
Total	20.22	33.45	29.66
Shore Fishing			
Angler hours			
Weekdays	8456		9727
Weekend/holiday	9026		10980
Total	17482	0	20707
Hours per acre			
Weekdays	197		234
Weekend/holiday	210		265
Total	407	0	499
Percent effort interviewed			
Weekdays	13.33		14.28
Weekend/holiday	29.39		25.05
Total	21.62	0	19.99

Source: Illinois Department of Conservation instantaneous counts) for that period. The percent effort interviewed for boat fishing increased almost 50 percent from 1989 to 1994-1995; however, for shore fishing there was no change (table 26). Totals of 647 and 742 hours per acre of fishing pressure were recorded during 1989 and 1994-1995, respectively. In 1989, shore fishing accounted for 63 percent of the fishing effort and boat fishing accounted for 37 percent; during 1994-1995, shore fishing accounted for 67 percent, and boats for 33 percent. These are close to the average. Normally, one would expect a 60-40 split.

Angler catch results are presented separately (tables 27a-27c) for fish caught (includes both fish harvested and those released) and for fish harvested. The results of the creel surveys show that seven fish species were represented in the 1989, 1994, and 1994-1995 population analyses: black crappie, bluegill, largemouth bass, channel catfish, walleye, warmouth, and northern pike. Miscellaneous species caught and harvested in low quantities included white crappie, rock bass, smallmouth bass, black and yellow bullhead, green sunfish, rainbow trout, golden shiner, gizzard shad, and carp. White crappie were caught during 1994-1995, but not in 1989.

In the 1989 creel survey on the basis of the number of fish caught, black crappie and bluegill made up 93.6 percent of the samples, and black crappie alone represented nearly 50 percent (table 27a). However, black crappie caught during the 1994-1995 survey only accounted for 17 percent of samples, while bluegill was the most commonly caught species with 64 percent of the catch fish population (table 27c).

An examination of tables 27a-c, on the basis of the weight of fish caught, four species - namely bluegill, black crappie, largemouth bass, and channel catfish - contributed the most in terms of weight caught. Fish weight caught in 1989 and 1994-1995 was, respectively, 142 and 124 pounds/acre (lb/ac). These are considered satisfactory fish productivity values, and are much higher than the much less productivity in Frank Holten State Park Lakes (58 lb/ac) in southwestern Illinois during the post-restoration monitoring period there (Raman and Bogner, 1994).

The ratio of fish harvested to caught, on the basis of the fish numbers, was 35 and 50 percent for the 1989 and 1994-1995 creel surveys, respectively. On the basis of total weight, the ratio was found to be 43 and 63 percent, respectively, for 1989 and 1994-1995. The harvested ratios increased in five years based both on fish number and fish weight.

Fish Flesh Analysis. According to the IDNR Office of Resource Conservation, no fish flesh analyses have been conducted during the past ten years.

Trophic State

Eutrophication is a normal process that affects every body of water from its time of formation. As a lake ages, the degree of enrichment from nutrient materials increases. In general, the lake traps a portion of the nutrients originating in the surrounding drainage basin. Precipitation, dry fallout, and ground-water inflow are the other contributing sources.

A wide variety of indices of lake trophic conditions have been proposed in the literature used for this study. These indices are based on Secchi disc transparency; nutrient concentrations; hypolimnetic oxygen depletion; and biological parameters, including chlorophyll *a*, species abundance, and diversity. In its *Clean Lakes Program Guidance Manual,* the USEPA (1980) suggests the use of four parameters as trophic indicators: Secchi disc transparency, chlorophyll *a*, surface water total phosphorus, and total organic carbon.

Table 27a. Fish Caught and Harvested by Anglers at Lake Le-Aqua-Na, January 1,1989 - November 15,1989

	Number of fish			*Weight*			
Species	*Per hour*	*Total number*	*Per acre*	*Pounds per hour*	*Total*	*Pounds per acre*	*Average, pounds*
Caught							
Black crappie	.272	15552	361.68	.040	2280	53.026	.1466
Bluegill	.447	13443	312.62	.057	1726	40.145	.1284
Channel catfish	.013	649	15.08	.013	665	15.455	1.0248
Largemouth bass	.034	1187	27.60	.036	1157	26.904	.9750
Northern pike	.003	65	1.52	.007	150	3.500	2.3077
Rainbow trout	.000	3	.07	.000	3	.064	.9424
Smallmouth bass	.000	6	.14	.000	5	.123	.8902
Walleye	.004	219	5.08	.001	80	1.864	.3668
Warmouth	.001	93	2.15	.000	25	.571	.2654
Miscellaneous*	.001	88	2.04	.000	32	.752	.3689
Total	**.776**	**31303**	**727.98**	**.156**	**6123**	**142.405**	**.1956**
Harvested							
Black crappie	.083	4869	113.22	.013	776	18.041	.1593
Bluegill	.197	5482	127.48	.028	788	18.326	.1438
Channel catfish	.010	445	10.36	.011	580	13.492	1.3025
Largemouth bass	.002	161	3.75	.004	357	8.293	2.2109
Northern pike	.000	14	.33	.002	61	1.427	4.3679
Rainbow trout	.000	3	.07	.000	3	.064	.9424
Smallmouth bass	Not recorded						
Walleye	.000	13	.31	.000	22	.510	1.6593
Warmouth	.001	67	1.57	.000	18	.429	.2739
Miscellaneous*	.000	11	.25	.000	4	.100	.4012
Total	**.293**	**11065**	**257.33**	**.060**	**2609**	**60.683**	**.2358**

Note:
* Rock bass, golden shiner, and black bullhead

Table 27b. Fish Caught and Harvested by Anglers at Lake Le-Aqua-Na, January 1,1994 - March 14,1994

Species	*Number offish*			*Weight*			
	Per hour	*Total number*	*Per acre*	*Pounds per hour*	*Total*	*Pounds per acre*	*Average, pounds*
Caught							
Black bullhead	Not recorded						
Black crappie	.083	212	5.12	.027	66	1.600	.3127
Bluegill	1.042	2325	56.02	.228	523	12.605	.2250
Channel catfish	.014	15	.38	.005	9	.224	.5980
Largemouth bass	.006	23	.56	.004	18	.426	.7612
Northern pike	.000	2	.06	.000	4	.099	1.8096
Rainbow trout	Not recorded						
Walleye	.001	6	.15	.000	4	.088	.6094
Warmouth	Not recorded						
Miscellaneous*	.002	2	.06	.000	-	.011	.1857
Total	**1.148**	**2587**	**62.33**	**.265**	**625**	**15.052**	**.2415**
Harvested							
Black bullhead	Not recorded						
Black crappie	.072	172	4.14	.026	61	1.473	.3562
Bluegill	.674	1584	38.18	.185	421	10.155	.2660
Channel catfish	.000	2	.05	.002	7	.163	3.7471
Largemouth bass	.000	1	.03	.000	3	.065	2.3127
Northern pike	Not recorded						
Rainbow trout	Not recorded						
Walleye	Not recorded						
Warmouth	Not recorded						
Miscellaneous*	Not recorded						
Total	**.747**	**1759**	**42.40**	**.213**	**492**	**11.855**	**.2797**

Note:
* Gizzard shad

Table 27c. Fish Caught and Harvested by Anglers at Lake Le-Aqua-Na, April 9,1994 - March 14,1995

	Number of fish			*Weight*			
Species	*Per hour*	*Total number*	*Per acre*	*Pounds per hour*	*Total*	*Pounds per acre*	*Average, pounds*
Caught							
Black bullhead	.000	24	.59	.000	18	.429	.7281
Black crappie	.084	3484	83.95	.020	824	19.865	.2366
Bluegill	.412	13254	319.36	.073	2140	51.570	.1615
Channel catfish	.021	975	23.50	.021	848	20.442	.8701
Green sunfish	.000	71	1.72	.000	4	.091	.0531
Largemouth bass	.062	1965	47.34	.041	835	20.129	.4252
Northern pike	.007	180	4.35	.007	295	7.120	1.6388
Rainbow trout	.000	15	.37	.000	17	.406	1.0923
Rock bass	.000	91	2.19	.000	33	.784	.3587
Smallmouth bass	.001	16	.39	.000	2	.041	.1039
Walleye	.004	119	2.87	.000	43	1.034	.3610
Warmouth	.005	237	5.72	.000	36	.870	.1520
White crappie	.004	251	6.06	.000	18	.429	.7281
Yellow bullhead	.000	17	.41	.000	16	.385	.9429
Miscellaneous*	.003	18	.43	.000	35	.843	1.9444
Total	**.603**	**20717**	**499.19**	**.166**	**5164**	**124.424**	**.2492**
Harvested							
Black bullhead	.000	9	.23	.000	14	.328	1.4452
Black crappie	.068	2713	65.39	.017	679	16.368	.2503
Bluegill	.213	6672	160.77	.051	1455	35.072	.2182
Channel catfish	.013	561	13.53	.019	709	17.077	1.2627
Green sunfish	Not recorded						
Largemouth bass	.002	88	2.13	.004	194	4.682	2.2048
Northern pike	.000	23	.57	.000	113	2.713	4.7906
Rainbow trout	.000	5	.13	.000	6	.135	1.0312
Rock bass	.000	47	1.13	.000	8	.197	.1741
Smallmouth bass	Not recorded						
Walleye	.000	8	.19	.000	17	.412	2.1487
Warmouth	.003	126	3.03	.000	26	.618	.2039
White crappie	.003	152	3.65	.000	33	.805	.2206
Yellow bullhead	.000	12	.29	.000	9	.217	.7540
Miscellaneous*	.000	1	.02	.000	0	.000	.000
Total	**.302**	**10417**	**251.02**	**.094**	**3263**	**78.626**	**.3132**

Note:
* Gizzard shad, carp

In addition, the lake trophic state index (TSI) developed by Carlson (1977) on the basis of Secchi disc transparency, chlorophyll *a*, and surface water total phosphorus can be used to calculate a lake's trophic state. The TSI can be calculated from Secchi disc transparency (SD) in meters (m), chlorophyll *a* (CHL) in ug/L, and total phosphorus (TP) in ug/L as follows:

on the basis of SD, $TSI = 60 - 14.4 \ln (SD)$ (1)

on the basis of CHL, $TSI = 9.81 \ln (CHL) + 30.6$ (2)

on the basis of TP, $TSI = 14.42 \ln (TP) + 4.15$ (3)

The index is based on the amount of algal biomass in surface water, using a scale of 0 to 100. Each increment of ten in the TSI represents a theoretical doubling of biomass in the lake. The advantages and disadvantages of using the TSI were discussed by Hudson *et al.* (1992). The accuracy of Carlson's index is often diminished by water coloration or suspended solids other than algae. Applying TSI classification to lakes that are dominated by rooted aquatic plants may indicate less eutrophication than actually exists.

The values of TSI for Lake Le-Aqua-Na at station 1S were calculated using the three formulas for each basin, based on Secchi disc transparency, TP, and chlorophyll *a* concentrations of each sample. The average and range of TSI values, and trophic state are listed in table 28. The trophic state of a lake can be categorized using TSI values and the information provided in table 29.

Lakes are generally classified by limnologists into three trophic states: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are known for their clean and cold waters and lack of aquatic weeds or algae, due to low nutrient levels. There are few oligotrophic lakes in the Midwest. At the other extreme, eutrophic lakes are high in nutrient levels and are likely to be very productive in terms of weed growth and algal blooms. Eutrophic lakes can support large fish populations, but the fish tend to be rougher species that can better tolerate depleted levels of DO. Mesotrophic lakes are in an intermediate stage between oligotrophic and eutrophic.

The great majority of Midwestern lakes are eutrophic. A hypereutrophic lake is one that has undergone extreme eutrophication to the point of having developed undesirable aesthetic qualities (e.g., odors, algal mats, and fish kills) and water-use limitations (e.g., extremely dense growths of vegetation). The natural aging process causes all lakes to progress to the eutrophic condition over time, but this eutrophication process can be accelerated by certain land uses in the contributing watershed (e.g., agricultural activities, application of lawn fertilizers, and erosion from construction sites). Given enough time, a lake will grow shallower and will eventually fill in with trapped sediments and decayed organic matter, such that it becomes a shallow marsh or emergent wetland.

The TSI values were evaluated only for station 1S data using a conventional method. The calculated mean TSI values shown in table 28 are almost identical for annual and summer means based on three water quality parameters. The mean TP-TSI was the highest; while the mean SD-TSI levels were essentially the same as the CHL-TSI means. Overall annual means for SD-TSI, TP-TSI, and CHL-TSI were, respectively, 62, 73, and 62. Overall summer means were almost identical to annual means. The trophic state of the lake can be classified as eutrophic, hypereutrophic, and eutrophic based on these three parameters, respectively. Thus the average of mean SD-TSI, TP-TSI, and CHL-TSI was 65.6, which leads to the conclusion that the lake is still eutrophic.

When considering the results of TSI calculations, one should keep in mind the assumptions on which the Carlson formulae are based: 1) Secchi disc transparency is a function

Table 28. Trophic State Index of Lake Le-Aqua-Na at Station 1

	Secchi disc			*Total phosphorus*			*Chlorophyll a*		
Year	*Mean*	*Range*	*N**	*Mean*	*Range*	*N*	*Mean*	*Range*	*N*
Annual									
1981	60.0	37-87	16	73.8	61-92	17	64.6	37-75	10
1984	62.8	40-83	26	74.3	67-84	14	68.9	40-84	14
1985	66.1	57-70	27	80.3	63-96	16	59.7	8-78	16
1986	60.8	47-93	16	72.7	57-94	16	58.5	34-75	16
1992	62.5	48-78	18	63.1	55-71	14	60.6	36-71	8
1993	60.7	44-87	19	72.0	61-89	8	61.4	45-82	8
1994	50.8	39-56	8	67.2	47-99	8	64.7	44-86	6
Total	**62.0**	37-93	130	72.5	47-99	93	**62.4**	8-86	78
	Eutrophic			**Hypereutrophic**			**Eutrophic**		
Summer									
1981	63.5	42-87	11	74.2	63-92	11	64.6	37-75	10
1984	62.2	40-80	23	73.1	67-84	11	72.0	53-84	11
1985	66.4	57-70	21	82.0	63-96	11	64.0	50-78	11
1986	62.8	47-93	11	74.2	58-94	14	61.5	48-75	11
1992	63.4	50-78	14	64.4	57-71	12	59.6	36-71	6
1993	61.5	44-87	17	73.8	61-89	6	60.8	55-67	6
1994	54.9	39-56	6	62.0	47-73	4	63.3	44-86	4
Total	**62.9**	39-93	103	**72.8**	47-96	66	**64.3**	36-86	59
	Eutrophic			**Hypereutrophic**			**Eutrophic**		

Note:
* N is Number of observations.

Table 29. Quantitative Definition of Lake Trophic State

Trophic state	*Secchi disc transparency* *inches*	*meters*	*Chlorophyll a, µg/L*	*Total phosphorus, lake surface, µg/L*	757
Oligotrophic	>157	>4.0	<2.6	<12	<40
Mesotrophic	79-157	2.0-4.0	2.6-7.2	12-24	40-50
Eutrophic	20-79	0.5-2.0	7.2-55.5	24-96	50-70
Hypereutrophic	<20	<0.5	>55.5	>96	>70

of phytoplankton biomass; 2) phosphorus is the factor limiting algal growth; and 3) TP concentration is directly correlated with algal biomass. These assumptions will not necessarily hold where suspended solids other than algal biomass are a major source of turbidity; where short retention times prohibit a large algal standing crop from developing; or where grazing by zooplankton affects algal populations.

Lake-Use Support Analysis

Definition

An analysis of Lake Le-Aqua-Na's use support was carried out employing a methodology developed by the IEPA (1994). The degree of use support identified for each designated use indicates the ability of the lake to: 1) support a variety of high quality recreational activities, such as boating, sport fishing, swimming, and aesthetic enjoyment; 2) support healthy aquatic life and sport fish populations; and 3) provide adequate, long-term quality and quantity of water for public or industrial water supply (if applicable). Determination of a lake's use support is based upon the state's water quality standards as described in Subtitle C of Title 35 of the State of Illinois Administrative Code (IEPA, 1990a). Each of four established use designation categories (including General Use, Public and Food Processing Water Supply, Lake Michigan, and Secondary Contact and Indigenous Aquatic Life) has a specific set of water quality standards.

For the lake uses assessed in this report, the General Use standards - primarily the 0.05 mg/L TP standard - were used. The TP standard has been established for the protection of aquatic life, primary-contact (e.g., swimming) and secondary-contact (e.g., boating) recreation, agriculture, and industrial uses. In addition, lake-use support is based in part on the amount of sediment, macrophytes, and algae in the lake and how these might impair designated lake uses. The following is a summary of the various classifications of use impairment:

Full = full support of designated uses, with minimal impairment

Full/threatened = full support of designated uses, with indications of declining water quality or evidence of existing use impairment

Partial/minor = partial support of designated uses, with slight impairment

Partial/moderate = partial support of designated uses, with moderate impairment

Nonsupport = no support of designated uses, with severe impairment

A lake that fully supports designated uses may still exhibit some impairment, or have slight to moderate amounts of sediment, macrophytes, or algae in a portion of the lake (e.g., headwaters or shoreline); however, most of the lake acreage should show minimal impairment of the aquatic community and uses. *It is important to emphasize that if a lake is rated as not fully supporting designated uses, it does not necessarily mean that the lake cannot be used for those purposes or that a health hazard exists.* Rather, it indicates impairment in the ability of significant portions of the lake waters to support either a variety of quality recreational experiences or a balanced sport fishery. Since most lakes are multiple-use water bodies, a lake can fully support one designated use (e.g., aquatic life) but exhibit impairment of another (e.g., swimming).

Lakes that partially support designated uses have a designated use that is slightly to moderately impaired in a portion of the lake (e.g., swimming impaired by excessive aquatic macrophytes or algae, or boating impaired by sediment accumulation). So-called nonsupport lakes have a designated use that is severely impaired in a substantial portion of the lake (e.g., a large portion of the lake has so much sediment that boat ramps are virtually inaccessible, boating is nearly impossible, and fisheries are degraded). However, in other parts of the same nonsupport lake (e.g., near a dam), the identical use may be supported. *Again, nonsupport does not necessarily mean that a lake cannot support any uses, that it is a public health hazard, or that its use is prohibited.*

Lake-use support and level of attainment were determined for aquatic life, recreation, swimming, and overall lake use, using methodologies described in the IEPA's *Illinois Water Quality Report 1992-1993* (IEPA, 1994).

The primary criterion in the aquatic life use assessment is an Aquatic Life Use Impairment Index (ALI); while in the recreation use assessment the primary criterion is a Recreation Use Impairment Index (RUI). While both indices combine ratings for TSI (Carlson, 1977) and degree of use impairment from sediment and aquatic macrophytes, each index is specifically designed for the assessed use. ALI and RUI relate directly to the TP standard of 0.05 mg/L. If a lake water sample is found to have a TP concentration at or below the standard, the lake is given a "full support" designation. The aquatic life use rating reflects the degree of attainment of the "fishable goal" of the Clean Water Act; whereas the recreation use rating reflects the degree to which pleasure boating, canoeing, and aesthetic enjoyment may be obtained at an individual lake.

The assessment of swimming use for primary-contact recreation was based on available data using two criteria: 1) Secchi disc transparency depth data and 2) Carlson's TSI. The swimming use rating reflects the degree of attainment of the "swimmable goal" of the Clean Water Act. If a lake is rated "nonsupport" for swimming, it does not mean that the lake cannot be used or that health hazards exist. It indicates that swimming may be less desirable than at those lakes assessed as fully or partially supporting swimming.

Finally, in addition to assessing individual aquatic life, recreation, and swimming uses, the overall use support of the lake was assessed. The overall use support methodology aggregates the use support attained for each of the individual lake uses assessed. Values assigned to each use-support attainment category are summed and averaged, and then used to assign an overall lake-use attainment value for the lake.

Lake Le-Aqua-Na Use Support

Support of designated uses in Lake Le-Aqua-Na was determined based on Illinois' lake-use support assessment criteria. Table 30 presents basic information along with assessed lake-use support information. Water quality data collected at station 1S during 1992, 1993, and 1994 were used for lake-use support analyses. Mean TSI was determined by averaging of all three-year SD-TSI, TP-TSS, and CHL-TSI values, for a value of 62.3. The mean of nonvolatile suspended solids concentrations observed during 1992-1994 at station 1S is 5.2 mg/L. As shown in table 30, aquatic life use, recreation use, and swimming use in the lake are assessed as full/threatened, partial/moderate, and partial/minor, respectively. The overall use support of the lake is 3.0; hence the lake can be classified as providing a partial/minor degree of use support.

Lake Budgets

Hydraulic Budget

A water budget was developed taking into account the measured inflow into the lake from Waddams Creek, extrapolated flow to account for the ungaged tributaries to the lake, outflow from the lake, direct precipitation on the lake, and lake evaporation.

Table 30. Assessment of Use Support in Lake Le-Aqua-Na

	Value	*All points*
I. Aquatic life use		
1. Mean trophic state index	62.3	50
2. Macrophyte impairment	20-25%	0
3. Mean nonvolatile suspended solids	5.2 mg/L	0
Total points:		50
Criteria points:		<75
Use Support:		**Full/Threatened**
	Value	*RUI points*
II. Recreation use		
1. Mean trophic state index	62.3	62
2. Macrophyte impairment	20-25%	10
3. Mean nonvolatile suspended solids	5.2 mg/L	5
Total points:		80
Criteria points:		75<RU1<90
Use Support:		**Partial/Moderate**
	Value	*Degree of use support*
III. Swimming use		
1. Secchi depth < 24 inches	0%	Partial/Minor
2. Fecal coliform > 200/100 mL	not available	
3. Mean trophic state index	62.3	Partial/Minor
Use Support:		**Partial/Minor**
IV. Overall use	**3.0**	
Use Support:		**Partial/Minor**

Note:
ALI is aquatic life use impairment index and
RUI is recreation use impairment index.

The general expression for the hydraulic budget of a lake is:

$$\Delta S = P + I + U - E - 0$$

where

ΔS = change in storage
P = precipitation on the lake surface
I = inflow from surface streams
U = subsurface inflow through the lake bottom
E = evaporation
O = outflow through surface outlets

Streamflows and precipitation values for Lake Le-Aqua-Na were obtained from actual field determinations and observations, and evaporation losses were calculated on the basis of values suggested by Roberts and Stall (1967). Table 31 gives the lake's water budget, showing the monthly values for inflows (Waddams Creek, total watershed, and precipitation on the lake) and outflows (Waddams Creek and evaporation), all expressed in cfs in this investigation. The inflow-outflow information is not provided for the months of January and February due to frozen conditions in the tributaries.

Waddams Creek inflow into the lake and the outflow from the impoundment were averaged monthly from flow values obtained from daily observations of staff gages. Stage-discharge relationships for Waddams Creek, upstream and downstream of the impoundment, were developed covering a wide range of flow conditions, from baseflow to the maximum observed flood conditions. Almost all of the storm events were gaged and water samples collected. A factor of 1.23 was used to estimate and account for the ungaged stream inputs to the lake. The last column in table 31 shows the inflow minus outflow. Month-to-month changes in lake storage were considered insignificant.

1993 was extremely wet compared to 1992 and 1994. Annual total precipitation was 34.61, 43.66, and 32.84 inches, respectively, for 1992, 1993, and 1994. Outflow exceeded inflow during six of the eight months in 1992. The annual average ground-water input was 0.39 cfs in 1992. After heavy rainfall in June 1993 (11.68 inches), inflows to the lake exceeded outflows from July 1993 onwards for the rest of the investigation. The lake recharged the ground-water resources during this period.

Estimated hydraulic retention times in the lake for 1992 to 1994 were, respectively, 100.99, 31.97, and 79.43 days. Table 32 shows these values and other relevant details such as total annual inflow and the number of lake volume displacements per year. It should be pointed out here that the tributary inflows and precipitation for the period March through December were used in these computations. IEPA reported hydraulic retention times of 58.52, 65.22, 93.23, and 38.34 days, respectively, for 1981, 1984, 1985, and 1986. These values are in the same range of values computed for the current investigation.

Nutrient Budget

Although nitrogen and phosphorus are not the only nutrients required for algal growth, they are generally considered to be the two main nutrients involved in lake eutrophication. Despite the controversy over the role of carbon as a limiting nutrient, the vast majority of researchers regard phosphorus as the most frequently limiting nutrient in lakes.

Table 31. Monthly and Annual Hydraulic Budgets for Lake Le-Aqua-Na for the Period 1992 - 1994

		Inflows, cfs			*Outflows, cfs*		
Month	*Rainfall, inches*	*Waddams Creek*	*Watershed*	*Precip. on lake*	*Waddams Creek*	*Evaporation*	*Inflow minus outflow, cfs*
4/92	4.97	3.11	3.83	0.30	4.66	0.16	-0.69
5/92	0.56	0.65	0.80	0.03	1.66	0.23	-1.06
6/92	1.52	0.10	0.12	0.09	0.60	0.27	-0.66
7/92	7.18	0.93	1.14	0.44	0.87	0.33	0.38
8/92	2.04	0.24	0.30	0.12	0.54	0.26	-0.38
9/92	4.62	1.38	1.70	0.28	0.99	0.19	0.8
10/92	1.02	0.00	0.00	0.06	1.64	0.12	-1.70
11/92	5.75	4.16	5.12	0.35	6.40	0.05	-0.98
12/92	0.57	4.57	5.62	0.03	4.85	0.02	0.78
Mean		1.68	2.07	0.19	2.47	0.17	-0.39
3/93	0.63	8.58	10.55	0.04	4.63	0.10	5.86
4/93	4.29	6.73	8.30	0.26	9.27	0.16	-0.87
5/93	4.24	2.59	3.19	0.26	3.09	0.23	0.13
6/93	11.68	9.64	11.86	0.71	13.54	0.27	-1.24
7/93	3.72	8.01	9.85	0.23	6.82	0.33	2.93
8/93	3.75	3.85	4.74	0.23	0.63	0.26	4.08
9/93	5.27	5.09	6.26	0.32	1.66	0.19	4.73
10/93	0.40	3.53	4.34	0.02	2.25	0.12	1.99
11/93	1.26	3.68	4.53	0.08	1.78	0.05	2.78
12/93	0.69	4.89	6.01	0.04	2.76	0.02	3.27
Mean		5.70	6.96	0.22	4.64	0.17	2.37
3/94	0.81	5.53	6.80	0.05	3.03	0.10	3.72
4/94	1.07	2.12	2.61	0.07	1.18	0.16	1.34
5/94	0.96	1.38	1.70	0.06	0.69	0.23	0.84
6/94	6.08	1.24	1.53	0.37	0.67	0.27	0.96
7/94	3.32	1.41	1.73	0.20	0.63	0.33	0.97
8/94	4.77	0.64	0.79	0.29	0.12	0.26	0.70
9/94	4.27	1.04	1.28	0.26	0.84	0.19	0.51
10/94	0.48	1.70	2.09	0.03	1.16	0.12	0.84
11/94	3.70	3.79	4.66	0.22	3.04	0.05	1.79
12/94	0.18	3.16	3.89	0.01	2.52	0.02	1.36
Mean		2.20	2.71	0.16	1.39	0.17	1.30

Table 32. Hydraulic Retention Times for Lake Le-Aqua-Na

Year	*Total annual inflows. acre-feet*	*Number of lake volumes displaced*	*Retention time, days*
1992	1367.21	3.02	100.99
1993	4343.61	9.60	31.77
1994	1736.23	3.84	79.43

Note: Only the period March through December is considered for each year.

Several factors have complicated attempts to quantify the relationship between lake trophic status and measured concentrations of nutrients in lake waters. For example, measured inorganic nutrient concentrations do not denote nutrient availability, but merely represent what is left over by the lake production process. A certain fraction of the nutrients (particularly phosphorus) becomes refractory while passing through successive biological cycles. In addition, numerous morphometric and chemical factors affect the availability of nutrients in lakes. Factors such as mean depth, basin shape, and detention time affect the amount of nutrients a lake can absorb without creating nuisance conditions. Nutrient budget calculations represent the first step in quantifying the dependence of lake water quality on the nutrient supply. It is often essential to quantify nutrients from various sources for effective management and eutrophication control.

A potential source of nitrogen and phosphorus for lakes is watershed drainage, which can include agricultural runoff, urban runoff, swamp and forest runoff, domestic and industrial waste discharges, septic tank discharges from lakeshore developments, precipitation on the lake surface, dry fallout (i.e., leaves, dust, seeds, and pollen), ground-water influxes, nitrogen fixation, sediment recycling, and aquatic bird and animal wastes. Potential sinks can include outlet losses, fish catches, aquatic plant removal, denitrification, ground-water recharge, and sediment losses.

The sources of nutrients considered for Lake Le-Aqua-Na were tributary inputs from both gaged and ungaged streams, direct precipitation on the lake surface, and internal nutrient recycling from bottom sediments under anaerobic conditions. The discharge of nutrients from the lake through Waddams Creek was the only readily quantifiable sink.

The flow weighted-average method of computing nutrient transport by the tributary was used in estimating the suspended sediments, phosphorus, and nitrogen loads delivered by Waddams Creek during normal flow conditions. Each individual measurement of nitrogen and phosphorus concentrations in a tributary sample was used with the mean flow values for the period represented by that sample to compute the nutrient transport for the given period. The total amount of any specific nutrient transported by the creek is given by the expression:

$$T = 2.446 \sum q_i \; c_i, \quad n_i$$

where

T = total amount of nutrient (nitrogen or phosphorus) in kg
q_i = average daily flow in cfs for the period represented by the ith sample
c_i = concentration of nutrient in mg/L
n_i = number of days in the period represented by the ith sample

A similar algorithm with appropriate constant (0.0255) was used for determining the sediment and nutrient transport during storm events. For each storm event, n_i is the interval of time represented by the ith sample, and q_i is the instantaneous flow in cfs for the period represented by the ith sample. The summation was carried out for all the samples collected in Waddams Creek during each storm event. There was one major storm event in 1992; 20 separate major storm events in 1993; and one in 1994.

Table 33 shows the water quality characteristics of Waddams Creek samples taken with an automatic sampler during the storm event that began at 0049 on April 15, 1993, and at 0253 on April 16, 1993. Generally, the concentrations of TSS, VSS, TP, etc., increased with time (during the rising portion of the hydrograph) and then decreased with the falling hydrograph. Table 34 gives the nutrient and sediment loads transported by Waddams Creek during the major storm events for the period of investigation. The automatic sampler was set to initiate sampling when

Table 33. Water Quality of Storm Event Samples, 4/15/93 - 4/16/93

Parameters	Time										
	0049	*0103*	*0118*	*0148*	*0427*	*0735*	*1011*	*1354*	*1640*	*2101*	*0253*
Ammonia-N	0.07	0.11	0.16	0.29	0.20	0.13	2.10	0.11	0.11	0.23	0.05
Nitrate + Nitrite-N	2.80	2.70	2.60	2.60	2.60	2.60	3.00	3.40	3.60	4.50	5.40
Kjeldahl-N	1.80	1.79	1.79	1.76	1.75	1.71	2.63	1.61	1.41	1.07	0.70
Total Phosphorus-P	0.440	0.463	0.555	0.738	0.723	0.797	0.615	0.586	0.525	0.357	0.18
TSS	328	582	502	602	510	573	414	480	246	252	21
VSS	34	64	34	60	52	52	41	46	26	28	3

Note: All parameters expressed in mg/L.

Table 34. Nutrients and Sediments Transported by Waddams Creek during Storms

Date	*Ammonia*	*Nitrate*	*Total Kjeldahl nitrogen*	*Total phosphorus*	*Total suspended sediments*
11/24/92	12	429	209	72	49,789
3/24/93	106	119	249	81	51479
3/26/93	90	77	407	107	57706
4/09/93	7	155	49	12	6080
4/16/93	31	290	129	45	30534
4/20/93	15	502	400	356	83447
6/08/93	43	795	604	123	94078
6/09/93	1	29	4	1	652
6/14/93	23	234	403	88	19948
6/18/93	25	170	560	148	34356
6/20/93	15	238	178	34	31910
6/25/93	15	178	337	99	66902
6/28/93	11	254	157	64	38492
6/30/93	34	160	260	117	155394
7/06/93	18	130	52	122	97959
7/08/93	7	98	248	64	61971
7/09/93	2	62	60	22	19376
7/11/93	4	77	97	24	17746
7/13/93	3	57	16	8	2949
10/05/93	9	361	177	52	32812
9/30/94	2	103	161	45	26826

Note: All parameters expressed in kg.

the staff gage reached a reading of 1.7 feet. A gage reading of 1.0 represented no flow conditions.

Nutrient and sediment loads conveyed through Waddams Creek for 1981, 1985, 1986, and 1992 to 1994 are shown in table 35. The loads for normal flow conditions, storm flow conditions, and total loads are given separately. As pointed out by IEPA (1990b), TSS inputs from the watershed were substantially reduced in 1985 and 1986 compared to 1981. This is still the case for 1992 to 1994. In spite of the fact that the total rainfall in 1993 (43.66 inches) was much above average, the suspended solids load in 1993 was only 15 percent of the pre-watershed management period. The rainfall in 1981 was only 29.5 inches, much below the long-term average for the area.

From the data gathered, it is apparent that the sediment transport from the watershed decreased substantially from 1981 to 1986, and continued to decrease thereafter. Also, with respect to phosphorus, which has a high degree of affinity to soil particles, phosphorus loading to the lake decreased substantially after 1985. Both these aspects reinforce the positive impact of integrated lake and watershed management on the lake's water quality. The nitrate loading to the lake increased from 1981 to 1986 and then showed a decreasing trend in 1992 and 1994 with the exception for the year 1993. The excessive nitrate loading to the lake in 1993 was due to the above normal precipitation and runoff events. The proportion of TKN in the total nitrogen loading decreased significantly since 1985 compared to 1981 reflecting the influence of increased subsurface flow due to the watershed management.

The nutrient and sediment budgets for the lake for 1981, 1985, 1986, 1992, 1993, and 1994 are shown in table 36, which lists total inflow, outflow, and net loading in the lake for total inorganic nitrogen, total nitrogen, TP, and TSS. As discussed earlier, TSS and TP loading to the lake decreased significantly after the completion of watershed treatments in 1985.

Outflows of TSS and TP from the lake during 1993 were particularly noteworthy. Suspended sediment and phosphorus concentrations in Waddams Creek downstream of the lake were much higher in 1993 than in other years, primarily due to the above average precipitation and incessant rains during the spring and early summer. One may recall that several Midwestern rivers experienced once-in-500-year floods that year. The sediment and phosphorous outflows from the lake were 1 to 3 orders of magnitude higher. An interesting and unusual phenomenon in 1993 was that the lake was a source of phosphorus instead of a sink for Waddams Creek. The net phosphorus loading to the lake was negative 15,053 kg.

Net loadings of inorganic nitrogen and total nitrogen in 1993 were higher compared to all years other than 1981. The net nitrogen loadings in 1981 (pre-watershed management period) were much higher than even the loadings observed in 1993. This was also true with respect to TP and TSS.

Illinois EPA (1990b) reported, based on its post-implementation monitoring in 1986, that the total nitrogen delivery to the lake from the watershed was not affected by the implementation of the watershed practices. Reduction in net loading in total nitrogen during 1986 was attributable to the significant decrease in the release of nitrogenous compounds from the lake bottom sediments during summer months. However, during this investigation, the watershed deliveries of total nitrogen were significantly lower compared to that in 1981 (table 36) and the net nitrogen loadings were all smaller than that in 1981. Because of much above average rainfall during 1993, the watershed delivery of total nitrogen was higher than that in 1981. For the same reason, Waddams Creek outflow of total nitrogen was also higher. The net loadings of total nitrogen were all much smaller during 1992-1994 than in 1981. They were respectively, 35, 60, and 18 percent of those in 1981.

Table 35. Nutrient and Sediment Loads Delivered through Waddams Creek during Storm Flows and Normal Flows

	1981			*1985*			*1986*		
Parameters	*Normal*	*Storms*	*Total*	*Normal*	*Storms*	*Total*	*Normal*	*Storms*	*Total*
Ammonia	122	2053	2175	191	1102	1293	67	398	465
Nitrate	5763	5761	11523	12558	4925	17483	19437	6684	26131
TKN	834	17609	18444	930	6941	7871	741	4225	4966
TP	187	7739	7927	278	1415	1693	261	819	1080
TSS	9396	6363652	6373048	17565	2027377	2044942	9114	707706	716820

	1992			*1993*			*1994*		
Parameters	*Normal*	*Storms*	*Total*	*Normal*	*Storms*	*Total*	*Normal*	*Storms*	*Total*
Ammonia	218	12	240	2530	459	2989	268	2	270
Nitrate	12679	429	13108	23242	3986	27228	7134	102	7237
TKN	1857	209	2066	4425	4387	8812	671	161	832
TP	266	72	338	483	1567	2050	158	45	203
TSS	34057	49789	83846	65024	903791	968815	4628	26826	31454

Note: All parameters expressed in kg.

Table 36. Nutrient and Sediment Budgets for Lake Le-Aqua-Na

	Inorganic nitrogen	*Total nitrogen*	*Total phosphorus*	*Total suspended sediments*
1981				
Watershed inputs	16848	36859	9749	7838848
Internal regeneration	19381	19382	2128	-
Precipitation on lake	89	89	0	-
Gross loading	36319	56330	11878	7838848
Waddams Creek outflow	5338	8216	573	30049
Net loading	30981	48114	11305	7808799
1985				
Watershed inputs	23094	31185	2082	2515278
Internal regeneration	10277	10277	1445	-
Precipitation on lake	-	57	0	-
Gross loading	33429	41520	3528	2515278
Waddams Creek outflow	10197	13736	1240	89406
Net loading	23232	27784	2288	2425872
1986				
Watershed inputs	32713	38250	1328	881689
Internal regeneration	0	0	675	-
Precipitation on lake	27	28	0	-
Gross loading	32740	38278	2008	881689
Waddams Creek outflow	13956	16292	545	17093
Net loading	18784	21986	1458	864596

Note: Watershed inputs are derived by extrapolating Waddams Creek inputs by a factor of 1.23.
All parameters expressed in kg.

Table 36. Concluded

	Inorganic nitrogen	*Total nitrogen*	*Total phosphorus*	*Total suspended sediments*
1992				
Watershed inputs	16418	18664	416	103131
Internal regeneration	5139	5139	723	-
Precipitation on lake	184	335	20	-
Gross loading	21741	24138	1159	103131
Waddams Creek outflow	6624	7360	174	23717
Net loading	15117	16778	985	79414
1993				
Watershed inputs	37166	44329	2522	1191642
Internal regeneration	0	0	0	-
Precipitation on lake	232	423	25	-
Gross loading	37398	44752	2547	1191642
Waddams Creek outflow	11596	15650	17600	268968
Net loading	25802	29102	-15053	922674
1994				
Watershed inputs	9234	9925	250	38688
Internal regeneration	2570	2570	362	-
Precipitation lake	174	318	19	-
Gross loading	11978	12813	631	38688
Waddams Creek outflow	2707	3921	392	15547
Net loading	9271	8892	239	23141

Note: Watershed inputs are derived by extrapolating Waddams Creek inputs by a factor of 1.23
All parameters expressed in kg.

In summary, the watershed treatments implemented for Lake Le-Aqua-Na were found to be effective in reducing the amount of sediment and phosphorus entering the lake. The treatments still appear to be effective ten years after the management program was initiated and implemented.

Lake Le-Aqua-Na Watershed

The Lake Le-Aqua-Na watershed encompasses an area of approximately 3.7 square miles in northwestern Stephenson County, Illinois. Lake Le-Aqua-Na itself (43.4 acres, 1.8 percent of the watershed) is located at the southeast end of the watershed.

Land use in the watershed is primarily cropland (1,570 acres, 67 percent), with areas of woodland (415 acres, 18 percent) and grassland (183 acres, 8 percent) on the floodplain and sloping area along drainage ways (Lake Le-Aqua-Na Planning Committee, 1990). The predominant crop rotations in the watershed are continuous corn, corn-soybeans, and corn-corn-oats-meadow-meadow. The average farm size is approximately 250 acres. Total erosion in the watershed is estimated by the Universal Soil Loss Equation to be 9,900 tons per year. Average sheet and rill erosion is estimated to be 4.2 tons per acre per year (ibid.). The calculated annual amount of sediment eroded within the watershed is 7,710 tons, while approximately 2,200 tons are annually delivered to Lake Le-Aqua-Na.

In order to reduce nutrients and sediment loads to the lake and to improve lake water quality for recreational uses, the Lake Le-Aqua-Na Planning Committee and federal and state agencies implemented watershed protection measures during the 1980s.

Figure 3 shows the type and location of watershed protection work. Detailed summaries of the activities can be found in the Lake Le-Aqua-Na Resource Plan (ibid.) and in the Phase II project report (IEPA, 1990b).

The majority of land in the watershed is protected by best management practices low in cost to the farmer. These practices include contour strip cropping (corn or soybeans alternated with closely seeded crops such as oats or alfalfa), contour planting, residue management (reduced tillage or no till), crop rotation, and enrollment in the Conservation Reserve Program. Most of the upper parts of the watershed are protected by these practices.

Mechanical practices were implemented in areas with high rates of sediment delivery to the stream or lake. Mechanical sediment control measures used in these critical areas include terraces, grass waterways, water and sediment control basins, and streambank stabilization. Cultural practices (above) were usually combined with the more expensive terraces and waterways, so most fields have several soil conservation practices in effect at the same time.

Riprap and rock filled gabions were used to stabilize sections of the Waddams Creek streambanks within the park boundaries (figure 23a) and on private lands (figure 23b). Livestock exclusion fences (figure 23 c) were constructed in areas 4 and 6 (figure 3) in order to keep cattle off of the fragile streambanks and to keep nutrients from entering the stream.

Several tributaries on the park property formed gullies that delivered large amounts of sediment directly to the lake. Terraces, sediment basins, and dry dams were constructed to minimize the sediment delivered from those sources. Selected stretches of lakeshore were also treated with riprap.

A post-restoration inspection of some of the best management practices used in the watershed was made by ISWS personnel and Mr. Jim Ritterbusch, District Conservationist, SCS, Stephenson County, in April 1993. The inspection showed that most of the practices were still in

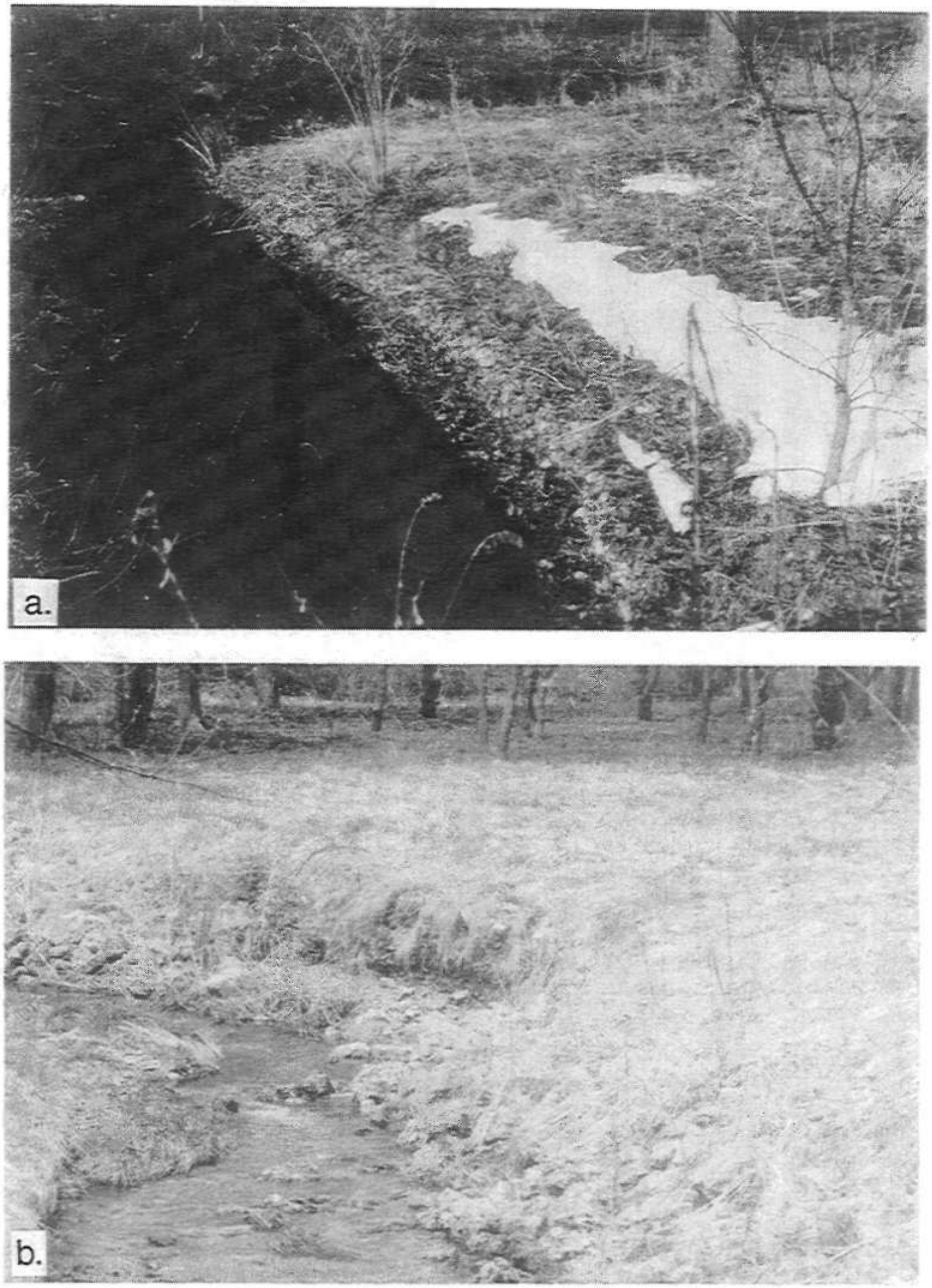
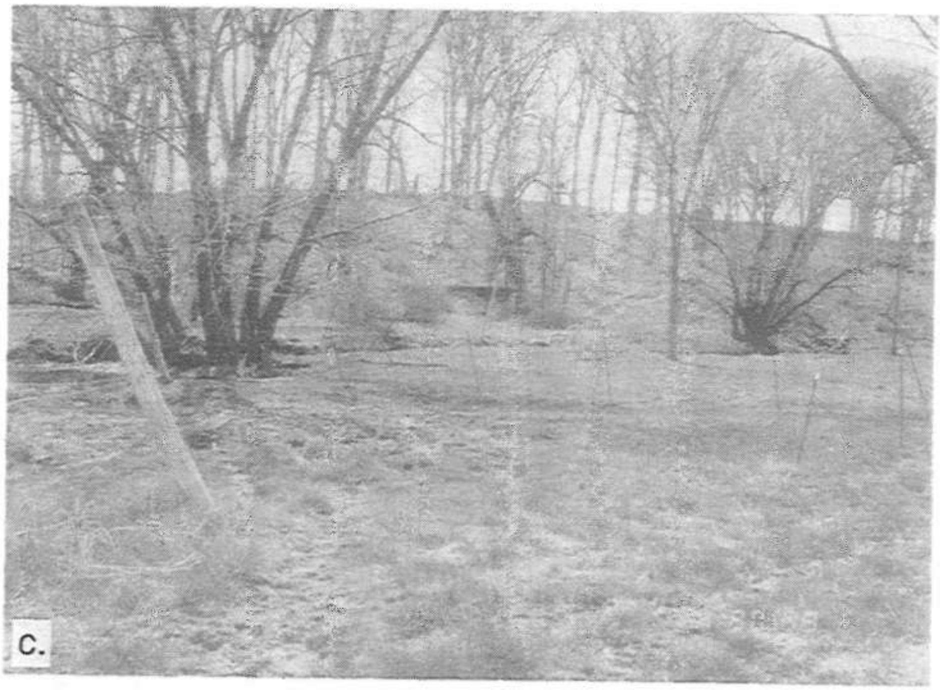


Figure 23. Current status of Lake Le-Aqua-Na watershed treatments



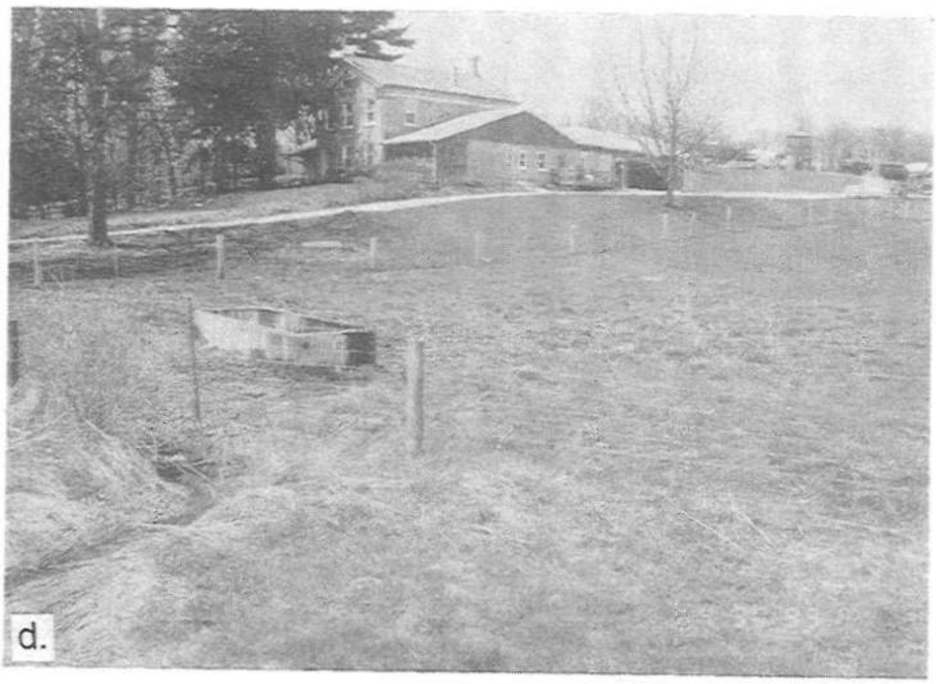


Figure 23. Continued

Figure 23. Continued

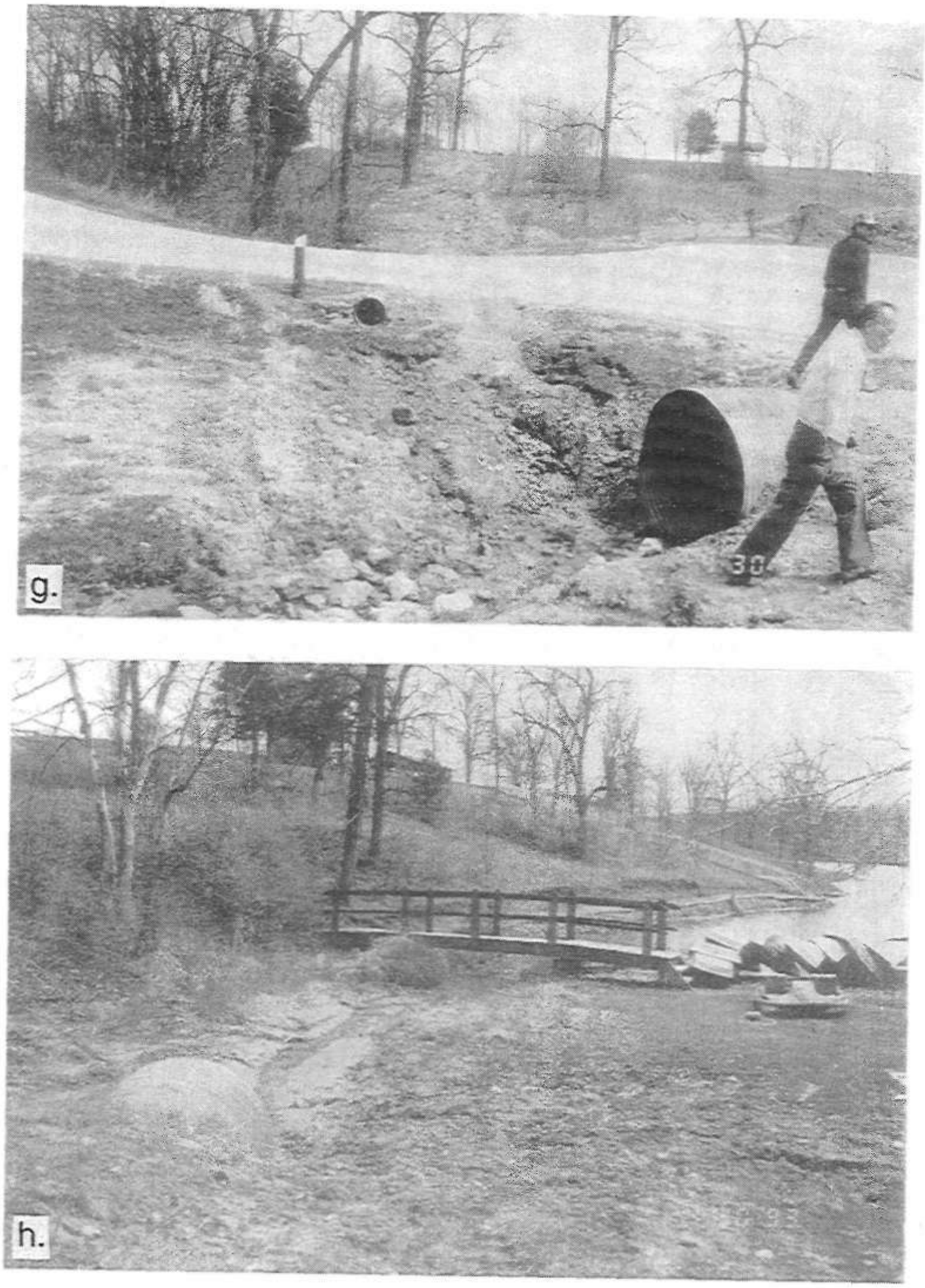


Figure 23. Concluded

place and functioning as designed, but some areas required maintenance, and some new problem areas had appeared.

Cost sharing for residue management, which began in 1983, was phased out over three years. At the beginning of the program, one landowner practiced no-till farming, while the target percent residues for most of the remaining farms were 20 to 30 percent. By 1993, no farms practiced strictly no-till farming, but almost all of the fields in the watershed retained residue levels of 40 percent or more. The overall shift to higher residue levels yields in calculated field soil loss rates that are both lower than during the cost-share program and within tolerable limits.

The effect of livestock on Waddams Creek was lessened when the only dairy operation in the watershed was closed. The dairy herd was sold, and now the landowner raises approximately 100 head of Scimitar cattle, which are usually pastured in fields away from the stream. When the dairy was operational, the herd was generally confined to a small area near the main barn, which intensified the physical and water quality degradation of the stream (J. Ritterbusch, personal communication, 1995).

Despite high maintenance requirements, the livestock exclusion fencing was still in place and in good condition during the spring of 1992. With the fencing in place, the only stretch of stream in the exclusion area that showed physical degradation due to livestock was at the cattle crossing. The cattle crossing was included in the design in order to allow access to a pasture on the south side of the stream.

Additionally, a landowner-designed spring development for watering the cattle was constructed across the road from the crossing (figure 23d). The development differs from an SCS design in that it lacks a concrete pad and the water outlet was not tiled. The lack of a concrete pad, coupled with overland flow from the spring-fed tank, results in a steady input of nutrients and soil particles to the stream.

A small number of cattle were pastured upstream of the exclusion area by another landowner, but the physical effects appeared to be limited to minor streambank erosion. Other areas which were no longer used for pasture appeared to be more stable.

The extremely heavy and frequent rains, along with the resulting high streamflows, during 1993 caused new problem areas to form and damaged some of the sediment control structures. Many of these problem areas delivered sediment directly to the creek or lake, so they were critical sites with respect to lake water quality and sedimentation.

A gabion flow control structure was built across Waddams Creek on the park grounds (figure 23e) to create an instream sediment basin. The extremely high streamflows in 1993 caused scour to occur along the sides of the structure. During some of the peak flows, the stream exceeded its banks. Part of the flow then followed an auxiliary channel to the south of Waddams Creek, reentering the main stem approximately 200 feet downstream of the sampling bridge. Severe scour occurred where the flow entered the auxiliary channel. With continued scouring, the bank could erode to the point where the entire streamflow, both during storms and baseflow, could be captured by the auxiliary channel.

The high volumes of water also caused a small breach at the culvert of the water and sediment detention structure on the northwest end of the lake. Minor scouring occurred around the pilings of the sampling bridge (station EPA02) at the playground.

Outside of the park, the roadside ditches along Five Corners Road and the auxiliary spillways on some of the sediment and water control structures showed evidence of gullying (figure 23f). The sediment contribution to the lake from these sources is unknown.

A good example of the need to quickly address maintenance problems can be seen in some construction activities in the park. A contractor for the local power company installed buried power lines for a campground area, an information stand, and a new concession building. The cables were buried in trenches that were dug directly down a hillside and in a ditch that ran downhill along the road leading from the park office to the concession stand and boat ramp. Initial attempts by the contractor at backfilling and reseeding were unsuccessful.

Without a protective cover of vegetation, rapid erosion occurred, especially along the roadside ditch. Backfill material was washed away, and the trench destabilized, forming a small but quickly growing gully (figure 23g). Since the slope of the hill was fairly steep, the situation would only worsen with time and threaten the stability of the roadway. The erosion problem was especially critical with respect to lake sedimentation. The roadside ditch emptied directly into the boat ramp area (figure 23h), so virtually all of the eroded soil was deposited in the lake.

The persistence of the park staff resulted in the successful repair of the erosion sites. The cable contractor came in for a second attempt at stabilizing the sites, but their efforts again proved inadequate, so a local landscaping contractor was brought in. The sites were properly backfilled and seeded, and are now stable.

Outside of the park, at stream restoration site 6, loss of some riprap was observed at a curve in the stream (figure 20b). This area was once a severely eroding, major sediment source, but received extensive treatment in 1985. The contribution of sediment from this site now appears to be minor, but could become significant if the work is not repaired.

A problem common to many restoration and stabilization projects is that time and fiscal constraints prevent park staff and SCS personnel from following up, evaluating, and maintaining best management practices after installation. Funding for such activities should be budgeted and obtained for this and future projects.

Sedimentation in Lake Le-Aqua-Na

A sedimentation survey of the lake was carried out during the summer of 1995. Transects shown in figure 24, established and demarcated by permanent concrete survey monuments, were again used in this survey. Soundings for water depth and sediment thickness were made from a boat using a taut line stretched along the transect lines at selected intervals. A spud bar was used to ascertain the depth of the original lake bottom. Figure 25 shows the cross sections of the lake at selected transects. The original lake bottom, the 1981 lake bottom, and the current lake bottoms are all shown in the figure. It is apparent that there is no significant difference in lake bottom configuration between the 1981 and 1995 surveys; consequently the bathymetric maps of the lake for 1981 and 1995 are the same as shown in figure 21.

Computations of lake capacities were made using methods described in the National Engineering handbook of the U.S. SCS (USDA-SCS, 1968). The method requires data such as the surface area of lake segments, the cross-sectional areas and widths of their bounding segments, and the shape factor to determine the original and present volume of each segment. These volumes are then integrated to determine the total lake volume. The reference elevation for the lake is the top of the spillway crest.

Results of the sedimentation survey are presented in table 37. The lake lost a total volume of 114 acre-feet since its formation in 1955, mostly before 1981. The volume loss since 1981 is only 24 acre-feet, or 4.2 percent. The volume loss has been 3.5 acre-feet per year for the entire period from 1955 to 1981. Since 1981, the rate of volume loss has been reduced to almost half,

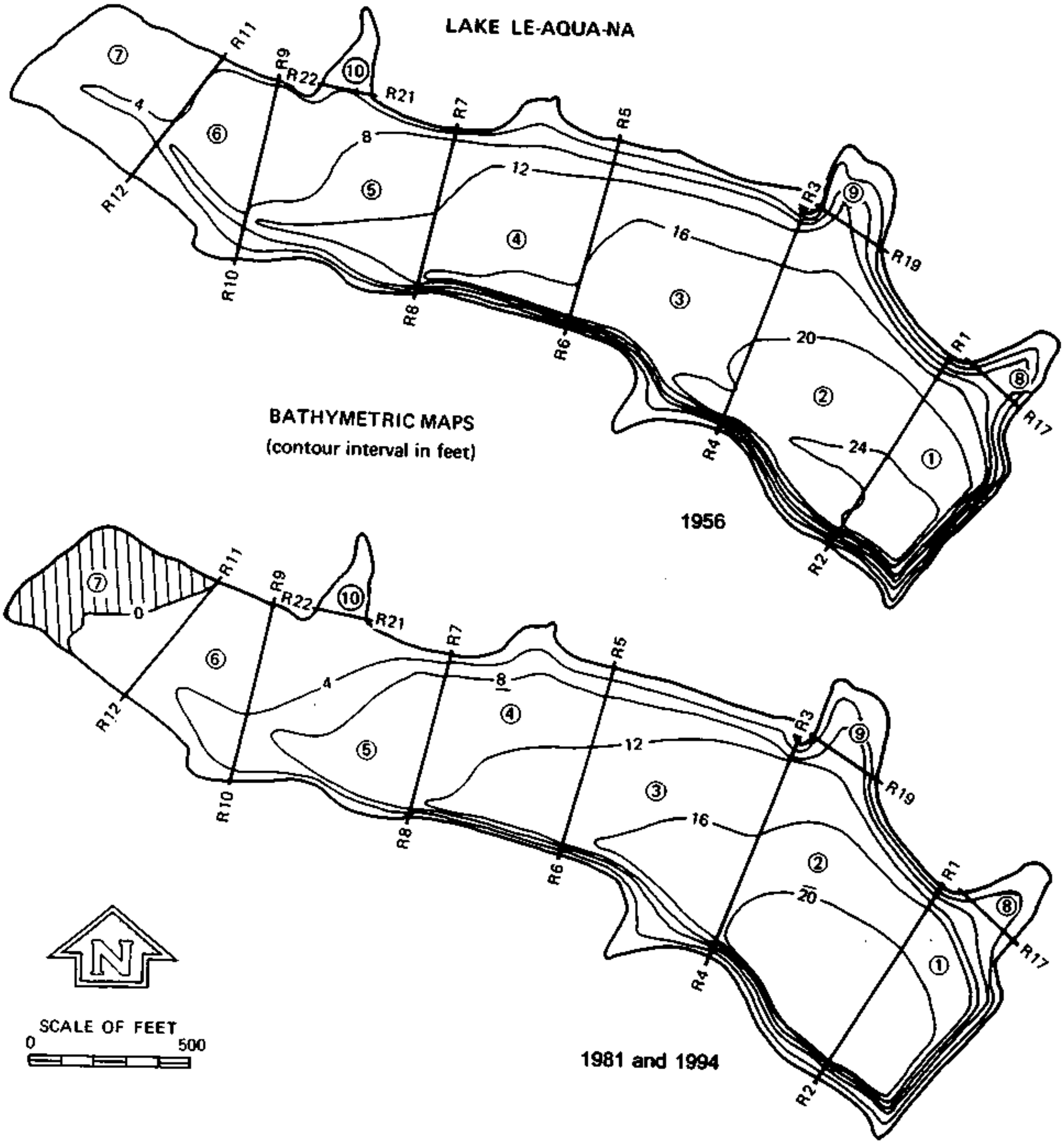


Figure 24. Bathymetric maps of Lake Le-Aqua-Na (contour intervals in feet)

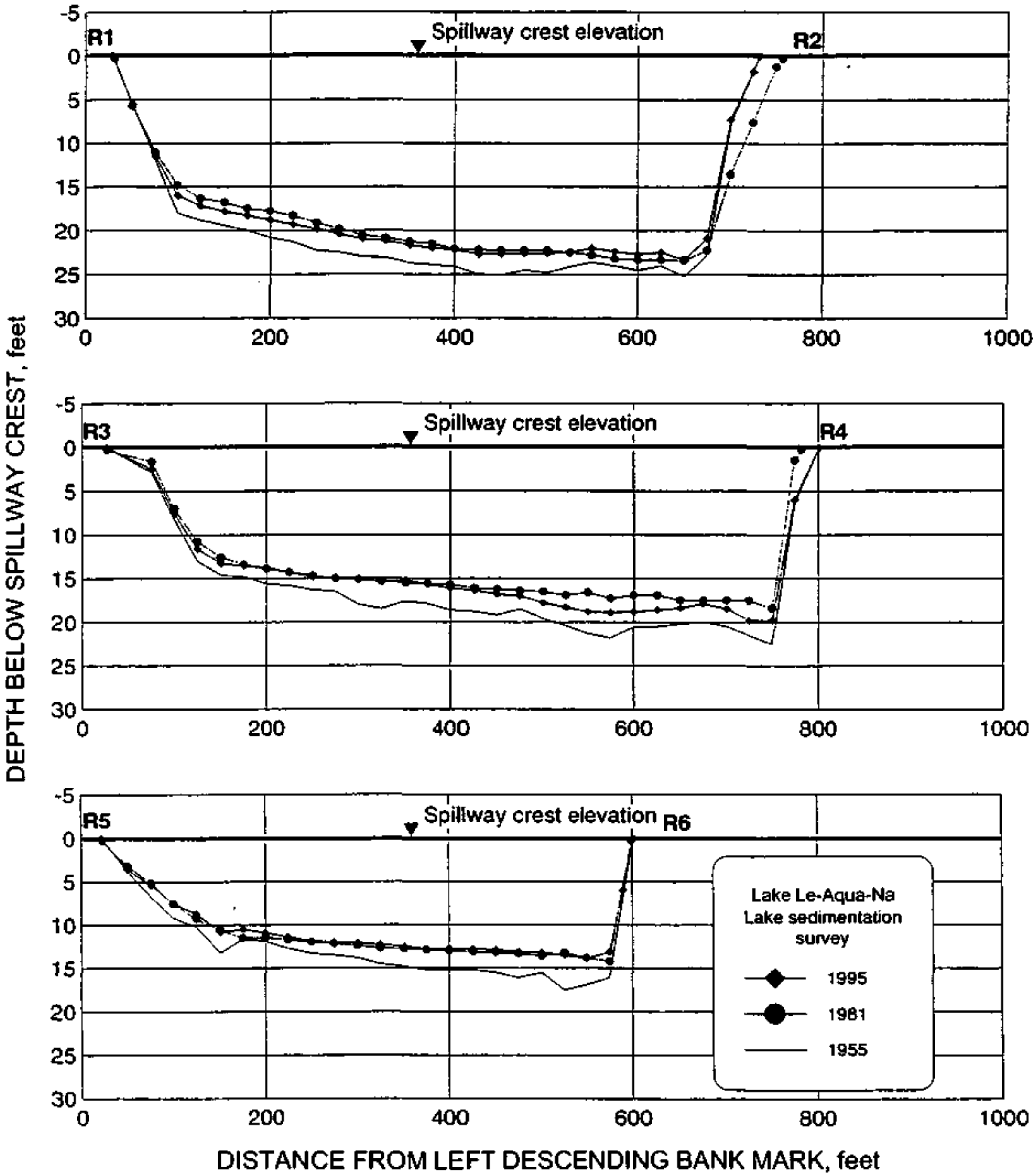


Figure 25. Lake cross sections at selected transects

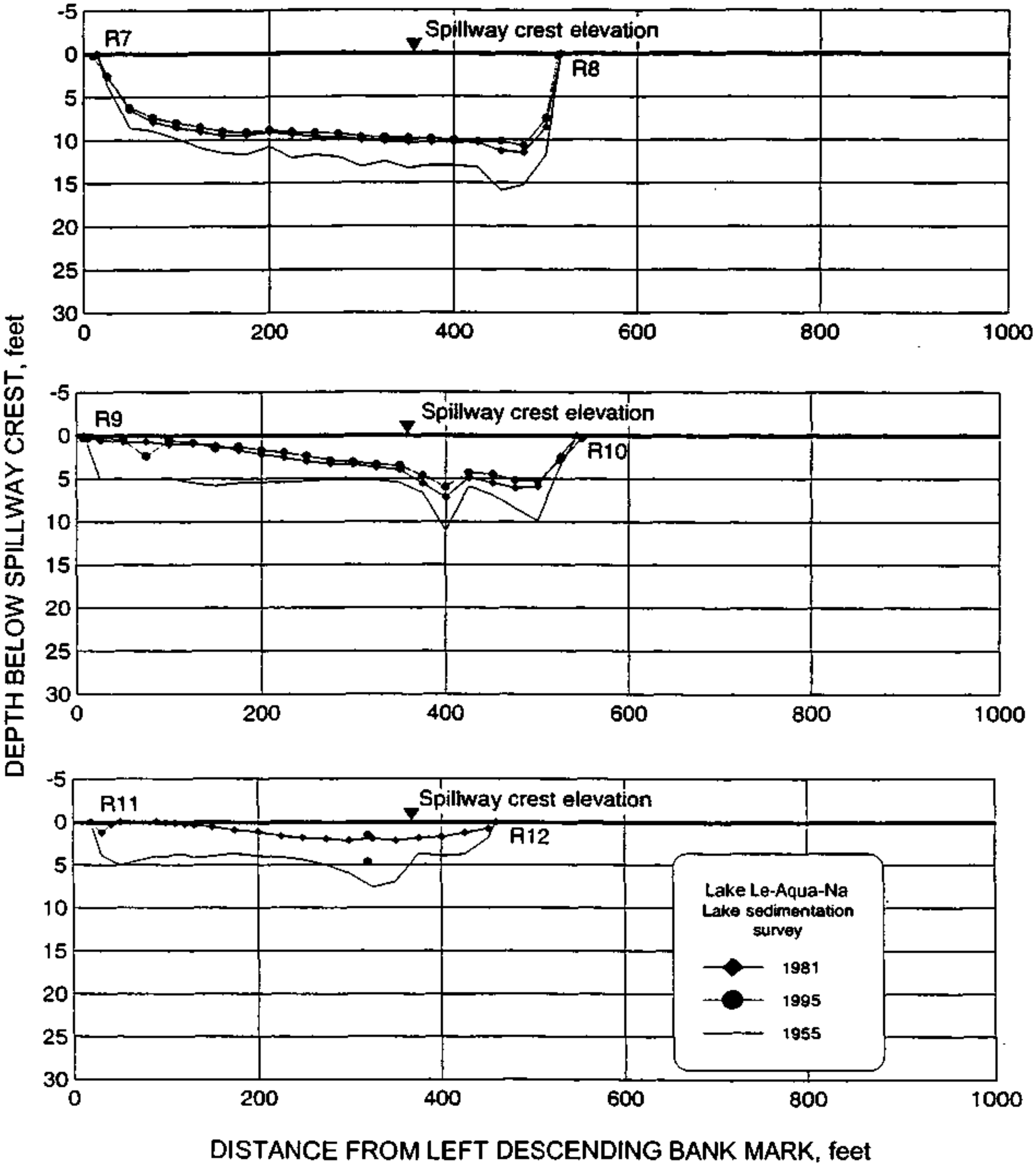


Figure 25. Continued

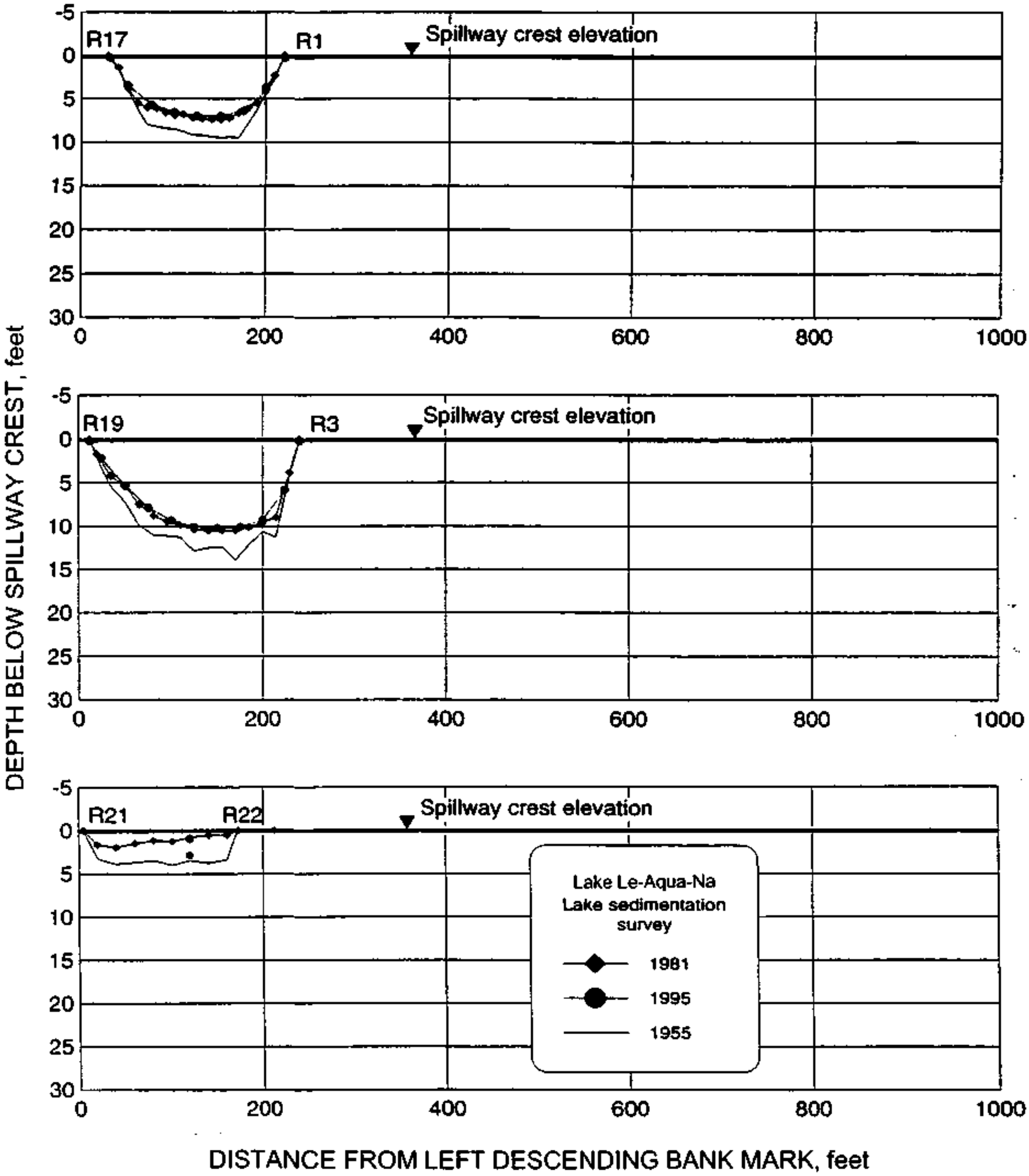


Figure 25. Concluded

Table 37. Summary of Sedimentation Survey, Lake Le-Aqua-Na

Year	*Interval since last survey, years*	*Surface area, acres*	*Volume, acre-feet*	*Loss of volume*		*Rate of loss, acre-feet/year*	*Rate of loss since last survey, acre-feet/year*
				acre-feet	*Percent*		
1955		46.0	566				
1981	26	43.4	476	90	15.9	3.5	3.5
1995	14	43.4	452	114	20.1	2.9	1.7

approximately 1.7 acre-feet per year. This can be attributed primarily to the watershed management program implemented in 1985. These results are corroborated by the reduction of sediment loading to the lake discussed earlier since the implementation of these management practices.

CONCLUSIONS

The following general conclusions can be drawn from the Phase III study conducted from April 1992 to March 1995.

- Field inspection of the watershed best management practices instituted since 1986 showed that most practices were still in place and functioning as designed. However, some areas required maintenance and some new problems did appear. These problems have been adequately addressed by the park personnel.

- Conservation practices in the Lake Le-Aqua-Na watershed, which were found to be successful by IEPA (1990b) in 1986, continue to be highly successful. The net sediment loading to the lake in 1993, when there were more than 20 intense rain events and when the upper Midwest endured one of the worst floods in recent memory, was only 11.8 percent of the loading observed in 1981. Incidentally, IEPA reported an 11.2 percent net loading in 1986 compared to 1981. The efficacy of watershed management in Lake Le-Aqua-Na is thus well established. The sedimentation survey done for the lake in 1995 did not show any measurable reduction in lake volume since 1981.

- Success of the watershed program is additionally supported by reductions in net total phosphorus loadings to the lake. Loadings were reduced to 8.7 percent and 2.1 percent, respectively, during 1992 and 1994 compared to pre-management loadings in 1981. Because of several intense rainstorms during 1993, phosphorus outflow exceeded the inflow, resulting in a significant negative loading.

- Contrary to IEPA observations about net loading of total nitrogen in 1986 (IEPA, 1990b), the loadings were all much smaller during 1992 - 1994 than in 1981. They were, respectively, 35, 60, and 18 percent of those in 1981.

- During this investigation, the lake was either thermally stratified or a significant temperature gradient existed during summer months, probably due to the breakdown of the destratification system. Consequently, the dissolved oxygen conditions in the near-bottom waters were not as good as those observed in 1986 when the aeration system was fully operational. The DO and temperature data for Phase III monitoring bear out the fact that proper maintenance and operation of the destratifier is imperative. Even though significant improvements in lake watershed management have been made over the past decade, hypolimnetic oxygen resources in Illinois lakes cannot be improved without adequately sized and properly maintained aeration systems.

- Examination of turbidity data indicates that most turbidity values were less than 20 NTU at all sampling points. These values varied without any trend. Only summer mean transparencies for 1994 at stations 1 and 2 were greater than 48 inches, which is the lower limit for a water body used for swimming. The 1993 and 1994 annual means for stations 1 and 2 were equal to or greater than 48 inches. This was also the case at station 1 in 1981.

- Average total phosphorus concentrations at the lake surface during spring turnover (late April-May) were below 0.05 mg/L. However, the total phosphorus of the bottom waters at the deepest station during summer months was several fold higher than the standard for all the years of this investigation. This is contrary to the observation made for 1986 (IEPA, 1990b).

- Ammonia-nitrogen and total kjeldahl nitrogen values exhibited trends similar to total phosphorus in the hypolimnetic strata during summer months. This is again a significant departure from the observations made by IEPA for 1986.

- During this investigation, 26 zooplankton species were observed: 11 cladecerans, 2 copepodas, 2 ostracods, and 11 rotiferas. The dominant species in the lake were *Diaptomus minutus* and *Eucyclops speratus.*

- A total of 49 different species of algae were found in all the samples collected during this study: 6 blue-greens (Cyanophytes), 12 greens (Chlorophytes), 18 diatoms (Bacillariophytes), 10 flagellates (Euglenophytes), and 3 desmids. Diatoms and green algae were the predominant algae, not the problem-causing blue-green algae dominant during the summer of 1981.

- Macrophyte growths occurred along the north bank of Lake Le-Aqua-Na and in the shallow west end of the lake. One to two feet of soft, organic-rich sediment was observed in the shallow west end, which is covered every year with dense aquatic vegetation.

- The lake continues to be eutrophic, and the trophic state has not changed from pre-implementation conditions. The overall use support of the lake was computed to be 3.0, hence the lake can be classified as providing a partial/minor degree of use support. Aquatic life use, recreational use, and swimming use of the lake were assessed as full/threatened, partial/moderate, and partial/minor, respectively.

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Appendix A: Water Quality Characteristics

Appendix A-l. Water Quality Characteristics of Lake Le-Aqua-Na, Station 1, Surface

Parameters	1981			1984			1981			1986		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	5	31-1	15	6	37-1	14	6	13-1	16	11	110-1	16
Secchi transparency, inches	52	192-6	16	45	154-8	26	29	5012	36	44	96-4	31
Conductivity, μmho/cm	314	370-152	16	390	490-340	13	427	526-337	16	433	571-301	16
Chemical oxygen demand, mg/L	-	-	-	27.3	67.0-9.0	14	20.0	43.0-7.0	16	17.0	44.0-7.0	16
pH	-	10.0-7.60	16	-	8.6-7.0	12	-	9.4-7.2	16	-	8.6-7.1	15
Total alkalinity, mg/L	187	250-120	16	181	218-154	14	206	274-137	16	224	274-154	16
Phenolphthalein alkalinity, mg/L	-	-	-	11	30-0	14	5	51-0	16	0	0-0	16
Total suspended solids, mg/L	9	38-0	17	12	42-2	14	9	19-1	16	15	145-1	16
Volatile suspended solids, mg/L	6	15-0	17	9	25-1	14	7	14-1	16	6	26-1	16
Ammonia nitrogen, mg/L	0.36	1.00-0.03	17	0.34	0.97-0.02	14	0.26	1.00-0.01	16	0.17	0.48-0.00	16
Total kjeldahl nitrogen, mg/L	1.24	2.02-0.41	16	2.06	4.30-1.10	14	1.63	2.40-0.90	16	0.97	1.70-0.50	16
Nitrate plus nitrite nitrogen, mg/L	0.7	1.9-0.0	17	0.80	2.4-0.0	14	0.90	3.8-0.0	16	1.6	4.0-0.0	16
Total phosphorus, mg/L	0.148	0.450-0.050	17	0.141	0.252-0.076	14	0.257	0.604-0.058	16	0.149	0.511-0.038	16
Dissolved phosphorus, mg/L	0.085	0.290-0.020	17	0.073	0.184-0.013	13	0.177	0.589-0.021	12	0.103	0.293-0.019	16

	1992			1993			1994		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	7	24-2	8	18	95-1	8	9	25-1	8
Secchi transparency, inches	39	90-11	21	50	174-6	24	70	168-24	12
Conductivity, umho/cm	405	452-317	8	438	517-340	8	444	633-302	8
Chemical oxygen demand, mg/L	27.8	41.0-16.0	8	20.0	32.0-14.0	7			
pH	-	9.3-7.7	8	-	8.8-7.8	8	-	9.8-7.9	7
Total alkalinity, mg/L	182	208-158	8	236	312-178	8	194	368-100	8
Phenolphthalein alkalinity, mg/L	8	30-0	8	2	8-0	8	7	40-0	8
Total suspended solids, mg/L	11	45-1	14	17	80-1	8	7	13-1	8
Volatile suspended solids, mg/L	8	32-1	14	5	10-1	8	4	13-1	8
Ammonia nitrogen, mg/L	0.16	0.40-0.03	14	0.22	0.39-0.02	8	0.20	0.80-0.01	8
Total kjeldahl nitrogen, mg/L	0.99	1.40-0.70	14	105	1.50-0.80	8	1.04	2.20-0.50	8
Nitrate plus nitrite nitrogen, mg/L	0.5	2.0-0.0	14	1.6	2.8-0.8	8	1.1	3.0-0.1	8
Total phosphorus, mg/L	0.065	0.106-0.035	14	0.140	0.371-0.103	8	0.156	0.730-0.020	8
Dissolved phosphorus, mg/L	0.022	0.046-0.008	8	0.079	0.173-0.047	8	0.110	0.628-0.008	8

Appendix A-2. Water Quality Characteristics of Lake Le-Aqua-Na, Station 1, Mid-depth

Parameters	*1981*			*1984*			*1985*			*1986*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	6	30-0	15	6	36-1	13	6	15-2	18	15	160-1	16
Secchi transparency, inches	-	-	-	-	-	-	-	-	-	-	-	-
Conductivity, µmho/cm	343	421-285	17	394	427-341	12	433	512-369	17	440	574-261	16
Chemical oxygen demand, mg/L	-	-	-	21.62	33.0-11.0	13	16.11	27.0-2.0	18	15.63	48.0-4.0	16
pH	-	9.2-7.7	7	-	8.5-7.1	11	-	8.4-7.0	15	-	8.6-6.9	15
Total alkalinity, mg/L	214	290-160	17	184	248-156	13	2	17-0	17	0	0-0	15
Phenolphthalein alkalinity, mg/L	-	-	-	4	30-0	13	2	17-0	17	0	0-0	15
Total suspended solids, mg/L	9	34-0	17	9	41-0	13	11	16-3	18	22	245-1	16
Volatile suspended solids, mg/L	6	17-0	17	5	12-0	13	7	13-3	18	7	40-1	16
Ammonia nitrogen, mg/L	0.64	1.71-0.17	17	0.39	0.99-0.02	13	0.26	1.00-0.01	18	0.22	0.54-0.00	16
Total kjeldahl nitrogen, mg/L	1.49	2.73-0.68	17	1.78	2.50-1.39	13	1.49	2.2-0.9	18	1.04	2.2-0.5	16
Nitrate plus nitrite nitrogen, mg/L	-	-	-	0.7	1.9-0.0	13	1.1	3.9-0.0	18	1.6	4.1-0.0	16
Total phosphorus, mg/L	0.217	0.510-0.060	17	0.147	0.269-0.082	13	0.245	0.660-0.062	18	0.176	0.784-0.039	16
Dissolved phosphorus, mg/L	0.154	0.420-0.020	17	0.068	0.200-0.012	12	0.126	0.522-0.016	12	0.100	0.224-0.013	12

	1992			*1993*			*1994*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	5	9-2	8	38	245-1	8	9	20-3	8
Secchi transparency, inches	-	-	-	-	-	-	-	-	-
Conductivity, µmho/cm	433	453-405	8	437	521-272	8	463	591-405	8
Chemical oxygen demand, mg/L	25.38	38.0-14.0	8	22.29	44.0-15.0	7			
pH	-	8.56-7.7	8	-	8.4-7.7	8	-	8.7-7.9	7
Total alkalinity, mg/L	202	260-158	8	229	304-170	8	212	340-100	8
Phenolphthalein alkalinity, mg/L	3	14-0	8	0	0-0	8	7	40-0	8
Total suspended solids, mg/L	8	13-4	8	44	292-1	8	6	14-2	8
Volatile suspended solids, mg/L	4	6-2	8	8	40-1	8	3	8-1	8
Ammonia nitrogen, mg/L	0.13	0.26-0.04	8	0.25	0.39-0.04	8	0.17	0.38-0.01	8
Total kjeldahl nitrogen, mg/L	0.93	1.3-0.6	8	1.20	2.1-0.7	8	1.00	1.5-0.5	8
Nitrate plus nitrite nitrogen, mg/L	0.7	2.0-0.1	8	1.6	2.7-0.8	8	0.8	2.3-0.1	8
Total phosphorus, mg/L	0.063	0.122-0.038	8	0.176	0.572-0.058	8	0.097	0.152-0.023	8
Dissolved phosphorus, mg/L	0.024	0.055-0.012	8	0.083	0.165-0.037	8	0.048	0.118-0.007	8

Appendix A-3. Water Quality Characteristics of Lake Le-Aqua-Na, Station 1, Near Bottom

Parameters	*1981*			*1984*			*1981*			*1986*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	15	53-2	16	6	36-1	13	6	17-2	13	17	170-1	16
Secchi transparency, inches	-	-	-	-	-	-	-	-	-	-	-	-
Conductivity, µmho/cm	379	480-290	17	394	427-341	12	462	560-372	14	470	647-320	16
Chemical oxygen demand, mg/L	-	-	-	21.62	33.0-11.0	13	17.85	33.0-1.0	13	15.38	43.0-1.0	16
pH	-	8.5-7.3	17	-	8.5-7.1	11	-	8.3-6.8	12	-	8.4-6.9	14
Total alkalinity, mg/L	251	305-205	17	184	248-156	13	222	291-154	13	237	325-171	16
Phenolphthalein alkalinity, mg/L	.	.	.	4	30-0	13	0	0-0	14	0	0-0	16
Total suspended solids, mg/L	28	170-0	17	9	41-0	13	10	20-3	14	23	238-1	16
Volatile suspended solids, mg/L	10	34-0	17	5	12-0	13	6	10-2	13	8	50-1	16
Ammonia nitrogen, mg/L	2.42	6.60-0.22	17	0.39	0.99-0.02	13	0.77	2.50-0.14	13	0.37	0.77-0.00	16
Total kjeldahl nitrogen, mg/L	3.49	8.46-0.62	17	1.78	2.50-1.39	13	1.74	3.60-1.00	13	1.25	2.40-0.50	16
Nitrate plus nitrite nitrogen, mg/L	0.66	2.05-0.05	17	0.7	1.9-0.0	13	0.9	3.9-0.0	13	1.6	4.1-0.0	16
Total phosphorus, mg/L	0.601	1.440-0.090	17	0.147	0.269-0.082	13	0.302	0.557-0.100	13	0.193	0.757-0.028	16
Dissolved phosphorus, mg/L	0.408	0.990-0.070	17	0.068	0.200-0.012	13	0.197	0.498-0.026	7	0.132	0.273-0.089	11

	1992			*1991*			*1994*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	9	23-4	8	62	435-5	8	9	29-3	8
Secchi transparency, inches	-	-	-	-	-	-	-	-	-
Conductivity, µmho/cm	489	592-432	8	440	505-240	8	474	624-414	8
Chemical oxygen demand, mg/L	25.63	35.0-15.0	8	27.29	69.0-14.0	7			
pH	-	8.6-7.2	8	-	8.1-7.7	8	-	8.3-7.9	7
Total alkalinity, mg/L	238	302-190	8	238	308-138	8	213	372-112	8
Phenolphthalein alkalinity, mg/L	1	6-0	8	0	0-0	8	6	44-0	8
Total suspended solids, mg/L	12	28-4	8	71	486-1	8	11	50-3	8
Volatile suspended solids, mg/L	5	10-1	8	11	62-1	8	9	50-1	8
Ammonia nitrogen, mg/L	1.18	3.90-0.06	8	0.33	0.63-0.21	8	0.20	0.42-0.01	8
Total kjeldahl nitrogen, mg/L	1.86	4.40-0.70	8	1.30	3.10-0.80	8	1.48	4.80-0.70	8
Nitrate plus nitrite nitrogen, mg/L	0.6	2.1-0.1	8	1.5	2.8-0.8	8	0.8	2.0-0.1	8
Total phosphorus, mg/L	0.403	1.066-0.039	8	0.22	0.874-0.058	8	0.155	0.656-0.027	8
Dissolved phosphorus, mg/L	0.347	0.967-0.014	8	0.084	0.127-0.043	8	0.046	0.128-0.014	8

Appendix A-4. Water Quality Characteristics of Lake Le-Aqua-Na, Station 2, Surface

Parameters	*1981*			*1984*			*1985*			*1986*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	-	-	-	7	38-1	14	6	15-1	16	13	72-1	16
Secchi transparency, inches	-	-	-	43	129-8	27	29	46-10	37	42	94-4	32
Conductivity, |imho/cm	-	-	-	387	482-340	13	427	515-337	14	418	531-303	17
Chemical oxygen demand, mg/L	-	-	-	29.00	52.0-9.0	14	20.81	47.0-2.0	16	15.25	33.0-1.0	16
PH	-	-	-	-	8.7-7.1	12	-	9.4-7.3	14		8.7-6.9	14
Total alkalinity, mg/L	-	-	-	184	225-160	14	202	257-154	16	222	257-188	15
Phenolphthalein alkalinity, mg/L	-	-	-	14	32-0	14	5	51-0	16	0	0-0	16
Total suspended solids, mg/L	-	-	-	10	40-1	14	9	17-1	16	13	96-1	16
Volatile suspended solids, mg/L	-	-	-	6	15-1	14	7	13-1	16	6	15-1	16
Ammonia nitrogen, mg/L	-	-	-	0.31	0.97-0.02	14	0.26	1.10-0.01	16	0.17	0.46-0.00	16
Total kjeldahl nitrogen, mg/L	-	-	-	2.06	3.0-1.2	14	1.51	2.90-0.90	16	0.98	1.6-0.6	16
Nitrate plus nitrite nitrogen, mg/L	-	-	-	0.8	2.5-0.0	14	1.0	3.9-0.0	15	1.6	4.1-0.0	16
Total phosphorus, mg/L	-	-	-	0.161	0.325-0.062	14	0.262	0.597-0.053	16	0.147	0.434-0.034	16
Dissolved phosphorus, mg./L	-	-	-	0.078	0.230-0.014	14	0.158	0.592-0.019	12	0.088	0.243-0.016	13

	1992			*1993*			*1994*		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	7	19-2	8	18	125-1	10	8	24-2	10
Secchi transparency, inches	42	93-11	20	49	156-8	24	68	156-24	13
Conductivity, µmho/cm	414	494-316	8	441	514-337	10	446	631-261	10
Chemical oxygen demand, mg/L	25.88	38.0-11.0	8	20.38	33.0-14.0	9	-	-	-
pH	-	9.26-7.41	8	-	8.7-6.91	10	-	9.7-8.0	9
Total alkalinity, mg/L	182	220-90	8	209	276-136	10	218	350-110	10
Phenolphthalein alkalinity, mg/L	13	40-0	8	1	10-0	10	8	60-0	10
Total suspended solids, mg/L	13	57-1	14	15	102-1	10	7	222-1	10
Volatile suspended solids, mg/L	8	31-1	14	4	12-1	10	5	22-1	10
Ammonia nitrogen, mg/L	0.17	0.37-0.04	14	0.28	0.51-0.07	10	0.17	0.73-0.02	10
Total kjeldahl nitrogen, mg/L	1.01	1.4-0.8	14	1.09	1.5-0.8	10	1.07	2.0-0.5	10
Nitrate plus nitrite nitrogen, mg/L	0.8	3.7-0.0	14	1.8	2.8-0.8	10	1.0	2.6-0.1	10
Total phosphorus, mg/L	0.070	0.170-0.036	14	0.174	0.389-0.049	10	0.141	0.669-0.015	10
Dissolved phosphorus, mg/L	0.034	0.146-0.011	9	0.118	0.292-0.038	10	0.086	0.570-0.006	10

Appendix A-5. Water Quality Characteristics of Lake Le-Aqua-Na, Station 3, Surface

	1984			1986			1992		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	6	24-1	14	6	27-1	15	8	16-3	8
Secchi transparency, inches	30	78-8	27	39	78-17	29	30	51-2	20
Conductivity, umho/cm	393	385-344	13	434	584-353	14	416	518-320	8
Chemical oxygen demand, mg/L	25.43	41-13	14	15.4	32.0-1.0	15	26.50	40.0-14.0	8
pH	-	9.0-7.1	12	-	8.5-7.0	13	-	9.2-7.5	8
Total alkalinity, mg/L	183	218-160	14	227	274-188	14	189	233-138	8
Phenolphthalein alkalinity, mg/L	15	30-0	14	4	34-0	14	13	32-0	8
Total suspended solids, mg/L	11	41-1	14	8	26-0	15	16	94-4	14
Volatile suspended solids, mg/L	6	15-0	14	5	16-0	15	10	62-2	14
Ammonia nitrogen, mg/L	0.36	0.98-0.02	14	0.12	0.33-0.01	15	0.14	0.39-0.01	14
Total kjeldahl nitrogen, mg/L	1.86	2.8-1.2	14	1.07	3.20-0.40	15	1.14	3.20-0.70	14
Nitrate plus nitrite nitrogen, mg/L	0.136	0.267-0.007	14	0.135	0.246-0.021	15	0.087	0.266-0.030	14
Total phosphorus, mg/L	0.067	0.138-0.018	14	0.076	0.170-0.013	15	0.033	0.131-0.011	8
Dissolved phosphorus, mg/L									

	1993			1994		
	Mean	*Range*	*n*	*Mean*	*Range*	*n*
Turbidity, NTU	16	85-1	9	9	37-2	9
Secchi transparency, inches	39	60-8	20	37	48-24	12
Conductivity, umho/cm	439	510-340	9	452	628-265	9
Chemical oxygen demand, mg/L	23.75	52.0-12.0	8	-	-	-
PH	-	8.5-6.9	9	-	9.6-7.9	8
Total alkalinity, mg/L	207	300-150	9	221	360-112	9
Phenolphthalein alkalinity, mg/L	2	12-0	9	6	20-0	9
Total suspended solids, mg/L	11	65-1	9	7	13-2	9
Volatile suspended solids, mg/L	3	9-1	9	4	8-1	9
Ammonia nitrogen, mg/L	0.27	0.67-0.02	9	0.16	0.69-0.02	9
Total kjeldahl nitrogen, mg/L	1.12	2.00-0.60	9	1.12	2.00-0.50	9
Nitrate plus nitrite nitrogen, mg/L	2.1	3.1-0.9	9	1.2	2.8-0.1	9
Total phosphorus, mg/L	0.185	0.453-0.049	9	0.150	0.699-0.028	9
Dissolved phosphorus, mg/L	0.130	0.378-0.040	9	0.091	0.566-0.006	8

Appendix B: Miscellaneous Documents

Appendix B-1. Lake Le-Aqua-Na Aeration/Destratification Unit Operation History

July 1985 - Unit installed - lasted 2 months
Gear reducer completely shot - bearings, wom gears, etc.

November 1985 - Gear reducer replaced for $812
This is a newer model reducer.

December 1985 - Gear reducer fails due to incorrect lubricant installed at factory.
Cold weather (below 15°F) requires a synthetic lubricant - No Charge

Jan. 17, 1986 - Back in operation

April 1986 - Ice chunk tears anchors loose.
$800 for divers to repair

May 1986 - Back in operation

August 1986 - Lightning knocks out unit

October 1986 - Sprocket/Chain drive breaks unit off

Nov./Dec. 1986 - Unit to be started again

March 2, 1987 - turned off in preparation of ice-out

May 15, 1987 - Aerator turned on

May 23, 1987 - Aerator out - hit by lightning

June 4, 1987 - New motor $205 Labor D & D
Aerator back in operation

Sept. 16, 1987 - Changing gear oil - gear unit fails - pulled unit - upper brass gear shot. Possible movement in shaft or slow seepage of lubricant

Dec. 8, 1987 - Gear reduction unit picked up at Grove Gear. A large unit DVLM 1425-3 at $1089 was required.

Dec. 17, 1987 - Unit installed with zero-max coupling. The coupling fails.
Lake froze with ½" ice.

Appendix B-2. Recorded History of Weed Control in Lake Le-Aqua-Na (date, target vegetation, herbicide type and quantity, and results)

June 4, 1982
Elodea, diquat, 1 gallon. The results of the treatment lasted until August when elodea reinvaded.

May 20, 1986
Curlyleaf Pond weed, Komeen, 7.5 gallons in beach area and 12.5 gallons in boat dock area. Curlyleaf pondweed and filamentous algae becoming extreme in beach and at boat dock. The localized treatment with the above chemical was effective in both areas for control of the weeds.

May 12, 1987
Curlyleaf Pondweed, Komeen, 7.5 gallons beach and 12.5 gallons boat dock. Results of treatment were not as effective as the preceding year; however control on the beach area where the chemical was directly applied was effective. There was no drift. In the concession bay, control was very slow in appearing and relatively ineffective.

May 27, 1987
Curlyleaf Pondweed, Aquathol-K, 30 gallons, 35-40% coverage - lake treated annually with 30 gallons of Aquathol-K, plankton boom intense during summer, average Secchi reading 59.0 inches (range 11-180 inches).

May 27, 1988
Curlyleaf Pondweed, Aquathol-K, 30 gallons. Curlyleaf pondweed again dominated the entire north shoreline and the upper end of the lake to a depth of 8-12 ft by mid-May. No weed harvesting took place in 1987, so treatment with 30 gallons of Aquathol-K was undertaken 5/27/88. Coontail and duckweed then replaced the curlyleaf by the fall, but the coverage was not excessive. Fishery biologist observed two patches of white waterlily during the year.

May 18, 1990
Coontail, filamentous algae. Koplex 7.5 gallons beach; 6 pounds $CuSO_4$ beach, 25 pounds $CuSO_4$. boat ramp east to bank. Treatment became effective May 21 but weeds (filamentous algae) soon returned. Fishery biologist advised park staff that treatment will be necessary shortly.

June 11, 1990
Coontail, filamentous algae, Sonar 1 gallon, 25 pounds CuSCv Fishery biologist treated concession bay and small strip along north shore with Sonar. Fishery biologist used $CuSO_4$ in the bay as a mixture/water for submersed filamentous algae and broadcasted the snow crystals at the surface. Aquatic vegetation became uprooted and floated about the lake making boating difficult in the concession bay. The park staff manually needed to remove weeds. Results of the vegetation treatment were seen on June 18. By July following a heavy rain on June 27, the coontail became dislodged and floated throughout the lake. It is not clear to him whether the weed treatment or the heavy rains raising the lake level 3' were responsible for de-rooting all coontail in the lake.

Appendix B-2. Concluded

1991
Vegetation appeared early; however, by late spring all vegetation was nonexistent and no herbicide treatment was necessary in 1991. By the fall survey only small patches of coontail were seen in the upper end of the lake.

May 19, 1992
Coontail curlyleaf pondweed, filamentous algae. Kiokex 12.5 gallons, 20 pounds. Treated boat dock, launch, and beach areas. Water level was down; water was still clear. The treatment had the beneficial results that were sought. The lake turned green the remainder of the year and no macrophyte regrowth was seen. The green coloration was healthy bloom and not of visible noxious blue green algae.

May 23, 1995
Curlyleaf pondweed. Aquathol 5 gallons, Sonar 1 quart. Fishery biologist treated the concession bay, beach, and a small strip along the north shore. Results were excellent. Beach received Sonar.

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