Contract Report 652

Phase I: Diagnostic-Feasibility Study of Otter Lake, Macoupin County, Illinois

by
Shun Dar Lin, William C. Bogner, and Raman K. Raman

October 1999

Illinois State Water Survey
Watershed Science Section
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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Illinois Environmental Protection Agency

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PART 1: DIAGNOSTIC STUDY OF OTTER LAKE

INTRODUCTION

The Watershed Science Section of the Illinois State Water Survey (ISWS) undertook a detailed and systematic diagnostic-feasibility study of Otter Lake commencing in April 1996. The major objective of the project was to develop an integrated protection/management plan for Otter Lake and its watershed, if needed.

The diagnostic study was designed to delineate the existing lake conditions; to examine the causes of degradation, if any; and to identify and quantify the sources of plant nutrients and any other pollutants flowing into the lake. On the basis of the findings of the diagnostic study, water quality goals were established for the lake. Alternative management techniques then were evaluated in relation to the established goals.

The project was funded (60 percent) by the Illinois Environmental Protection Agency (Illinois EPA) through the Illinois Clean Lakes Program under Conservation 2000, with cost-sharing by the lake owner of the Auburn, Divernon, Girard, Pawnee, Thayer, and Virden (ADGPTV) Water Commission. The project was contracted by the ADGPTV Water Commission to the ISWS.

Lake Identification and Location

Otter Lake is located in the west half of North Otter and South Otter Townships in Macoupin County, Illinois, west of Girard (figure 1). The dam site is located in section 7, T.11N, and R.7W. It is approximately midway between Girard and Palmyra. The Otter Lake watershed, including the lake surface area, is approximately 12,990 acres (4,965 hectare or ha) encompassing Macoupin and Sangamon Counties. Lake identification, location, and other pertinent information regarding Otter Lake is listed in table 1.

The primary use of Otter Lake is public water supply. It also supports recreational activities such as camping, fishing, boating, water skiing, and picnicking. Although swimming is not normally permitted, the ADGPTV Water Commission allows underwater search and rescue teams to perform training in Otter Lake.

Acknowledgments

This investigation was jointly sponsored by the ADGPTV Water Commission and the Illinois EPA, as an Illinois Clean Lakes Program Phase I study.

Special thanks to Obille A. Butcher, a Commissioner; Dennis Ross, general manager; Elbert Nash, former general manager of the ADGPTV Water Commission; Albert Pritchett, manager of the water treatment plant; and Jack Roberts, the Otter Lake Park concession stand owner. They were very courteous and shared their information and knowledge about the lake and

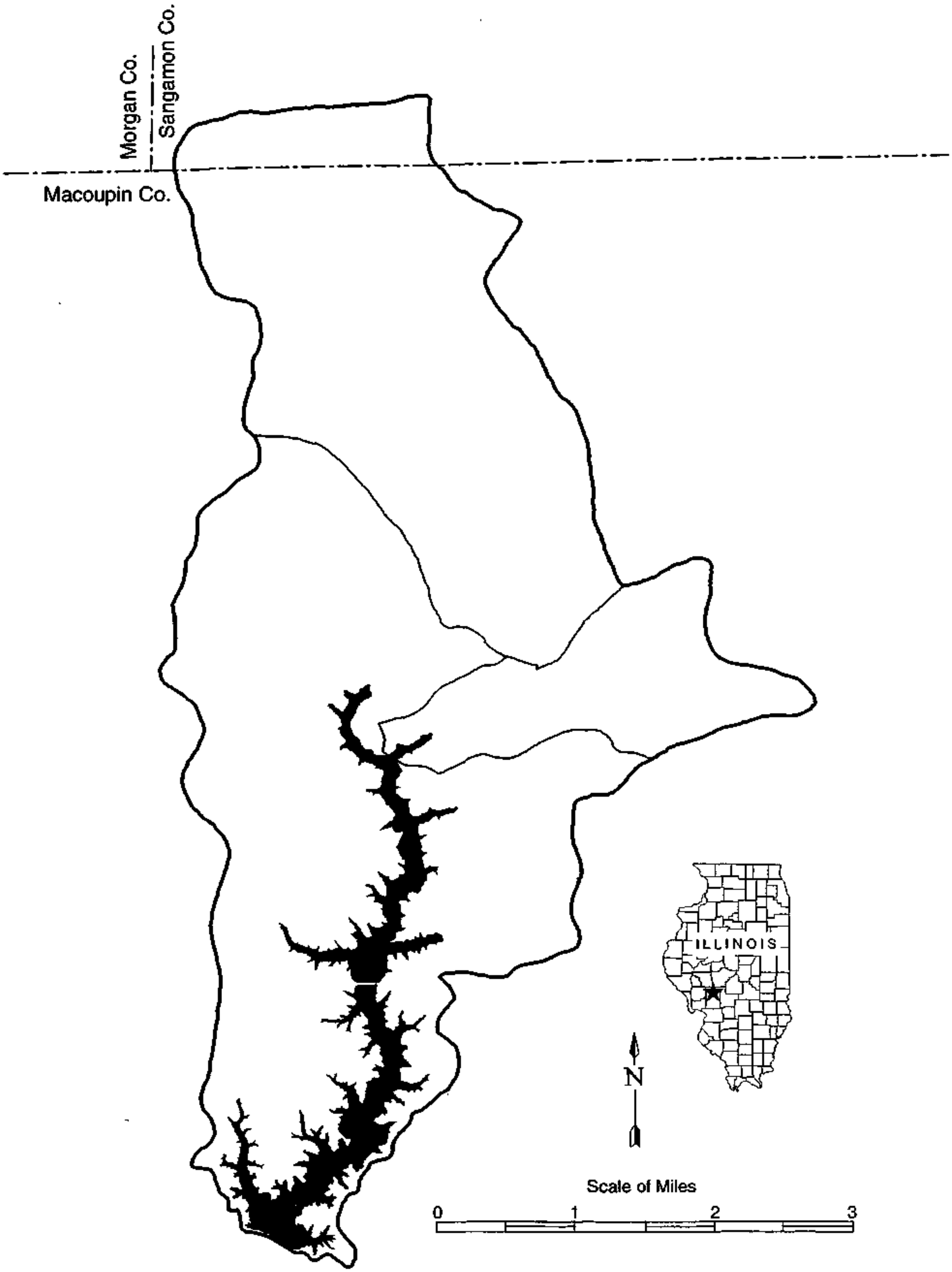


Figure 1. Location of study area

Table 1. Lake Identification and Location

Lake name:	Otter Lake
IEPA/STORET lake code:	RDF
State:	Illinois
County:	Macoupin
Ownership:	Auburn, Divernon, Girard, Pawnee, Thayer, and Virden (ADGPTV) Water Commission
Nearest municipalities:	Springfield, Decatur, and East St. Louis, IL, St. Louis, MO
Latitude:	39° 24' 32"
Longitude:	89° 54' 33"
USEPA region:	V
USEPA major basin name and code:	Upper Mississippi River, 07
Major tributary:	West Fork Otter Creek
Outflowing stream:	Otter Creek
Receiving water body:	Illinois River and Mississippi River via Hodges Creek and Macoupin Creek
Water quality standards:	General standards promulgated by the Illinois Pollution Control Board and applicable to water designated for aquatic life and whole body contact recreation: Title 35, Section C, Chapter 1, Part 302, Subpart B

Notes: IEPA - Illinois Environmental Protection Agency
USEPA - U.S. Environmental Protection Agency
STORET - storage and retrieval

the watershed, which made data collection easier. Without their full cooperation, this task could not have been accomplished in a timely and orderly fashion. The authors owe a debt of gratitude to each of them.

The Illinois EPA Lake and Watershed Unit (Planning Section, Division of Water Pollution Control), under the direction of Gregg Good, was responsible for overall administration and coordination of this project. Amy Jo Walkenbach was in charge of field operations. Jeff Mitzelfelt provided information about publicly owned lakes within a 50-mile radius of Otter Lake. Chemical and biological analyses were performed by the Illinois EPA staff.

Professor Richard L. Farnsworth and Wanghung Yang of the Department of Agricultural and Consumer Economics, University of Illinois, and Ivan Dozier of the Natural Resources Conservation Service provided information on soil types, subwatershed, and soil type of Otter Lake Watershed. Several ISWS personnel contributed to the successful completion of the project. Darin Osland and Mike Nichols helped collect the field data. Kingsley Allan was responsible for the Geographic Information System (GIS) component of this project. John Beardsley and Long Duong assisted in preparing illustrations. Linda Hascall prepared the graphics. Linda Dexter prepared the drafts and the final reports. Eva Kingston and Agnes Dillon edited the final report. The efforts and assistance of all who worked on this project are gratefully acknowledged and appreciated.

The views expressed in this report are those of the authors and do not necessarily reflect the views of the sponsor or the Illinois State Water Survey.

STUDY AREA

Lake and Watershed

Otter Lake, located in south-central Illinois, is seven miles west of Girard. The lake covers all or parts of Sections 5, 6, 7, and 8 of South Otter Township (T.11N, R.7W.) and Sections 20, 28, 29, 31, 32, and 33 of North Otter Township (T.12N, R.7W.) in Macoupin County, and the southwest quarter of Talkington Township (T.13N, R.7W.) in Sangamon County (figure 1). The watershed of Otter Lake includes portions of the northwest quarter of South Otter Township, the west half of North Otter Township, and the southwest quarter of Talkington Township in Sangamon County. The study area is approximately 20 miles (32 kilometers or km) southwest of Springfield.

The three-year construction of Otter Lake was completed in 1968. Originally, the lake was an 800-acre (324 ha) basin. However, Otter Lake currently has a surface area of 765 acres (310 ha). The lake has a shoreline of 39 miles (63 km) and is approximately 5 miles (8 km) long and ¼ mile (0.4 km) wide. The maximum depth of Otter Lake is 50 feet (15 meters or m), and the mean depth is 19.7 feet (6.0 m). Including the lake's surface area, the Otter Lake watershed area encompasses approximately 12,990 acres (5,257 ha). The land-to-lake ratio is 16:1. The general information pertaining to Otter Lake and its watershed is listed in table 2.

Table 2. General Information Pertaining to Otter Lake

County	**Macoupin**	**Ownership**	
IEPA lake code	RDF	Owner/Manager: ADGPTV Water Commission	
Lake location	6.5 miles west of Girard	Address: 119 West Madison, Box 51, Girard, IL	
Deepest point **Latitude**	39°24'32"	Telephone: 217/627-2242	
Longitude	89°54'33"	**Inflowing stream**	Otter Creek
Lake surface area, acres	765	**Outflowing stream**	Otter Creek
Length of shoreline, miles	39	**Other publicly owned lakes in the county**	
Maximum depth, feet	50	Beaver Dam, Bunker Hill New, Carlinville City,	
Average **depth, feet**	19.7	Gillespie New, Gillespie Old, Mt. Oliver New,	
Lake storage capacity, acre-feet	15,000	Mt. Oliver Old, Palmyra-Modesto City, Shipman	
Watershed drainage area, acres	12,990	City, Staunton, Sunset	
Hydraulic retention time, years	1.6	**Unique features**	
Lake type	Dammed stream	A roadway divides the lake into two distinct	
Year constructed	1968	portions, connected by a box culvert.	

Notes: IEPA - Illinois Environmental Protection Agency
ADGPTV - Auburn, Divernon, Girard, Pawnee, Thayer, and Virden

Site History

The Illinois legislature passed a law in 1963 authorizing the formation of commission style organizations relating to water supply projects; whereby the six cities and villages of Auburn, Divernon, Girard, Pawnee, Thayer, and Virden created the ADGPTV Water Commission in 1964. The ADGPTV Water Commission was organized by the appointment of a water commissioner by each member city or village.

The first duty of the ADGPTV Water Commission was to resolve the water shortage crises (the area was dependent on City, Water, Light, and Power from Springfield for its potable water) and look for a new water source. The ADGPTV Water Commission engaged Casler and Associates of Jacksonville, Illinois, in March 1964 to conduct a survey of suitable sites and to recommend a site for the construction of an adequate storage reservoir. The site on the west fork of Otter Creek west of Girard was considered superior in all respects and was selected for development. In January 1965, the ADGPTV Water Commission initiated the planning and design phase of the project. The designed storage capacity of the lake was 5.5 billion gallons (15,000 acre-feet). The construction contracts were awarded in June 1968, and the work began soon thereafter. The dam and spillway were completed in October 1968, and Otter Lake then began to fill in. The water-supply project was financed by the Farmer's Home Administration of the U.S. Department of Agriculture. The total project cost over $3.7 million.

Otter Lake is a water supply source for the cities or villages of Auburn, Divernon, Girard, Pawnee, Thayer, and Virden; it also serves some rural homes The village of Nilwood was later added to the system. The system currently has approximately 14,500 customers.

Water Treatment Plant

The raw water intake tower of the water treatment plant is located at the south end of the north portion of the lake (immediately north of the county road 3000 N). There is a destratifier (an aerator) located 500 feet northwest of the intake. The raw water from the intake is pumped to the treatment plant. Lime, alum, and activated carbon are added in a rapid mixing chamber. The water is passed through a flocculator basin, a settling basin, a recarbonation basin, and three filters. The treated water is chlorinated and fluoridated and stored in a clear well. High service pumps deliver the potable water to elevated storage tanks located in each community served by the ADGPTV Water Commission. A schematic flow diagram of the treatment process is shown in figure 2.

Water quality data for the raw (lake) water and the finished water for the period from April 1996 through June 1997, furnished by the ADGPTV Water Treatment Plant, are summarized in table 3. For 1996-1997 the overall mean pumpage was 1.716 million gallons per day (mgd). The plant was designed for a capacity of 2.5 mgd. The treatment process increases the pH values because of the lime softening process. On the basis of overall average values, total alkalinity decreased from 105 to 23 milligrams per liter (mg/L) as calcium carbonate ($CaCO_3$); total hardness reduced from 148 to 102 mg/L as $CaCO_3$; and turbidity removal amounted to 0.15 nephelometric turbidity unit (NTU) from 17.8 NTU.

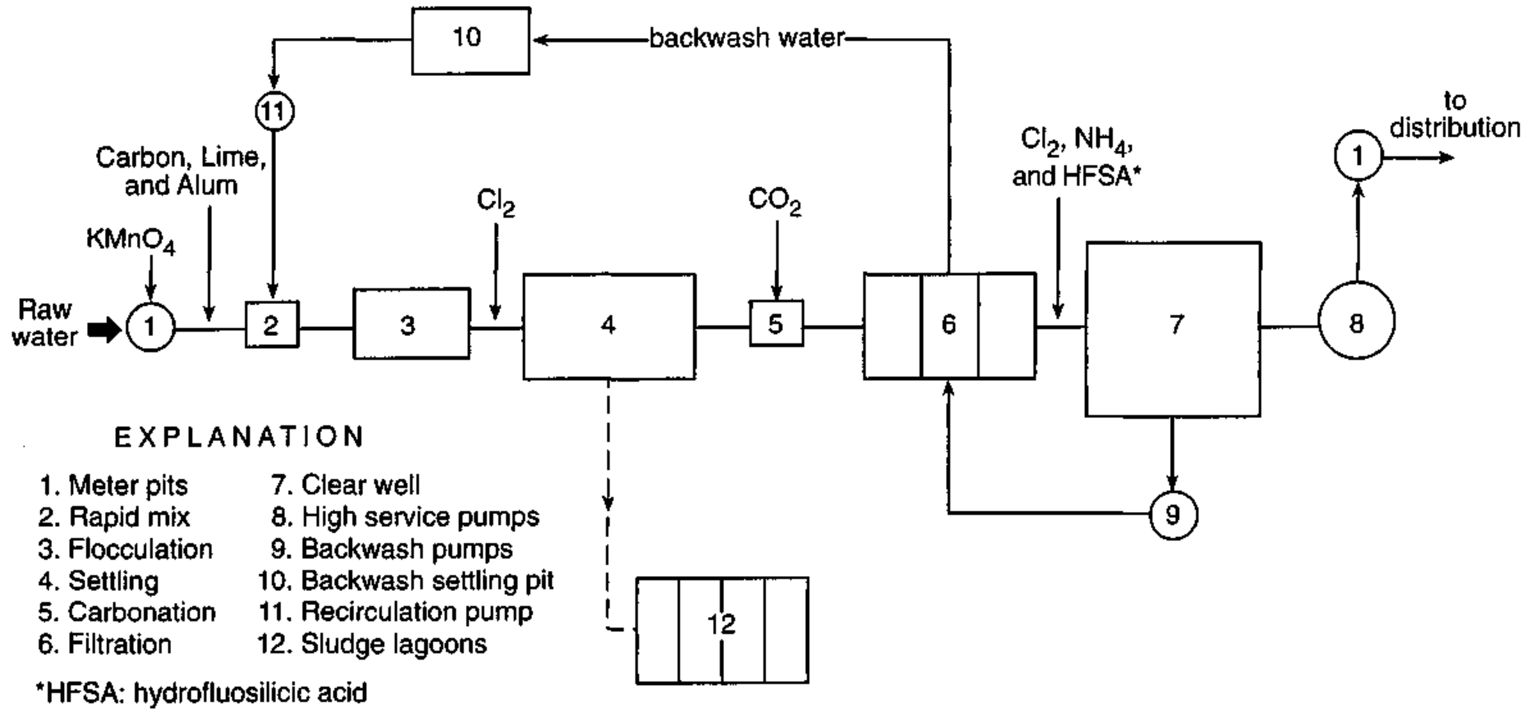


Figure 2. Schemetric flow diagram of the ADGPTV Water Treatment Plant

Table 3. Water Quality of the Raw and Finished Water at the ADGPTV Water Treatment Plant

Month, 1996/1997	*Flow, 1000 gpd*		*Range of pH*		*Total alkalinity, mg/L as $CaCO_3$*			
					Raw		*Finished*	
	Mean	*Range*	*Raw*	*Finished*	*Mean*	*Range*	*Mean*	*Range*
April	1563	1350-1815	8.2-9.2	8.6-9.5	114	90-130	50	20-100
May	1549	1155-1845	7.3-9.3	8.3-11.4	106	82-159	37	12-102
June	1734	1410-2055	7.4-8.7	8.6-9.9	93	70-104	26	8-40
July	1840	1465-2160	8.1-9.2	8.7-10.5	92	84-100	36	10-70
August	1816	1605-2010	8.1-8.9	8.7-9.2	85	74-94	37	28-46
September	1708	1560-1890	7.9-8.7	8.6-9.1	85	80-90	35	24-46
October	1604	1395-1755	7.7-8.5	8.6-9.3	89	80-100	39	32-46
November	1692	1410-1830	7.8-8.1	8.6-9.2	91	84-96	36	26-42
December	2139	1560-4155	7.5-8.2	8.5-9.3	92	86-98	33	22-40
January	1720	102-3225	7.4-7.9	8.3-9.1	95	88-102	31	14-62
February	1806	1605-2070	7.3-7.8	8.4-9.1	92	82-102	24	12-34
March	1807	1710-2115	7.4-8.4	8.6-9.4	93	88-106	28	14-38
April	1787	1320-2010	7.7-8.8	8.3-9.3	98	88-108	34	20-46
May	1456	1240-1790	8.0-8.8	8.2-9.6	104	88-122	26	14-40
June	1523	1280-1700	7.8-8.5	7.8-9.0	105	100-116	23	18-34
Average	1716	102-4155	7.3-9.3	8.2-11.4	96	70-159	33	8-102

Month, 1996/1997	*Total hardness, mg/L as $CaCO_3$*				*Turbidity, NTU*			
	Raw		*Finished*		*Raw*		*Finished*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
April	163	158-174	133	110-168	10.8	4.0-46.0		
May	158	125-180	122	51-300	80.0	27.0-164		
June	151	140-164	96	90-110	39.0	14.0-83		
July	140	126-152	104	83-120	16.0	7.0-25		
August	129	120-144	95	86-104	16.4	9.6-28		
September	127	120-136	90	76-104	15.8	9.3-24.2		
October	135	128-150	103	90-110	12.8	8.3-20.2		
November	143	136-152	102	86-120	7.6	3.9-14.8		
December	143	136-150	100	90-120	3.4	2.6-4.3		
January	142	136-146	92	84-100	3.2	2.3-4.6		
February	156	144-174	96	90-106	5.3	2.3-35.5		
March	145	134-162	101	90-118	23.0	17.0-51		
April	160	142-174	113	96-134	14.0	6.9-20	0.10	0.05-0.40
May	166	158-176	98	88-118	8.5	4.1-14	0.17	0.05-0.45
June	159	148-172	92	80-104	11.2	4.6-38	0.20	0.09-0.41
Average	148	120-180	102	51-300	17.8	2.3-164	0.16	0.05-0.45

Notes: ADGPTV - Auburn, Divernon, Girard, Pawnee, Thayer, and Virden
Blank spaces - no data
gpd - gallons per day
mg/L as $CaCO_3$ - milligrams per liter as calcium carbonate
NTU - nephelometric turbidity units

Source: ADGPTV Water Treatment Plant

Otter Lake is bisected at its midpoint by an elevated, earth-fill roadway (Emerson Airline Road, at 3000 N). The roadway and a relatively small culvert divide the lake; this division in effect creates two lakes with different water quality characteristics. The north portion of the lake acts as a settling basin, trapping most of the settleable matter before it is transported to the south portion of the lake. Although Otter Lake is relatively young, siltation has been reported to have adversely affected the recreational uses and fish habitat in the northern, shallow, upper end of the lake.

The lake water quality generally has been very good. However, in October 1991, the Illinois EPA advised the ADGPTV Water Commission that preliminary tests indicated atrazine concentration in the lake (raw) water was 6.8 micrograms per liter (µg/L), which exceeded the proposed maximum contaminant level (MCL). The proposed MCL for atrazine is 3.0 µg/L.

The source of atrazine is its agricultural use in the watershed. In order to improve lake water quality and avert watershed problems, the ADGPTV Water Commission organized the Otter Lake Ecosystem Planning Committee or OLEPC (formerly Otter Lake Resource Planning Committee) to develop a comprehensive plan to manage the lake and its watershed. The results of atrazine monitoring for six years will be discussed later.

Otter Lake Park

Otter Lake Park is unique. Four camper areas adjoin the lake and Emerson Airline Road. They are named the north, west, south, and southeast; the south and southeast areas are connected. These areas have the largest number of campers; the north area has the least campsites. The total number of camp sites is 256. There are seven toilet facilities, five domestic wastewater dump stations (one in each of the four camper areas and one in the main parking area), and five public bathing facilities. Playground facilities are available at each camp area. There is no shelter in the park area. A Boy Scout campground is located at the southwest corner of the lake. There is a concession stand on the east shore just south of Emerson Airline Road.

The current concessionaire at Otter Lake Park (Jack Roberts) is the third owner of the concession stand. He purchased the concession stand and signed a 10-year lease for the land and lake use from the ADGPTV Water Commission. He is responsible for collecting charges from the campers and managing the Otter Lake Park.

Most of the campers are long-term (year round) customers from such areas as Springfield, Decatur, Alton, and Peoria. Overnight camping is available from April 15-October 15. The charge is $10.00 per night without hook-up, $12.50 per night with electric and water hook-up; there is a $2.00 discount for senior citizens. Costs for boating permits are variable and depend on the size of the motor, whether the boater is a camper or not, number of days used, etc.

Lake recreational uses include boating, water skiing, and fishing. Daily fishing limits are: three large mouth bass, 15 inches; six Walleye, 14 inches; six channel catfish; three hybrid striped bass, 17 inches; one muskie, 48 inches. Maximum boating speed is 35 miles per hour (mph). In the fishing areas, the maximum speed is only 5 mph. Unfortunately, in practice, no one has policing power for the lake. The central portion of the south lake is designated for water skiing.

Climatologic Conditions

The following climatological summary for Springfield, which is 30 miles northeast of the study site, is based on a period of record of over 100 years (1879 to 1992).

Springfield has a temperate continental climate dominated by maritime tropical air from the Gulf of Mexico from about May through October; and maritime polar air from the Pacific Ocean in the spring, fall, and winter, with short-duration incursions of continental polar air from Canada in winter. Mid-winter high temperatures (°F) are typically in the 30s, summer highs are usually in the 80s (°F), with lows about 20°F lower. Spring and fall are composed of a mix of winter- and summer-like days; rather large day-to-day temperature fluctuations are common. The greatest day-to-day changes in temperature occur in late fall, winter, and early spring.

Winters usually are punctuated with two to eight cold, dry, arctic outbreaks, with daily lows dropping into the -10°F range. These outbreaks generally persist for three to five days, and often are preceded by a winter storm that can reach severe proportions, consisting of snowfalls of 6 inches or more with strong winds or freezing precipitation.

Summers are humid with dew points in the 60s (°F) and afternoon relative humidities in the 60 percent range. Usually about 25 days per year have temperatures greater than 90°F; temperatures greater than 100°F are infrequent.

Average (1961-1990) precipitation for Springfield is just over 35 inches, including about 27 inches of snow. There is great variability from year to year. There are about 120 days with thunder and about 10 days with freezing precipitation. On average, precipitation is most frequent and greatest in magnitude during the warmer half of the year. Thunderstorms are common in the afternoon and evening, primarily during spring and summer. Some 51 tornadoes were recorded in Sangamon County since 1858; interestingly, 18 of those occurred on August 6, 1977.

Sixty percent of the mean annual precipitation falls from April through September. The frost-free growing season averages about 175 days, beginning about April 25 and ending about October 20.

The highest temperature on record is 112°F (July 14, 1954); the lowest temperature on record is -24°F (February 13, 1905). The wettest year on record is 1882 with 58.21 inches of precipitation; the driest year on record is 1914, with only 22.76 inches of precipitation. During the 113 complete years of record (1880-1992) there were:

- 5 years with more than 50 inches of precipitation,
- 8 years with more than 45 inches of precipitation,

- 19 years with precipitation in the range of 35-46 inches,
- 57 years with less than 35 inches of precipitation, and
- 24 years with less than 30 inches of precipitation.

Geological and Soil Characteristics of the Drainage Basin

Drainage Area

The drainage area for Otter Lake is delineated in table 2. The drainage area of the lake as shown is 12,990 acres (lake area not included). All of the watershed land is in private ownership, with the exception of 765 acres of the lake and 955 acres of shoreline and near-lake areas owned by the ADGPTV Water Commission.

The primary land use in the watershed is row crop production (65 percent), and an additional 17 percent of the watershed is in pasture or hay production. Forest and wildlife areas make up 9 percent of the watershed, farmsteads and feedlots account for 3 percent, and Otter Lake covers 6 percent of the area.

Geology, Soil, and Topography

The soils of the watershed of Otter Lake are predominantly Ipava-Virden and Hickory-Rozetta-Keomah Associations. These soils are formed in loess, alluvium, and glacial material. Slopes range from nearly level to gently sloping in the upland areas to very steep in the incised stream valley sides. Upland soils experience some moderate-to-severe drainage deficiencies.

The loess consists of Peorian loess and Roxana silts. The thickness in northern Macoupin County is generally about 7 feet. The mantle of loess is generally thinner in the more sloping areas. The nearly level to gently sloping Ipava and Virden soils are formed entirely in loess. Keller soils along streams are formed in either loess or the underlying Illinoisan glacial till material. Soils on stream valley floors are formed from recent alluvium that eroded from the upland soils.

Bedrock of the Pennsylvanian Period underlies the loess and glacial material in Macoupin County. This bedrock consists mainly of shale, sandstone, siltstone, and limestone.

Hydrologic Description of Otter Lake

Hydrologic System

The hydrologic system of Otter Lake is composed of the following major units:

- the lake pool,
- surface drainage from the main tributary and smaller tributaries to the lake,

- the water supply withdrawal,
- the local ground-water system,
- direct precipitation on the lake,
- evaporation from the lake surface, and
- discharge over the spillway.

Surface Inflow and Outflow Conditions

For any surface, runoff will be initiated only when precipitation volume has wetted all surfaces and filled all depressions (puddles). After these initial losses have been exceeded, the precipitation rate must be greater than the infiltration rate for the surface for surface runoff to occur. For impervious surfaces (paved surfaces and building roofs), infiltration potential is very low, and runoff begins when initial losses have been met. For pervious surfaces (bare or vegetated soil and wooded areas), runoff occurs only for storm events that exceed infiltration capacity.

The water level rises as runoff enters the lake, increasing the volume of water stored. Excess flow is passed downstream when the level of the lake rises and exceeds the top of the spillway. The water storage below the spillway level provides a low flow water supply source when stream flow is low or zero. During these low flow periods, the stored water volume is subject to additional losses to surface evaporation and, in some cases, seepage into the ground.

Lake levels follow a general trend of steady decline through the summer months when evaporation and water supply withdrawal rates exceed inflow rates; stabilize during the fall and winter as the weather cools; and, hopefully, rise rapidly in the spring in response to high precipitation and saturated soil conditions. During most years the spring rise will include a surplus that is passed over the spillway. The balance of inflows and outflows from the lake will be discussed in more detail later.

Ground-Water Conditions around Otter Lake

Ground-water availability for development for domestic water use in the area is generally limited to large-diameter shallow wells dug or bored in the surficial till and finished above bedrock. The shallow bedrock in the area is nonwater-bearing shales with only a few thin beds of water-yielding sandstone and creviced limestone. Water from shallow bedrock formations is limited to less than 5 gallons per minute (gpm). Water from bedrock formations below 200 feet is likely to be highly mineralized.

In general, ground-water levels adjacent to the lake probably conform to lake levels. The low transmissivity of the surface till deposits suggests limited ground-water inflow or outflow from the lake.

Public Access to the Lake Area

There are several locations of public access on Otter Lake. The boat launch area (figure 3) is the major boat access point to the lake. Four camper areas have accessibility to the lake shore. However, bank fishing is not common at and near these sites due to steep banks. On the south end of the lake, the area of the dam and spillway provide access to the lake. There is no defined parking facility; however, road-side parking is available. The ADGPTV Water Commission owns the land around the perimeter of the lake, and 90 percent of that land is in permanent (wooded) vegetative cover. Most of the banks are steep, which makes most of the shoreline inaccessible. There is no public transportation to the Otter Lake Park area.

The boat ramp area is well maintained and has parking facilities for 36 vehicles and 18 trailers. Additional parking is available at the parking lot. The boat ramp area is trapezoidal in shape. The north and south sides measure 145 and 225 feet, respectively; and the distance between them is 385 feet. The parking facility is immediately west of the water treatment plant and north of the blacktop road. A four-lane (48 feet) concrete boat ramp is located at the north side of the parking lot. The west side of the parking lot has a guard rail. A grassy lawn with four park benches and playground equipment is between the guard rail and the lake.

Additional parking areas are around the four camper areas (north, south, southeast, and west) within hiking distance to the lake shore. A concession stand is located immediately south of the road opposite to the main parking lot (figure 3). There are 256 camper sites and a picnic ground with 25 picnic tables.

Size and Economic Structure of Potential User Population

Potential User Population

No big city or town is near the lake area. It is difficult to know exactly where the visitors come from. The campers are all potential lake users. Other visitors are most likely to come from the seven small cities and villages. Current populations are: Auburn, 3,724; Divernon, 1, 178; Girard, 2,164; Nilwood, 238; Pawnee, 2,384; Thayer, 730; and Virden, 3,635. The total population of these communities is 14,053.

Major population centers within a 50-mile (80-km) radius of Otter Lake are listed in table 4. The data are based on the 1990 U.S. Population Census (U.S. Department of Commerce, 1993). The pertinent population and economic information for these communities are given in table 5 (U.S. Department of Commerce, 1992, 1993). The nearby large municipalities are: Springfield (30 miles NE), Jacksonville (30 miles NW), Taylorville (35 miles E), and Jerseyville (35 miles SW). The combined population of these surrounding cities (excluding the lake owner communities) is 187,858. Although the potential user population is likely to be from the areas in table 4, it is believed that visitors outside of the 50-mile radius, such as from Alton and Peoria, also may be potential users.

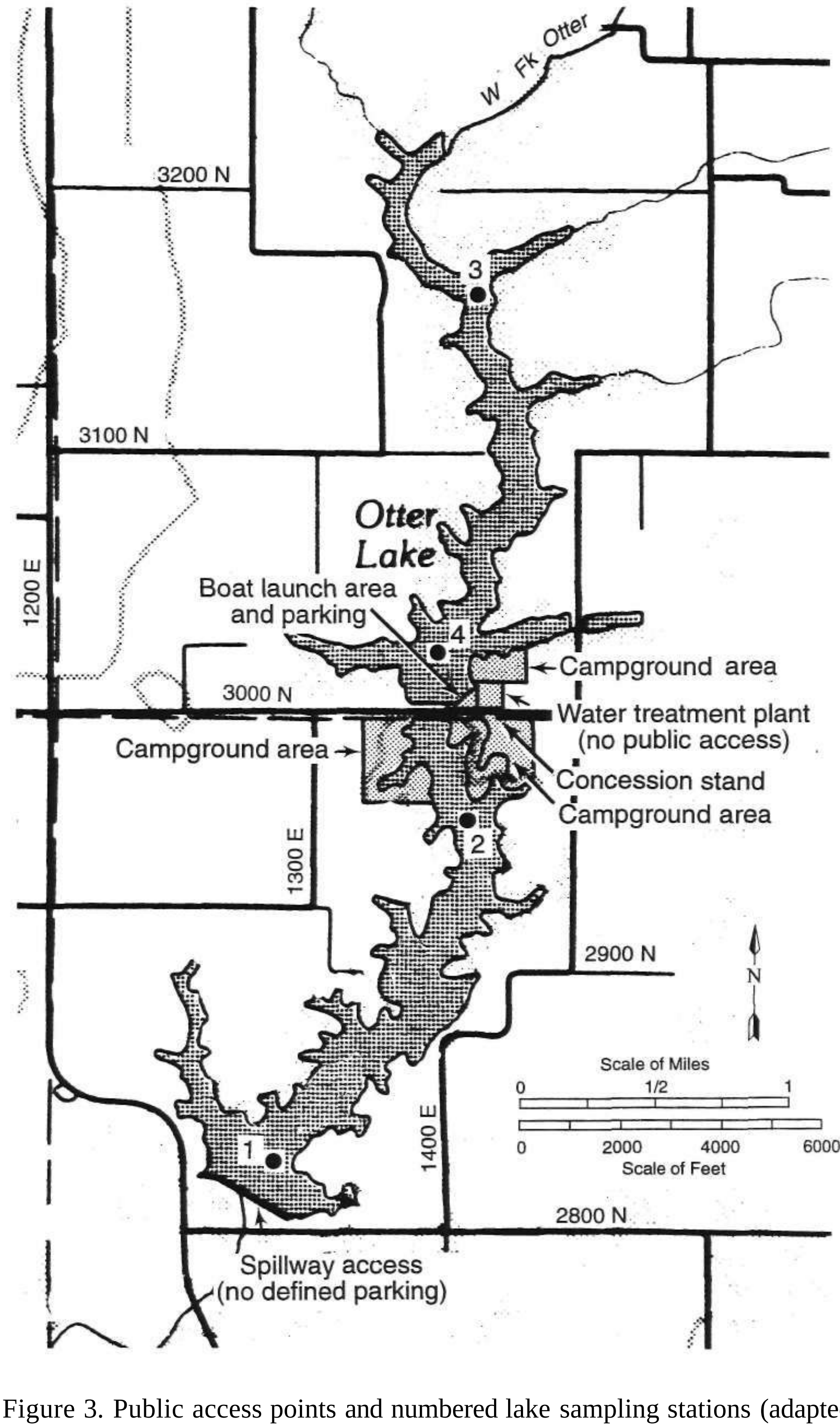


Figure 3. Public access points and numbered lake sampling stations (adapted from DeLorme Mapping, *Illinois Atlas and Gazetteer*, Freeport, Maine, 1991)

Table 4. Demographic and Economic Data for Towns/Cities Surrounding Otter Lake

	Population				*Number*	*Persons*	
Town/city	*Total*	*Female*	*Under 18 years, %*	*Over 65 years, %*	*of households*	*per household*	*Per capita income, $*
Auburn	3,724	1,966	30.7	12.9	1,330	2.75	11,610
Carlinville	5,460	2,912	23.3	19.7	2,102	2.34	10,314
Carrolton	2,507	1,380	23.9	22.7	1,040	2.37	11,740
Chatham	6,074	3,074	32.6	5.7	2,070	2.93	14,563
Gillespie	3,645	1,959	26.5	19.3	1,466	2.49	10,402
Girard	2,164	1,145	28.1	18.2	813	2.55	9,111
Hillsboro	4,400	2,389	26.6	21.8	1,753	2.43	11,907
Jacksonville	19,324	10,284	22.8	17.3	7,400	2.29	12,282
Jerseyville	7,382	3,983	25.1	20.2	2,940	2.42	10,380
Litchfield	6,883	3,718	25.5	20.4	2,727	2.43	10,274
Mount Olive	2,126	1,138	24.3	22.2	901	2.36	10,672
Nokomis	2,534	1,392	24.8	25.7	1,042	2.35	9,966
Pawnee	2,384	1,255	28.2	12.2	910	2.62	13,023
Roodhouse	2,139	1,123	27.2	18.1	865	2.47	9,206
Springfield	105,227	56,787	24.3	14.9	45,006	2.29	14,813
Staunton	4,806	2,579	25.1	21.7	1,919	2.46	12,275
Taylorville	11,133	6,049	23.7	19.5	4,717	2.31	12,288
Virden	3,635	1,963	26.6	19.9	1,395	2.52	15,417
Waverly	1,402	751	24.1	21.2	582	2.41	11,304
White Hall	2,814	1,491	24.9	24.1	1,123	2.40	9,173

Source: U.S. Department of Commerce, 1993

Table 5a. Population and Economic Data for Areas near Otter Lake

County	Area (square miles)	Population	Wholesale (thousands, $)	Manufacturing: Number of establishments	Manufacturing: Units	Manufacturing: Number of employees	Manufacturing: Value added (thousands, $)	Total number of establishments	Total number of employees	Per capita income, $
Bond	380.2	14,991	182,930	16	27	600	32,000	24	7,957	10,407
Christian	709.2	34,418	306,058	26	60	12,000	69,600	27	17,521	11,676
Greene	543.1	15,317	82,111	14	10	400	12,200	18	7,411	9,884
Jersey	309.2	20,539	88,828	12	4	200	4,900	14	10,805	11,132
Macoupin	863.7	117,207	200,965	35	32	1,000	36,800	41	22,839	11,365
Madison	725.1	249,238	1,666,204	217	1,122	19,500	1,308,500	217	129,493	13,272
Montgomery	703.8	30,728	192,901	43	82	1,600	95,500	44	15,175	10,724
Sangamon	868.3	178,386	1,297,076	126	169	4,300	197,500	144	102,440	14,947
Scott	251.0	5,644	213,217	8	3	100	3,500	3	2,931	10,505

Sources: U.S. Department of Commerce, 1992, 1993
Rand McNally Company, 1997

Table 5b. General Employment Categories for Areas near Otter Lake

County/County seat	*Major employment categories*
Bond/Greenville	Agriculture; construction; manufacturing (textile and fiber products, primary metal industries, electrical equipment, and components); trucking; wholesale and retail trade; professional and related services.
Christian/Taylorville	Agriculture; mining; contruction; manufacturing (nodurable goods, electrical equipment and components); retail trade; real estate; services (business, education, health, motels and hotels).
Greene/Carrollton	Agriculture; construction; manufacturing (electrical equipment, printing and publishing); retail trade; professional and related services.
Jersey/Jerseyville	Agriculture; construction; manufacturing (primary metal industries, fabricated metal products); trucking; retail trade; general and professional services.
Macoupin/Carlinville	Agriculture; construction; manufacturing (durable and nondurable goods); transportation and public utility; retail trade; finance; professional and personal services.
Madison/Edwardsville	Agriculture; manufacturing (food and kindred products, textile products, chemical and allied products, fabricated metal products, electronic equipment); wholesale trade; retail trade; financial; services (business education, engineering, hotels and motels, health, government).
Montgomery/Hillsboro	Agriculture; manufacturing (food and kindred products, machine and components); trucking and transportation; retail trade; finance; professional and related services.
Morgan/Jacksonville	Agriculture, construction; manufacturing (food and kindred products); printing, publishing, and allied industries; retail trade; professional and related services.
Sangamon/Springfield	Government, agriculture; construction; manufacturing (printing and publications, allied industries, machinery and component equipment); transportation and communications, public utility; retail trade; financial; real estate; services (public administration, business, automotive, education, hotels and motels, computer and data processing, engineering and management, health, amusement).
Scott/Shelbyville	Agriculture; manufacturing (food and kindred products, nondurable goods); finance; insurance; real estate; professional and related services.

Economic Characteristics

The average per capita income of the 50-mile surrounding communities (table 4) is $11,536. The per capita income ranges from $9,111 in Girard to $14,813 in Springfield. Tables 5a and b show population and economic data for counties within 50 miles (80 km) of Otter Lake and list sources of employment. The per capita income for the nine counties listed in table 5 a averages $11,546 with a range from $9,884 in Greene County to $14,947 in Sangamon County. The primary industry is agriculture. Light manufacturing industries and construction are also the major sources of employment. Government and personal services are major employment sources in Sangamon County. Surrounding communities and counties can be characterized as being middle income, with plentiful employment sources, low unemployment rates, and adequate housing for individuals.

Historical Lake Uses and Conditions

Summary of Historical Lake Uses

Otter Lake and its park area historically have been used for: public water supply; recreation: boating, fishing, water skiing, camping, picnicking, and duck hunting; and aesthetic enjoyment: viewing the lake and associated wildlife.

Long-term historical data on attendance at Otter Lake Park are not available. However, for the last five years, the current concessionaire, Jack Roberts, provided an excellent estimate through records of leases, permits, and daily rental data. The following information was provided by Mr. Roberts: an average of three persons per campsite, three persons per boat, three visits per campsite and/or boat permits for a year, and 500 persons for bank fishermen and picnickers. The estimated lake and park attendance for 1993-1997 is in table 6. The attendance declined from over 15,000 in 1993 and 1994 to less than 12,000 during 1995-1997. Most campers have one boat, and many of them have two or more, and come numerous times through the year; fishermen come repeatedly.

Estimates provided by the Macoupin County SWCD (1993) for the annual visits in permitted activities (in 1992) is as follows: fishing, 8,500; camping, 6,300; boating, 2,000; Scouts, 150; and miscellaneous visits, 2,200, for a total of 19,150 visitors to the lake.

Duck hunting is allowed on the shallow north end of the lake for 60 days starting from the third Saturday of October (O.A. Butcher, personal communication, 1998). Sixteen duck blind sites are allotted by lottery at a fee of $100, but there is more demand (90) for the sites than are available. Hunting is allowed from sunrise to noon. The lake is off-limits to other uses during the hunting period.

Time sharing and space zoning are practiced at Otter Lake to minimize the conflicts among various recreational uses. Water skiing is permitted only in the portion of the lake south of Emerson Airline Road that traverses through the middle of the lake.

Table 6. Annual Attendance, Otter Lake Park

Year	*Camper site leased*	*Boat permit sold*	*Overnight campers*	*Estimated attendance*
1993	249	1,354	204	15,839
1994	254	1,327	187	15,290
1995	256	974	99	11,867
1996	257	876	144	11,129
1997	254	954	113	11,711

Source: Jack Roberts, concessionaire at Otter Lake Park

Historical Lake Conditions and Management

As mentioned previously, the lake has been experiencing siltation at the upper end, shoreline erosion, and atrazine problems. The Illinois EPA has placed the ADGPTV Water Commission on high atrazine advisory since October 1991. The OLEPC was formed in June 1992 to develop a comprehensive plan to manage the natural resources in the watershed and to maintain and improve the quality of life in the Otter Lake area. The planning committee is comprised of representatives from the ADGPTV Water Commission, the Macoupin County SWCD, the U.S. Natural Resources Conservation Service (NRCS), watershed farmers, and each community.

A Technical Advisory Committee (TAC) was organized in October 1992 to make recommendations for the watershed management plan. Technical advisors include representatives from the Illinois EPA, NRCS, Illinois Department of Natural Resources (IDNR), Illinois Department of Agriculture, Consolidated Farm Service Agency, Macoupin County Farm Bureau, and the Cooperative Extension Service.

Management of Otter Lake and its watershed has been initiated as an interagency cooperation and assistance program. Through the efforts of the planning committee and the TAC, with funding under 319, Water Quality Incentive Programs (WQIP) were carried out in 1994-1996. The detailed management projects for Otter Lake and its watershed are shown in table 7. A bald cypress demonstration planting for shoreline erosion control was carried out by the Boy Scouts in June 1993.

The 319 program provides formula grants to the states to implement nonpoint source projects and programs in accordance with Section 319 of the Clean Water Act (CWA). Examples of previously funded projects include best management practices (BMPs) installation for animal waste; design and implementation of BMP systems for stream, lake, and estuary watersheds; basinwide landowner education programs; and lake projects previously funded under the CWA Section 314 Clean Lakes Program.

In fiscal year 1994, WQIP funds were used to encourage farmers to adopt water quality improvement practices on their farms. Additional WQIP funds were granted in fiscal years 1995 and 1996. The locations of land treatments under the WQIP practices are presented in figure 4. A special 319 project provided cost-share for the construction of two sedimentation basins in the tributaries (East Fork and West Fork) before waters enter into the lake. There is an on-going riprap project by the ADGPTV Water Commission for shoreline erosion control and wetland construction for atrazine reduction. The design diagram of a sedimentation basin is presented in figure 5. Artificial wetlands were built to reduce the atrazine input to the lake.

The Macoupin County Farm Bureau has conducted a pesticide and livestock inventory. Ciba-Geigy (atrazine supplier) has been working with the ADGPTV Water Commission since 1993 to monitor and analyze atrazine levels in the lake and finished waters. Weekly samplings were conducted during 1995 and 1996. Ciba-Geigy provided sample containers, and water works personnel collected water samples. The Cooperative Extension Service has initiated an atrazine

Table 7. Management Projects for Otter Lake and Its Watershed

1991	
October	• Illinois Environmental Protection Agency (EPA) advisory: high atrazine in lake water
1992	
May 4	• Auburn, Divernon, Girard, Pawnee, Thayer, and Virden (ADGPTV) Water Commission requested assistance from the Soil and Water Conservation District (SWCD)
May 7	• SWCD approved the request
June 5	• First meeting in Girard • Otter Lake Resource Planning Committee (OLRPC) was formed
October	• Technical Advisory Committee (TAC) was organized with members from various governmental agencies • Made recommendations for watershed management
1993	
March 8	• Applied for Water Quality Incentive Program (WQIP) funds • Agricultural Stabiization and Conservation Service (ASCS) County Committee funded $10,500 for Agricultural Conservation Practices (ACP) cost-share
June	• 250 bold cypress demonstration plantings for shoreline erosion control by the Boy Scouts • Ciba Giegy atrazine testing initiated
August	• ADGPTV Water Commission was placed on restricted status by the Illinois EPA because the average atrazine level was 4.9 μg/L • 319 grant submitted to the Illinois EPA
November	• Ecosystem planning pilot format developed
1994	
February	• ADGPTV Water Commission requested a variance from the restrictions from the Illinois Pollution Control Board (IPCB) • WQIP funding approved
March	• Watershed soil mapping field update completed • First WQIP sign-up conducted
April	• Planning committee adopted ecosystem planning concept • Planning committee revised pilot format
May	• A conditional variance was granted with the proviso that a watershed management plan must be enacted by September 1996 and that six-month progress reports be filed to the Illinois EPA • 319 funding obtained for cost-share for the construction of water and sediment control basins • SWCD initiated additional field inventories

Table 7. Continued

1994	
June	• Well sealing demonstration in watershed
July	• Additional WQIP funding requested
August	• Watershed land-use inventories completed
September	• Technical advisory update completed
October	• Base Geographic Information System (GIS) data layers compiled
November	• First draft of ecosystem plan prepared
December	• 319-funded basin site selection confirmed • Otter Lake Ecosystem Planning Committee (OLEPC) requested that the Consolidated Farm Service Agency (CFSA) County Committee prioritize ACP cost-share to the Otter Lake watershed • ADGPTV Water Commission installed riprap for shoreline erosion control
1995	
January - December	• Extensive atrazine tests of waters by Ciba-Geigy and ADGPTV Water Commission • Atrazine tests for waters through the 319-funded structures
February	• FY 95 WQIP funding secured
March	• "Farming Your Watershed" meeting held • UI ecosystem planning study initiated • FY 95 WQIP sign-up begins • Interagency review of Otter Lake ecosystem plan
April	• OLEPC meeting • FY 95 WQIP sign-up ends • Draft plan sent to technical advisors for comment
May	• TAC comment period ends
June	• UI detailed land-use study begins • TAC comments incorporated into ecosystem plan • Construction on 319-funded basins begins
July	• Planning committee approves plan
August	• Plan action items/responsibility established
September	• SWCD approves ecosystem plan • First annual Otter Lake Rally Day held • Preliminary application for Illinois Clean Lakes Program

Table 7. Concluded

1995	
October	• Distribute copies of the ecosystem plan • Identify and establish shoreline erosion abatement demonstration areas
November	• Enroll in the volunteer lake monitoring program • Aggressively promote WQIP sign-up and participation • Seek an EPA 319 Grant to establish baseline lake data (sediment survey, shoreline erosion, tissue sampling)
December	• Establish a neighbor-to-neighbor network to help ensure plan implementation • Locate a volunteer for a site-specific, whole farm ecosystem plan • Begin site-specific ecosystem planning
1996	
January - December	• Extensive atrazine tests for waters
January	• Developed a long-term plan for project implementation
March	• Identified potential fish hatchery sites adjacent to the lake • Conducted a mailing to remind watershed farms to fine tune atrazine use this planting season
April	• Established regular media contacts to publicize planning and implementation efforts • Diagnostic/feasibility study commenced
July	• Conducted a tour to show established conservation practices in the watershed
December	• Evaluated first year progress, advertised results, updated plan
1997	
May	• Routine lake monitoring and water sampling completed
September	• ADGPTV Water Commission open house and barbecue
October	• Lake bathymetric survey completed
Fall	• Priority Lake and Watershed Implementation Program from Illinois EPA ($25,000 Illinois EPA and $15,000 ADGPTV). Total cost is $40,000

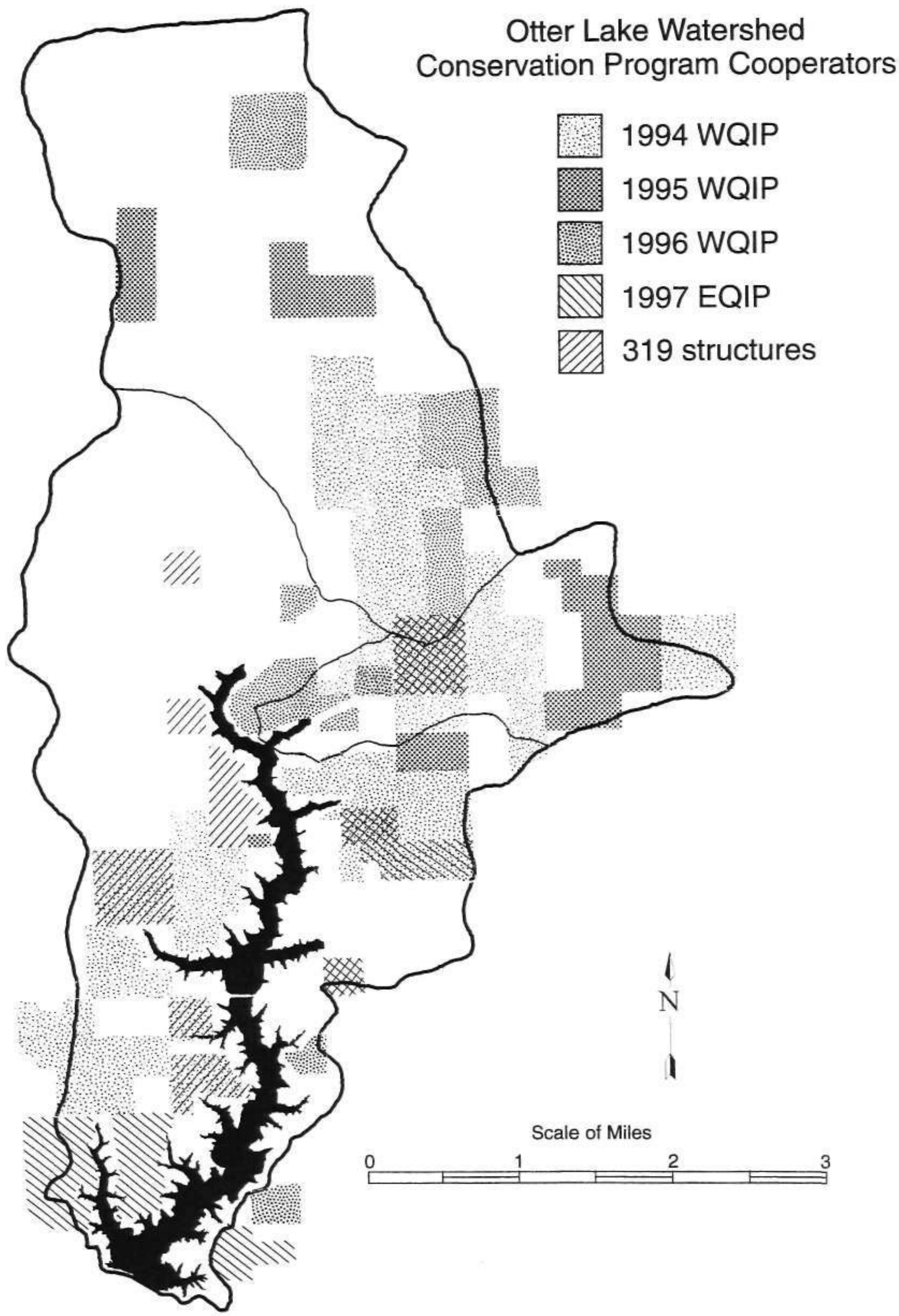


Figure 4. Land treatment areas under the Water Quality Incentive Program

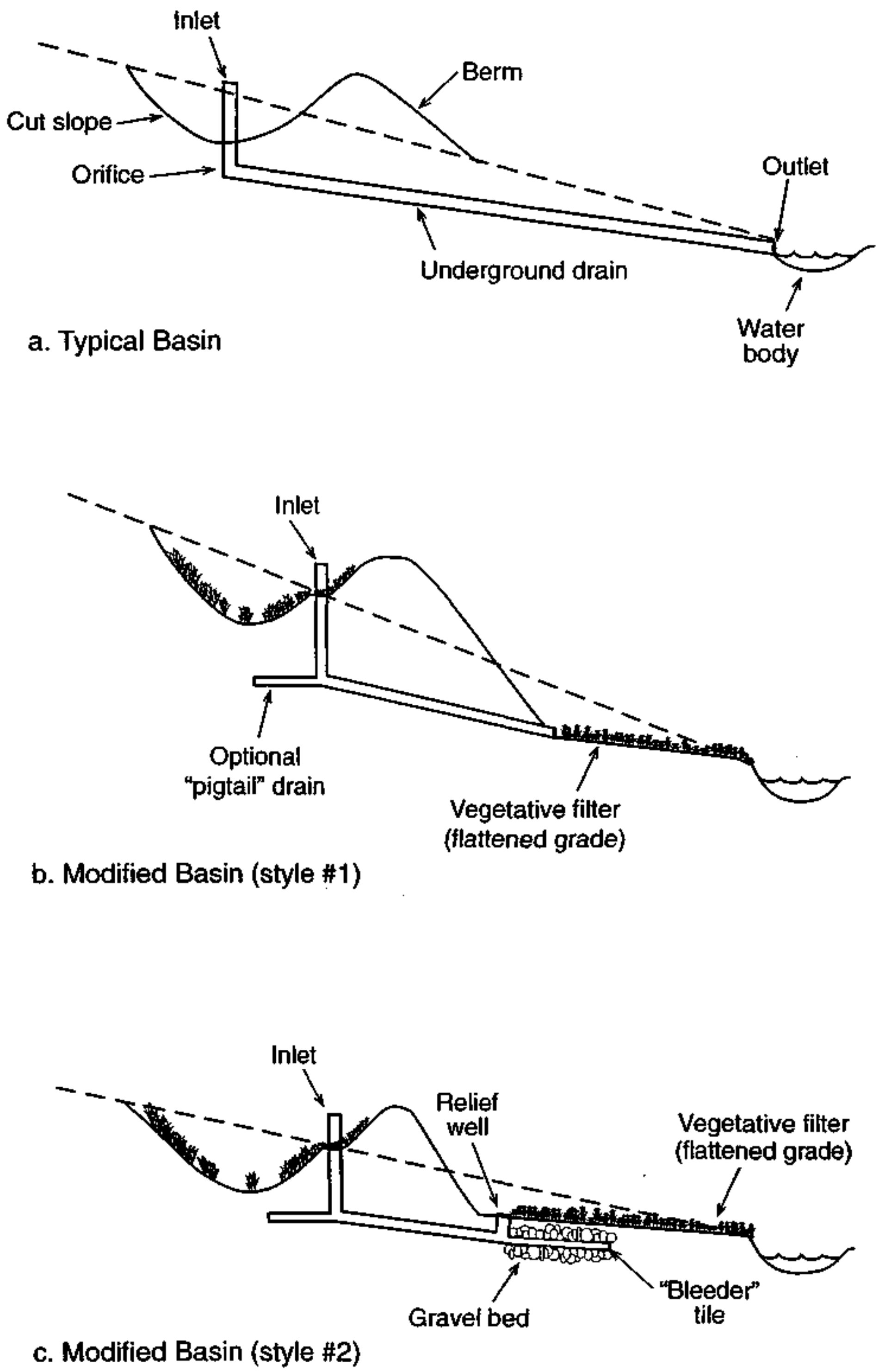


Figure 5. Design diagram of sediment basins

tile sampling program. The Illinois EPA continues quarterly monitoring of the water samples. Results of atrazine concentrations in Otter Lake waters and finished waters will be discussed later.

Population Segments Adversely Affected by Lake Degradation

Degradation of Otter Lake has been a gradual process. The degradation problems are agricultural chemical (such as atrazine) contamination, siltation, and shoreline erosion.

The water quality is of utmost concern for the ADGPTV Water Commission and its customers. Since 1991 the finished water has been under Illinois EPA's atrazine advisory and restriction, but not during the study period. Unfortunately, the problems have persisted and are most likely to affect the drinking water consumption, although np health risks have been demonstrated.

Siltation at the upper end of the lake has a minor effect on lake volume, but reduced water depth impacts shoreline aesthetics and boat access. Siltation is reported to have adversely affected fisheries in the lake.

More than one-half of shoreline currently is estimated to have erosion problems. This affects the lake users in different ways. The aesthetic values of the lake and wooded area adjacent to the shoreline are reduced. The erosion is more significant in areas in which the shoreline erosion is severe and results in nearly vertical banks. The deposition of shoreline sediment into the water adjacent to the shore will destroy fish habitat and thereby affect fishing. The steep bank areas discourage hikers and other visitors for safety reasons, resulting in the reduction of the recreational value of the lake.

The population segments adversely affected by lake degradation are difficult to quantify. For Otter Lake, the uses affected by degradation will gradually increase over time. However, the atrazine problem, which has public health, agricultural, and economic implications, could undermine the purpose for which the lake was created. Even though steps have been taken to bring this problem under control, efforts to mitigate the problem need to be accelerated.

As mentioned previously, Otter Lake is used as a public drinking water source for several communities, and it is heavily used for recreation purposes (e.g., boat fishing, motor boating, water skiing, ice fishing, camping, picnicking, hiking, waterfowl observation, duck hunting, water sports, and scouting). Few locations offer bank fishing. Four camp areas adjoin the lake. Each year more than 11,000 people use the recreational facilities, including campers, fishermen, and picnickers.

The ADGPTV Water Commission annually holds a "September barbecue" and open house of the water treatment plant at the plant site near the boat dock parking area. This family-oriented activity offers food and entertainment; it is done primarily to educate the area residents about the water-treatment system and the commission's activities in lake and watershed management. Unfortunately, the attendance for this public event is meager.

Comparison of Lake Uses to Other Lakes in the Region

Within 50 miles (80 km) of Otter Lake, there are 40 lakes with a surface area of 20 acres (8 ha) or more. These lakes and information about size, maximum depth, existence of boat ramps, and lake uses are listed in table 8. Among these lakes, eight lakes have surface areas greater than 1,000 acres. Otter Lake is the tenth largest lake in surface area within the region.

Uses for most of these lakes include recreation, boating, fishing, swimming, picnicking, and public water supply. Otter Lake's uses are similar to the others, except that swimming is not allowed.

Point Source Discharges

There are no known point sources of municipal or industrial discharges into Otter Lake. The wastewater and solid wastes disposals from the four camper areas and at the boat ramp area are well managed, periodically evacuated from concrete vaults, and disposed off-site properly.

Land Use and Nonpoint Pollution

Watershed Land Use

The Otter Lake watershed is composed of cropland, pasture and hayland, woodland, and water (figure 6). A breakdown of land uses in acres, as a percentage of the total drainage area, and inadequately protected acreages is shown in table 9. Recently, R.L. Farnsworth and W.H. Yang (personal communication, 1998) divided the Otter Lake watershed into 24 subwatersheds (figure 7). The breakdown of land uses for the 24 subwatersheds is presented in table 10. Based on 1998 results (table 10), approximately 78.4 percent of the watershed is agricultural farm land. Land use in the watershed is primarily cropland. Sixty-five percent of the total watershed is cultivated for row crop production (Macoupin County SWCD, 1995). The predominant crops are corn, soybeans, and wheat, which are the typical agricultural products in Illinois. There is no urban development in the watershed.

Nonpoint Pollution Sources

The primary concerns of nonpoint pollution sources are agricultural chemicals (such as atrazine and nutrients) from tile drainage, feed lot runoff, and eroded soils.

Eroded Soils. Table 9 shows that 22.9 (21.9 plus 1.0) percent of land in the watershed is unprotected. An estimated 1,920 acres (777 ha) of highly erodible soil are in the Otter Lake watershed. Most of these highly erodible soils are in hayland, pasture, and woodland uses. Approximately 120 acres (48.6 ha) of the highly erodible soils in cropland is eroding at an average of 14 tons per acre per year (t/a/y). There are 830 acres (336 ha) of potentially highly erodible soils in the watershed where sheet and rill erosion generate approximately 6 t/a/y. Another 1,150 acres (465 ha) of cropland erodes at an average of 4.5 t/a/y. The remaining 6,300 acres (2,550 ha) of cropland erodes at an estimated 2.5 t/a/y. The total erosion rate in the

Table 8. Public Lakes within a 50-Mile Radius of Otter Lake

Lake code	*Lake name*	*County*	*Area, acres*	*Mean depth, feet*	*Boat ramps*	*Lake uses**
SDH	Ashland Old	Morgan	5.0	12.0	0	F,R
RDH	Beaver Dam	Macoupin	56.5	7.4	1	R,BR,P,C,PK
RDG	Carlinville	Macoupin	168.0	8.2	1	S,R,C,P
RDZJ	Flat	Jersey	165.0	3.0	1	R
RDZK	Fowler	Jersey	231.2	3.0	1	R,P,C
SDU	Gillespie New	Macoupin	207.0	10.2	1	S,R,C,P,BR
SDT	Gillespie Old	Macoupin	71.0	9.8	1	S,R,P
ROL	Glen Shoals	Montgomery	1084.0	12.0	0	F,R
ROP	Gov Bond (Greenville)	Bond	775.0	13.0	1	S,R,P
RDZF	Greenfield	Greene	40.0	10.2	0	S,P,PK
ROY	Greenville Old	Bond	21.6	9.1	1	P,S,PK,BR
ROZA	Highland Silver	Madison	550.0	10.0	1	R,P
ROT	Hillsboro Old	Montgomery	108.7	10.6	1	BR,R,S,P,PWS
RJC	Horseshoe	Madison	2107.0	2.0	1	R,P,PK
RDI	Jacksonville	Morgan	476.5	12.8	1	S,R,C,P
REH	Kincaid City	Christian	30.7	8.0	1	R,P
RON	Lou Yaeger	Montgomery	1205.0	9.6	2	C,FC,F,P,R,S
SDL	Mauvaisse Terre	Morgan	172.0	5.3	1	R,C,P
RDL	Meredosia	Morgan	1692.0	2.5	1	R,BR
SDB	Morgan	Morgan	24.0	3.0	0	P,S
RJF	Mt. Olive New	Macoupin	47.8	7.1	1	P,BR
RJG	Mt. Olive Old	Macoupin	32.5	11.2	1	P,BR
RDF	Otter	Macoupin	765.0	21.0	1	R,C,IF,P,PWS,WTF
RDZP	Palmyra-Modesto	Macoupin	35.0	15.0	0	P,S
ROF	Pana	Shelby	219.5	13.8	0	F,R,P,PWS,WS
RDP	Pittsfield	Pike	241.0	12.3	1	R,C,P,S
RDA	Pohlman	Calhoun	95.0	3.0	1	R,P,C,PK
ROE	Ramsey	Fayette	46.6	8.6	1	R,BR,C,P
SDO	Royal	Calhoun	68.0	3.0	0	C,P
REB	Sangchris	Christian	2165.0	15.1	1	R,P,C,PK
SDK	Shipman	Macoupin	13.0	9.3	0	F,P,PWS
REF	Springfield	Sangamon	4024.0	15.4	1	S,R,C,P,PK
RJA	Staunton	Macoupin	78.8	12.4	1	BR,R,S,P
SDM	Swan	Calhoun	2345.0	3.0	1	C,P,R,BR
REC	Taylorville	Christian	1148.0	6.9	1	S,R,P,C
RJO	Tower	Madison	77.0	17.0	1	S,R,P,BR,PK,CN
ROD	Vandalia	Fayette	660.0	13.7	1	C,F,P,PWS,R,WS
REK	Virginia New	Cass	15.0	9.0	1	P,R
ROU	Walton Park	Montgomery	25.0	6.0	1	F,R,P
SDC	Waverly	Morgan	135.0	5.1	1	R,P
RDZG	White Hall	Greene	33.8	15.4	1	P,R,BR
REZA	New Berlin Lake	Sangamon	4.0	16.0	0	F,PWS
RJE	Bunker Hill New Lake	Macoupin	24.8	18.0	0	F,P,PWS
SDZF	Hettick	Macoupin	79.0	8.7	1	F,P
SDZO	Ashland New Lake	Morgan	13.5	11.0	0	F,PWS,R

Notes: * BR = boat rental, C = camping, F = fishing, FC = flood control, IF = ice fishing, P = picnicking, PK = park, PWS = public water supply, R = recreation, S = swimming, WTF = waterfowl hunting, and WS = water skiing.

Source: J. Mitzelfelt, personal communication, 1998

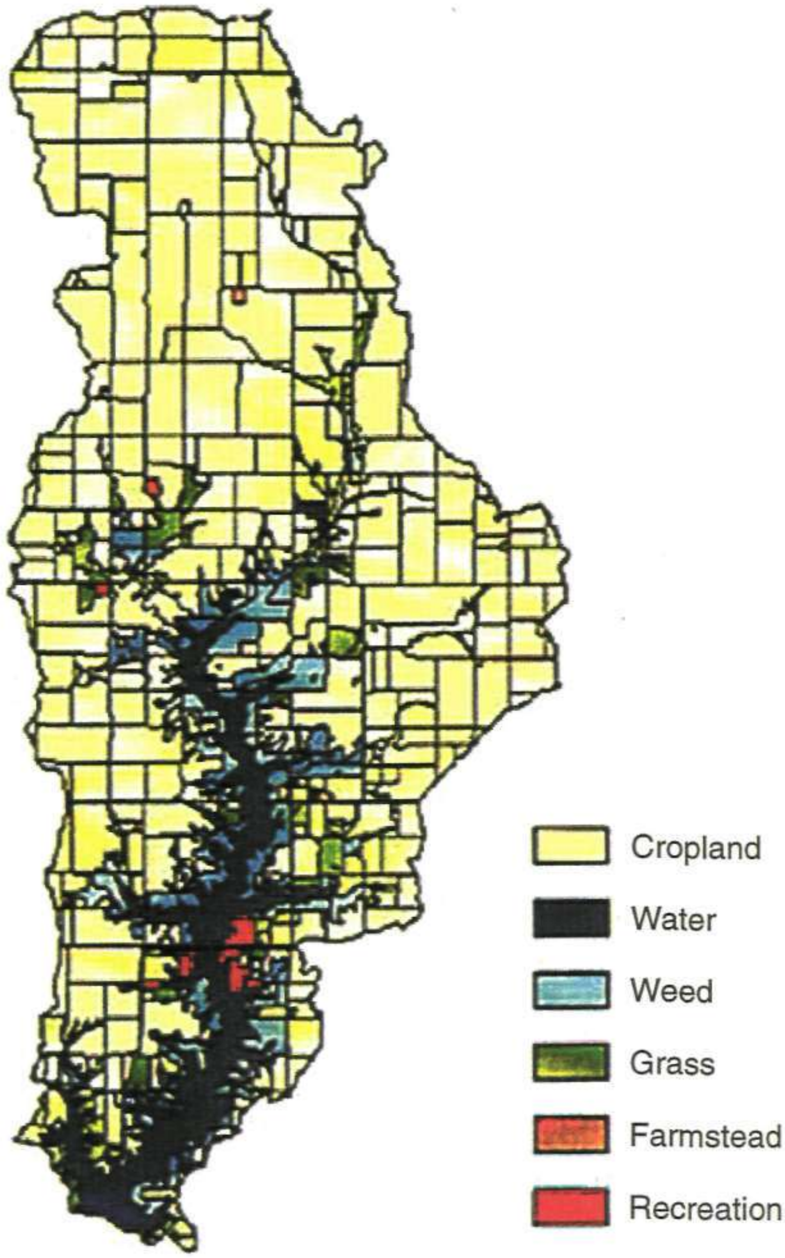


Figure 6. Otter Lake Watershed land-use map
(Source: Farnsworth and Yang, personal communication, 1998).

Table 9. Land Use and Unprotected Acreage in Otter Lake Watershed

	Land use		*Unprotected area*	
Type	*Acres*	*Percent of watershed*	*Acres*	*Percent of watershed*
Agricultural	(11,015)	(84.7)	(2,850)	(21.9)
Cropland	8,400	64.7	2,100	16.1
Pasture and hayland	2,185	16.8	650	5.0
Farmstead/others	320	2.4		
Feedlots	110	0.8	100	0.8
Forest/wildlife	(1,210)	(9.4)	(130)	(1.0)
Water Commission	955	7.4	80	0.6
Private	255	2.0	50	0.4
Water	765	5.9		
Total	12,990	100	2,980*	22.9*

Notes: * Agricultural plus forest/wildlife
Blank spaces — not applicable
Parentheses - sum of the group

Source: Macoupin County SWCD, 1995

Table 10. Land Use Distribution in Otter Lake Subwatersheds

Subwatershed	*Area, acres*	*Percentage of area*					
		Farm land	*Water*	*Wood*	*Grass*	*Farmstead*	*Recreation*
1	952.33	100.00	0.00	0.00	0.00	0.00	0.00
2	253.89	100.00	0.00	0.00	0.00	0.00	0.00
3	330.47	100.00	0.00	0.00	0.00	0.00	0.00
4	764.43	96.07	0.00	0.56	3.37	0.00	0.00
5	288.45	98.01	0.00	0.00	0.00	1.29	0.00
6	250.54	100.00	0.00	0.00	0.00	0.00	0.00
7	274.59	90.74	0.00	0.01	8.29	0.96	0.00
8	688.29	86.25	0.93	3.90	7.23	1.69	0.00
9	378.81	92.08	0.00	6.79	1.13	0.00	0.00
10	383.82	96.89	0.00	0.00	2.69	0.42	0.00
11	267.28	89.07	0.00	7.30	3.42	0.21	0.00
12	890.09	72.05	6.68	17.53	3.67	0.07	0.00
13	457.42	81.90	0.60	5.24	10.63	1.63	0.00
14	272.55	99.20	0.00	0.00	0.80	0.00	0.00
15	1208.96	86.71	1.54	8.68	3.07	0.00	0.00
16	424.86	86.39	3.10	10.51	0.00	0.00	0.00
17	358.88	55.47	14.87	29.66	0.00	0.00	0.00
18	695.95	61.58	12.10	23.05	2.30	0.97	0.00
19	1085.86	70.49	10.96	14.43	2.00	0.22	1.90
20	601.87	72.01	4.84	14.40	8.75	0.00	0.00
21	277.48	32.44	26.69	33.27	5.47	0.38	1.75
22	429.24	62.81	16.88	8.38	11.93	0.00	0.00
23	428.34	44.63	19.27	27.84	2.48	0.18	5.60
24	721.31	36.66	37.33	20.68	5.19	0.14	0.00
Total	12,685.71	78.45	6.97	10.35	3.53	0.32	0.39

Source: R.L. Farnsworth and H.W. Yang, personal communication, 1998

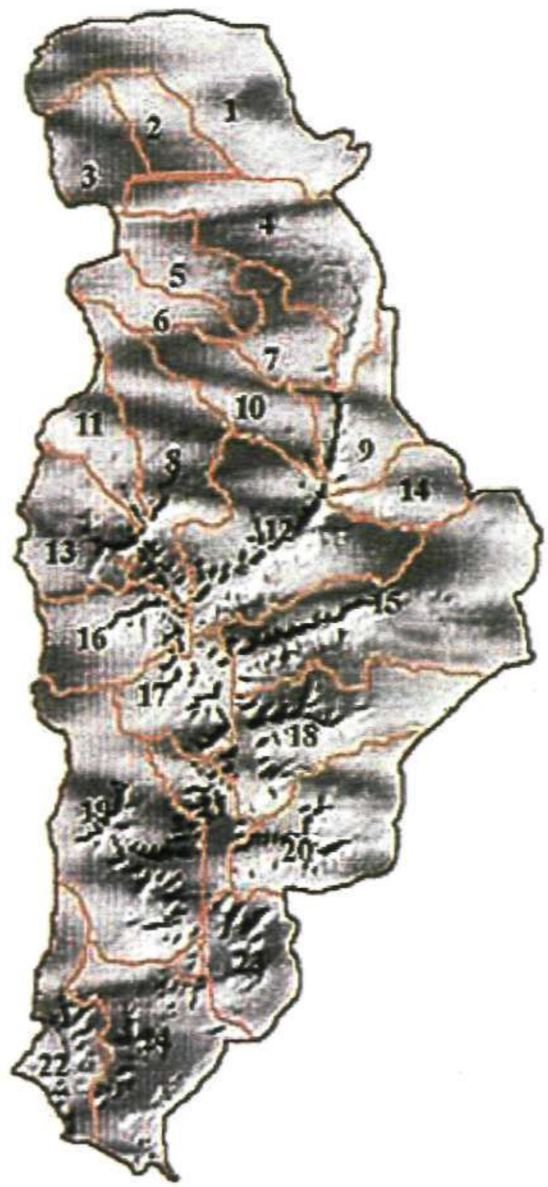


Figure 7. Watershed and numbered subwatersheds of Otter Lake
(Source: Farnsworth and Yang, personal communication, 1998)

watershed is 27,585 tons per year. Table 11a presents the estimated soil erosion rates from different sources from croplands (Macoupin County SWCD, 1993). Assuming a sediment delivery rate of 75 percent off-field movement and a 39 percent watershed transport efficiency, a potential soil loading rate of 8,070 (27,585 x 0.75 x 0.39) tons of eroded soils enter into Otter Lake annually. In addition, Macoupin County SWCD (1993) estimated an additional 5,500 tons per year of sediment to the lake is eroded from gully, ephemeral gully, and streambank erosion. This estimate was less than lake sediment survey result (23,804 tons/year).

The protected land areas, excluding cropland, consist of 3,825 acres (1,548 ha). Assuming an average soil erosion rate of 0.5 t/a/y, the soil loss for the protected lands would be 1,913 tons per year. The portion of these sediments delivered to Otter Lake is estimated as 560 (1,913 x 0.75 x 0.39) tons per year. Thus the total annual sediment input to the lake is estimated as 14,130 (8,070 + 5,500 + 560) tons.

Sedimentation at the upper end of Otter Lake only creates problems for boaters to reach that area. It has not yet affected the water-supply system. Erosion in the watershed has reduced the lake surface area by about 6 acres since completion of the lake in 1965.

Farming. There are 100 farms in the Otter Lake watershed, with an average farm size of 285 acres. There are no low income or minority farmers. The types of farming are grain and livestock production.

Eight farms in the watershed produce a substantial number of livestock each year: an estimated 300 head of cattle, 7,500 hogs, 200 sheep, and 25 poultry. Animal wastes and solid and liquid wastes are combined and disposed of on the farms. The storage capacity of livestock waste ranges from 90 to 730 days, with an average of 170 days. Several waste disposal methods are practiced: directly inject waste into soil (38%), spread and incorporate (50%), and spread on top of the land (12%). Spreading operations are performed each month but concentrated in the months of March, May, October, and November. Eighty-three percent of the producers have adequate waste-handling facilities. Only one producer intends to expand his livestock operation to double the size. Livestock operations in the watershed are well managed. Their contributions of nutrients were not assessed separately.

Similar to other watersheds in Illinois, subsurface drainage systems are commonly used on cropland in the Otter Lake watershed. Subsurface drainage using clay tile or polyvinyl chloride pipes (so-called field tiles) can lower the water table enough to aerate the root zone and to improve plant growth. Of the 8,400 acres of cropland in the watershed, approximately 2,330 acres have a whole-field subsurface drainage system. Field tile has been identified as a potential conduit for some nutrients and pesticides in water.

As previously mentioned, the concentration of atrazine in Otter Lake water was elevated by the farm drainage and by runoff water from surrounding cropland. Atrazine is used as a herbicide. Since 1991, the ADGPTV Water Commission received the Illinois EPA's atrazine advisory and restriction. In 1993, Otter Lake had an average atrazine concentration of 4.9 µg/L.

Table 11a. Total Erosion Rate and Sediment Yield from Cropland in Otter Lake Watershed

Source, cropland	*Area, acre*	*Erosion rate, tons/acre/year*	*Total erosion rate tons/year*	*Sediment yield, tons/year*
Highly erodible land	120	14.0	1,680	492
Potentially highly erodible land	830	6.0	4,980	1,457
Other sloping cropland	1,150	4.5	5,175	1,514
Other cropland	6,300	2.5	15,750	4,707
Total	8,400		27,585	8,070

Source: Macoupin County Soil and Water Conservation District, 1993

Table 11b. Estimated Nonpoint Nutrient Loading Rates

		Total nitrogen		*Total phosphorus*	
Land use	*Acres*	*Export rate, lb/a/y*	*Loading rate, lb/y*	*Export rate, lb/a/y*	*Loading rate, lb/y*
Cropland and feedlots	8,510	8.6	73,190	0.50	4,255
Pasture and hayland	2,185	3.2	6,990	0.25	546
Woodland	955	1.3	1,240	0.10	124
Resident and farmstead	575	1.2	690	0.10	69
Total	12,225		82,110		4,994

Note: lb/a/y - pounds per acre per year

Sources: City of Charleston, 1992; Berrini, 1992

Since then, atrazine levels in lake and finished waters have been monitored, and the results show higher levels than standards allow. Results of this atrazine monitoring will be discussed in detail later. Management projects for Otter Lake and its watershed during 1991-1997 are presented in table 7.

Nutrient Loadings. Nutrient loadings from nonpoint pollution sources within the watershed consist of nitrogen and phosphorus, which result primarily from runoff related to agricultural activities. Other sources include pasture and hayland, woodland, residential and other development, and atmospheric deposition. Rain water quality was not determined during this study.

Macoupin County SWCD (1995) indicated little contribution of plant nutrients from atmospheric deposition. Analytical results from the National Atmospheric Deposition Program (NADP) managed by the Water Survey indicate that atmospheric nitrogen deposition (wet and dry forms) in the watershed may be significant. Nitrogen deposition, like all other sources of nitrogen in the watershed, is subject to plant uptake as well as complex interactions within the soil chemistry system and the atmosphere.

The estimated total nitrogen (the sum of nitrite, nitrate, and total Kjeldahl nitrogen) and total phosphorus loads emanating from nonpoint sources for the entire watershed are shown in table 11b. Nutrient export rates for nitrogen and phosphorus were estimated from values used by Crawford, Murphy, & Tilly, Inc. (1995) and the City of Charleston (1992). An estimated 82,110 pounds (41 tons) of nitrogen and 4,994 pounds (2.5 tons) of phosphorus are added to the lake annually from the watershed, in which 89 percent of nitrogen and 85 percent of phosphorus were contributed by agricultural activities.

BASELINE AND CURRENT LIMNOLOGICAL DATA

In order to evaluate the lake water quality, both historical and current limnological data were gathered. A sampling program was developed to collect data from the lake and its tributaries for 19 consecutive months, April 1996 through October 1997. These data are referred to as the current baseline data. In situ monitoring and water and sediment sample collections were carried out. In addition, monitoring for macrophytes, a bathymetric survey, stage-level measurements, and flow determinations were carried out as required. The historical data were obtained from the Illinois EPA, other agencies, and publications.

Morphometric Data

The pertinent morphometric details of Otter Lake are presented with general lake information in table 2. Some data are again listed below:

Item	*English units*	*System International units*
Surface area	765 acres	310 hectares
Watershed area	12,990 acres	5257 hectares

Maximum depth	50 feet	15.2 meters
Average depth	19.7 feet	6.0 meters
Shoreline length	39 miles	62.7 km
Storage capacity	15,000 acre-feet	18.5 x 10^6 cubic meters
Retention time	1.6 years	1.6 years

Materials and Methods

Field Measurements

In order to assess the current conditions of the lake, physical, chemical, and biological characteristics were monitored from April 11, 1996-October 3, 1997. The lake was monitored twice a month from April 1996-September 1996 and monthly from October 1996-October 1997, except in December 1996 and September 1997. A total of 23 sampling visits were made.

During these sampling trips, lake water samples were collected at three sites (stations 1, 2, and 3), and they were collected at station 4 (figure 3) commencing on May 9, 1996. In addition to the regular lake sampling, trips were made to the lake for collecting tributary water samples during storm events (at the watershed gaging station RDF 02) and from the spillway outflow (RDF 01, near station 1).

Grab water samples were taken at 0.3 m (1 foot) below the surface as surface sample and 0.6 m (2 feet) above the lake bottom for stations 1, 2, and 4 as near bottom samples, and only the surface samples were taken for station 3 during the study period. A middepth sample also was collected at station 1. Lake sediment samples also were collected twice at stations 1, 2, 3, and 4 during this study period.

In situ observations for temperature, dissolved oxygen (DO), and Secchi disc readings were made at the sampling sites on the lake. A Hydrolab DataSonde I model 2070-DS with a 50-foot cable and probe was calibrated at the site using the saturated air chamber standardization procedure. Temperature and DO measurements were obtained in the water column at 1-foot intervals from the surface.

Secchi disc transparencies were measured using an 8-inch diameter Secchi disc, which was lowered until it disappeared from view, and the depth was noted. The disc was lowered further, then slowly raised until it reappeared. This depth also was noted, and the average of the two depths was recorded. Secchi disc visibility is a measure of a lake's water transparency, or its ability to allow sunlight penetration.

Water Chemistry

Grab samples for water chemistry analyses were collected near the surface (1 foot below), near the bottom (2 feet above the lake bottom if the water depth was greater than 10 feet), and at mid-depth for station 1 in two 500-milliliter (mL) plastic containers. Water samples for nutrient analyses were collected in 125-mL plastic bottles with and without filtration (0.45-micrometer or µm, membrane filter) that contained reagent-grade sulfuric acid as a preservative. These samples were kept on ice until transferred to the laboratory for analyses. Samples for metals were collected in 500-mL plastic bottles containing reagent-grade nitric acid as a preservative. Samples for organic analyses were collected in 1-gallon dark amber bottles filled to the brim without any headspace. The methods and procedures involved in the analytical determinations followed Illinois EPA methods.

Chlorophyll

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 2 feet above the bottom of the lake, and raised at a constant rate to the surface. For chlorophyll analysis, a measured amount of sample was filtered through a Whatman GF/C (4.7-centimeters or cm, glass microfiber filter) using a hand-operated vacuum pump. The chlorophyll filters then were folded into quadrants and wrapped in aluminum foil, and the filtrate volume was measured using a graduated cylinder. Filters were kept frozen in the laboratory until analyzed. Chlorophyll concentrations were analyzed by the Illinois EPA.

Macrophytes

A macrophyte survey was conducted in August 1996 by the Illinois EPA field staff. The entire perimeter of the lake was surveyed by moving a boat along the shoreline and macrophyte communities. Visible macrophyte areas were sketched onto the lake map with indication of the size and density of each macrophyte zone. Macrophytes were identified by common name as accurately as possible. If growth of an unidentified species was present, a specimen was collected to identify at the field office. The survey enabled the delineation of the areal extent and abundance of macrophytes in the lake.

While surveying the lake perimeter, the amount of each type of major shoreline development/land use also was noted. Land-use categories included, but were not limited to, woodland, pasture, residential, shrub/brush, golf course, picnic/camping, grass bordered crop, wetland, highway/dam, and industries.

Sediment

Surficial sediment samples were collected using an epoxy-coated Ekman dredge. Portions of each sample were placed in a 250-mL plastic bottle for metal and nutrient analyses and in a specially prepared 200-mL glass bottle for trace organics analyses according to the Illinois EPA guidelines (1987).

Data Analyses

Statistical analyses were performed for means and standard deviation for each grouped data. Student's *t*-test was used to evaluate any significant difference between the mean concentrations of the historical data (1977-1994) and the current study data (1996-1997).

In-Lake Water Quality

The analytical results of historical samples and routine water samples (current study) from four locations in Otter Lake, listed in the appendix, are based on each station and are associated with different sampling date and water depth. Water quality data provided include turbidity, Secchi disc transparency, conductivity, pH, total and phenolpthalein alkalinity, total and volatile suspended solids, nitrogen (ammonia, nitrate/nitrite, and total Kjeldahl), and total and dissolved phosphorus. Sampling dates and site depths also are given.

The observed data for each station are divided into two groups: historical and current study data. The raw data and the results of their statistical analysis for each station are presented in table 12 (historical) and table 13 (current study). Tables 12a-f present the historical data of water quality parameters for stations 1, 2, and 3, including the surface (S) and bottom (B) samples for stations 1 and 2, collected during 1977, 1979, 1980, 1982, 1984, 1989, 1991, and 1994 under the Ambient Lake Monitoring Program (ALMP) by the Illinois EPA. Tables 13a-h list the water quality monitored during the 1996-1997 diagnostic study and the statistical summary for each parameter for stations 1, 2, 3, and 4, respectively. The historical and current conditions of most parameters monitored were compared for stations 1, 2, and 3. The results of statistical analyses with *t*-tests are given in table 14. The upward arrows in the table indicate that the mean water quality parameter at a station during this study period was significantly (95 percent confidence level) higher than that during the past. The downward arrows indicate the reverse condition. The equal sign suggests that there is no significant difference between the two means of a water quality parameter.

Physical Characteristics

Temperature and Dissolved Oxygen. Lakes in the temperate zone generally undergo seasonal variations in temperature throughout 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 are mixed with the lower layers by wind action. Spring turnover is a complete mixing of a lake when the water temperature is uniform from top to bottom. By late spring, differences in thermal resistance cause the mixing to cease, and the lake approaches the thermal stratification of the summer season. Almost as important as water temperature variations is the physical phenomenon of increasing density with decreasing temperature. These two interrelated forces are capable of creating strata of water of vastly different characteristics within the lake.

During thermal stratification, the upper layer (epilimnion) is isolated from the lower layer (hypolimnion) of water by a temperature gradient (thermocline). Temperatures in the epilimnion and hypolimnion are essentially uniform. The thermocline typically will 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 stagnated.

Table 12a. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 1 Surface (RD-A06-F-1)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as CaCO₃)*	*Phenolph-thalein alkalinity (mg/L as CaCO₃)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
06/21/77	0		46	330	8.1	107		5	2	0.100		0.000	0.020		
05/22/79	1	22.0	18		7.8	90	0	15	3	0.020	0.70	1.700	0.080	0.040	
06/12/79	1	8.5	30	285	8.4	50	0	11	2	0.010	0.70	1.500	0.020	0.010	48
07/30/79	1	5.6	26	260	9.0	64	15	7	2	0.010	1.20	0.370	0.030	0.010	49
08/16/79	1	5.7	24	240	9.0	59	9	11	5	0.010	1.20	0.010	0.040	0.010	43
09/25/79	1	3.0	72	250	8.1	80	0	6	3	0.020	0.80	0.010	0.020	0.020	40
10/26/79	1	2.6	48	255	7.0	80	0	5		0.160	0.70	0.180	0.020	0.020	47
06/24/80	1	1.5	76	216	8.7	100	12	12	2	0.100	0.60	0.300	0.010	0.010	43
09/02/80	1	5.0	30	312	8.4	90	0	6	2	0.014	1.00	0.006	0.040	0.002	43
05/24/82	1	2.1	54	132	8.4	94	38	2	1	0.020	0.60	1.620	0.010	0.007	41
08/09/82	1	3.2	42	290	8.3	90	20	4	3	0.100	0.80	13.000	0.025	0.015	42
05/17/84	1	11.0	24	298	7.7	85	0	3	0	0.030	0.60	2.900	0.045	0.020	52
08/17/84	1	1.5	78	277	8.6	80	20	4	2	0.040	0.30	0.050	0.001	0.001	51
04/18/89	1	3.6	48	337	7.9	130	0	4	2	0.110	0.90	0.380	0.012	0.001	46
06/07/89	1	0.8	94	343	8.4	120	10	1	1	0.100	0.60	0.200	0.013	0.001	47
07/14/89	1	3.7	66	324	8.5	95	5	2	1	0.100	0.70	0.100	0.021	0.001	43
08/17/89	1	4.6	36	313	8.4	100	5	6	3	0.090	1.00	0.100	0.006	0.001	47
10/13/89	1	0.2	56	335	8.6	105	1	3	1	0.110	0.60	0.100	0.024	0.011	50
04/25/91	1	1.5	36	317	9.1	95	10	5	2	0.010	1.00	2.400	0.161	0.106	45
06/10/91	1	2.3	54	329	8.4	100	10	1	1	0.020	0.60	2.300	0.023	0.013	46
07/05/91	1	1.1	72	328	8.8	100	0	2	1	0.060	0.70	2.300	0.034	0.001	47
08/14/91	1	5.2	20	287	9.0	80	0	5	4	0.010	1.30	0.900	0.021	0.012	46
10/07/91	1	2.6	48	305	7.8	100	0	5	3	0.190	0.89	0.180	0.023	0.012	41
04/21/94	1	2.2	18	353	7.9	100	0	28	6	0.030	1.10	1.970	0.145	0.038	40
06/13/94	1	4.2	44	325	7.9	90	0	10	5	0.040	0.84	1.970	0.020	0.004	47
07/11/94	1	3.0	84	326	8.4	100	0	5	2	0.040	0.32	1.780	0.014	0.002	46
08/02/94	1	3.9	72	325	8.5	110	5	4	2	0.010	0.69	1.420	0.013	0.001	51
10/13/94	1	3.7	66	324	7.9	100	0	3	1	0.090	0.73	0.240	0.023	0.003	46
Count		27	28	27	28	28	27	28	27	28	27	28	28	27	26
Minimum		0.2	18	132	7.0	50	0	1	0	0.010	0.30	0.000	0.001	0.001	40.0
Maximum		22.0	94	353	9.1	130	38	28	6	0.190	1.30	13.000	0.161	0.106	51.5
Average		4.2	49.4	297	8.3	92.6	5.9	6.3	2.3	0.059	0.78	1.357	0.033	0.014	45.6
Standard deviation		4.2	21.7	47.7	0.5	16.9	9.0	5.5	1.4	0.050	0.25	2.467	0.037	0.021	3.4

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 12b. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 1 Bottom (RD-A06-F-1)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (jjmho/cm)*	*pH*	*Total alkalinity (mg/L as CaC0$_3$)*	*Phenolph-thalein alkalinity (mg/L as CaC0$_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
05/22/79	42	38.0			6.7	40	0	23	4	0.040	1.00	1.400	0.130	0.060	
06/12/79	46	27.0		246	6.6	40	0	10	2	0.060	0.60	1.300	0.070	0.040	
07/30/79	47	44.0		340	6.2	87'	0	39	5	0.730	1.60	0.300	0.120	0.020	
08/16/79	41	19.0		300	6.9	90	0	21	8	0.620	1.30	0.480	0.070	0.040	
09/25/79	38	9.0		300	6.9	120	0	10	2	0.920	1.40	0.030	0.040	0.020	
10/26/79	45	4.4		272	7.1	80	0	9	3	0.190	0.70	0.210	0.040	0.010	
06/24/80	41	6.0		285	7.8	102	0	11	4	0.500	1.00	0.200	0.020	0.010	
09/02/80	41	6.0		355	6.7	130	0	11	5	1.050	1.80	0.000	0.130	0.120	
05/24/82	39	2.4		285	7.1	108	0	3	1	0.050	0.80	1.560	0.018	0.010	
08/09/82	40	4.1		302	7.2	125	0	3	1	1.200	1.70	0.260	0.038	0.017	
05/17/84	49	26.0		308	6.7	98	0	17	0	0.030	0.80	2.500	0.075	0.023	
08/17/84	49	1.4		361	6.7	130	0	4	3	0.030	0.50	2.000	0.001	0.001	
04/18/89	44	2.5		338	7.2	120	0	3	1	0.180	0.90	0.380	0.010	0.001	46
06/07/89	45	12.0		355	7.6	130	0	10	4	1.200	1.60	0.100	0.109	0.001	47
07/14/89	41	12.0		368	6.9	125	0	4	2	1.600	2.10	0.100	0.144	0.126	43
08/17/89	45	25.0		395	6.9	162	0	66	21	2.500	3.80	0.100	0.532	0.360	47
10/13/89	48	8.2		406	6.9	170	0	32	10	2.900	3.60	0.100	0.330	0.280	50
04/25/91	43	3.2		224	7.6	105	0	3	2	0.200	1.00	2.000	0.101	0.090	45
06/10/91	44	2.7		341	6.8	120	0	11	3	0.790	1.40	1.100	0.109	0.042	46
07/05/91	45	4.7		356	7.4	120	0	10	2	1.300	2.10	0.390	0.101	0.023	47
08/14/91	44	22.0		377	7.1	140	0	14	4	2.200	3.10	0.010	0.256	0.199	46
10/07/91	39	20.0		373	6.9	150	0	30	8	2.700	3.40	0.010	0.196	0.148	41
04/21/94	38	7.9		333	7.4	95	0	26	6	0.200	1.20	1.940	0.084	0.037	40
06/13/94	45	3.1		375	6.9	105	0	17	4	0.400	1.00	1.570	0.053	0.029	47
07/11/94	44	8.4		414	7.1	120	0	46	10	1.400	2.20	0.120	0.380	0.175	46
08/02/94	49	4.5		443	7.0	140	0	27	6	2.100	2.50	0.030	0.544	0.431	51
10/13/94	44	17.0		403	6.9	155	0	17	5	2.000	2.50	0.020	0.204	0.153	46
Count		27		26	27	27	27	27	27	27	27	27	27	27	15
Minimum		1.4		224	6.2	40	0	3	0	0.030	0.50	0.000	0.001	0.001	40.0
Maximum		44.0		443	7.8	170	0	66	21	2.900	3.80	2.500	0.544	0.431	51.0
Average		12.6		341	7.0	115.1	0.0	17.7	4.7	1.003	1.69	0.674	0.145	0.091	45.7
Standard deviation		11.5		53.6	0.3	31.2	0.0	15.0	4.2	0.902	0.94	0.792	0.146	0.114	2.9

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 12c. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 2 Surface (RD-A06-F-2)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolphthalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
06/21/77	0		44	350	7.6	106		6	4	0.000		0.000	0.020		
05/22/79	1	23.0	14		7.8	90	0	12	3	0.040	0.70	2.700	0.100	0.050	35
06/12/79	1	6.4	24	275	8.5	40	40	9	1	0.020	0.90	1.600	0.040	0.010	30
07/30/79	1	9.0	24	260	9.1	60	14	10	3	0.010	1.40	0.210	0.030	0.010	31
08/16/79	1	5.3	24	240	8.6	64	0	7	4	0.010	1.30	0.030	0.040	0.010	30
09/25/79	1	3.3	60	250	8.0	90	0	6	3	0.010	0.70	0.030	0.030	0.010	30
10/26/79	1	4.4	33	257	7.3	75	0	9	2	0.210	0.80	0.320	0.030	0.010	33
06/24/80	1	2.0	67	140	8.7	100	4	1	0	0.100	0.60	0.300	0.030		30
09/02/80	1	4.0	28	280	8.2	90	10	4	1	0.010	0.90	0.000	0.020	0.002	30
05/24/82	1	2.4	48	284	8.3	98	24	4	1	0.020	0.60	1.920	0.018	0.007	29
08/09/82	1	3.7	30	271	8.3	90	20	5	4	0.110	0.80	13.000	0.029	0.015	30
05/17/84	1	25.0	16	288	7.4	88	0	1	0	0.030	0.60	3.400	0.078	0.045	36
08/17/84	1	27.0	54	275	8.6	80	20	45	38	1.100	1.80	0.300	0.259	0.178	29
04/18/89	1	3.5	38	336	8.2	120	0	5	2	0.130	0.80	0.420	0.016	0.001	28
06/07/89	1	0.9	114	339	8.3	120	10	1	1	0.150	0.70	0.210	0.024	0.001	30
07/14/89	1	2.9	54	324	8.5	105	5	4	2	0.140	0.30	0.100	0.021	0.001	31
08/17/89	1	4.3	28	310	8.5	100	5	7	4	0.100	1.10	0.100	0.024	0.009	32
10/13/89	1	1.3	66	331	8.1	110	0	3	1	0.170	0.60	0.100	0.031	0.010	29
04/25/91	1	1.4	36	314	8.9	100	15	5	3	0.010	1.03	2.500	0.115	0.095	31
06/10/91	1	0.1	54	331	8.3	100	10	4	2	0.040	0.60	2.600	0.018	0.006	30
07/05/91	1	2.0	60	334	8.7	100	10	3	1	0.040	0.80	2.200	0.019	0.006	30
08/14/91	1	5.0	22	288	9.1	90	10	5	4	0.050	1.40	0.870	0.024	0.008	29
10/07/91	1	3.3	40	305	8.0	90	0	6	4	0.200	0.80	0.170	0.039	0.013	29
04/21/94	1	16.0	8	317	7.3	90	0	28	6	0.170	1.30	2.400	0.140	0.065	33
06/13/94	1	2.9	42	326	8.2	90	0	14	7	0.020	1.10	2.100	0.019	0.004	30
07/11/94	1	5.5	60	330	8.4	100	0	4	2	0.050	1.00	1.760	0.017	0.003	31
08/02/94	1	3.3	64	326	8.6	110	10	4	2	0.010	0.80	1.340	0.018	0.002	30
10/13/94	1	2.9	66	332	7.7	100	0	2	1	0.150	0.78	0.220	0.028	0.002	31
Count		27	28	27	28	28	27	28	28	28	27	28	28	26	27
Minimum		0.1	8	140	7.3	40	0	1	0	0.000	0.30	0.000	0.016	0.001	28.0
Maximum		27.0	114	350	9.1	120	40	45	38	1.100	1.80	13.000	0.259	0.178	35.5
Average		6.3	43.5	297	8.3	92.7	7.7	7.6	3.8	0.111	0.90	1.461	0.046	0.022	30.5
Standard deviation		7.4	22.3	44.2	0.5	17.3	9.8	9.0	6.9	0.205	0.32	2.499	0.052	0.039	1.7

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/crr - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 12d. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 2 Bottom (RD-A06-F-2)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (/mho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
05/22/79	32	66.0			6.9	60		60	6	0.040	0.90	1.500	0.170	0.050	
06/12/79	28	33.0		287	6.7	60		14	1	0.040	0.60	1.800	0.090	0.030	
07/30/79	28	23.0		350	6.8	100		26	4	0.650	1.70	0.460	0.080	0.020	
08/16/79	28	8.3		300	7.5	90		13	6	0.440	1.10	0.280	0.040	0.010	
09/25/79	28	25.0		320	6.8	140		32	8	1.500	2.40	0.010	0.220	0.050	
10/26/79	30	3.2		258	7.3	90		4		0.170	0.70	0.260	0.030	0.020	
06/24/80	28	11.0		300	7.8	107		18	5	0.500	1.00	0.100	0.070	0.010	
06/24/80	29			300	7.8										
06/24/80	30			300	7.8										
09/02/80	28	18.0		340	6.8	130		19	3	1.200	2.00	0.000	0.250	0.200	
Count		8		9	10	8		8	7	8	8	8	8	8	
Minimum		3.2		258	6.7	60		4	1	0.040	0.60	0.000	0.030	0.010	
Maximum		66.0		350	7.8	140		60	8	1.500	2.40	1.800	0.250	0.200	
Average		23.4		306	7.2	97.1		23.3	4.7	0.568	1.30	0.551	0.119	0.049	
Standard deviation		19.7		27.6	0.5	29.0		17.1	2.3	0.536	0.65	0.700	0.084	0.063	

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L -- milligrams per liter, blank spaces - no data

Table 12e. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 3 Surface (RD-A06-F-3)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
06/21/77	0		26	280	8.1	88		45	9	0.000		0.000	0.060		
05/22/79	1	78.0	6		7.4	40	0	39	7	0.040	1.00	3.600	0.220	0.100	9
06/12/79	1	31.0	12	300	7.6	50	0	11	1	0.070	0.80	2.700	0.110	0.060	16
07/30/79	1	14.0	18	250	9.1	65	18	18	8	0.010	1.70	0.010	0.100	0.020	10
08/16/79	1	9.4	24	250	7.6	70	0	19	12	0.230	1.40	0.010	0.120	0.010	10
09/25/79	1	8.1	24	270	8.3	80	10	15	8	0.010	1.00	0.010	0.090	0.010	10
10/26/79	1	15.0	18	264	7.4	90	0	18	4	0.080	0.70	0.340	0.060	0.020	17
06/24/80	1	5.0	36	134	9.0	98	6	16	2	0.100	0.80	0.200	0.070	0.010	
09/02/80	1	8.0	18	265	8.2	90	5	11	4	0.084	1.30	0.010	0.080	0.005	15
05/24/82	1	3.5	30	157	8.3	96	25	6	2	0.010	0.70	2.860	0.028	0.003	13
08/09/82	1	5.2	18	267	8.2	85	15	18	8	0.130	1.60	0.660	0.082	0.019	14
05/17/84	1	53.0	6	274	7.2	85	0	4	2	0.030	1.00	4.400	0.133	0.077	18
08/17/84	1	2.0	30	259	8.7	80	20	5	4	0.030	0.40	1.900	0.020	0.010	15
04/18/89	1	5.7	20	352	8.5	115	1	13	4	0.100	1.60	0.970	0.056	0.011	15
06/07/89	1	2.2	32	312	8.7			5	5	0.100	1.10	0.240	0.053	0.001	18
07/14/89	1	7.3	26	317	8.4	100	5	10	5	0.180	0.90	0.100	0.047	0.005	16
08/17/89	1	6.9	20	329	8.9	100	5	13	9	0.100	1.70	0.100	0.060	0.057	16
10/13/89	1	0.3	34	322	8.4	100	1.	6	2	0.440	1.10	0.100	0.051	0.017	17
04/25/91	1	7.4	24	359	8.8	100	10	13	6	0.070	1.60	5.400	0.171	0.105	17
06/10/91	1	1.9	32	344	8.3	100	0	4	2	0.050	0.80	3.100	0.052	0.019	16
07/05/91	1	4.3	32	319	8.8	90	10	7	4	0.040	1.20	1.800	0.067	0.016	16
08/14/91	1	5.7	13	294	8.9	90	10	8	6	0.020	1.60	0.070	0.075	0.014	15
10/07/91	1	7.5	20	304	7.9	100	0	17	5	0.280	1.00	0.050	0.091	0.017	15
04/21/94	1		4	294	7.1	65	0			0.300	1.70	4.400	0.314	0.130	16
06/13/94	1	3.1	36	333	8.4	100	10	16	7	0.040	1.20	3.400	0.040	0.009	13
07/11/94	1	7.1	28	330	8.6	100	10	6	5	0.070	0.72	1.620	0.062	0.009	15
08/02/94	1	2.9	24	317	8.6	110	10	19	10	0.020	1.42	0.590	0.118	0.014	16
10/13/94	1	3.2	32	320	7.7	110	0	6	2	0.200	1.10	0.140	0.068	0.018	15
Count		26	28	27	28	27	26	27	27	28	27	28	28	27	26
Minimum		0.3	4	134	7.1	40	0	4	1	0.000	0.40	0.000	0.020	0.001	9.0
Maximum		78.0	36	359	9.1	115	25	45	12	0.440	1.70	5.400	0.314	0.130	18.0
Average		11.5	23.0	289	8.3	88.8	6.6	13.6	5.3	0.101	1.15	1.385	0.089	0.029	14.6
Standard deviation		17.4	9.1	52.0	0.6	17.9	7.1	9.7	2.9	0.105	0.37	1.669	0.061	0.035	2.4

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 12f. Water Quality Characteristics for the Historical Record through March 1996 in Otter Lake at Station 3 Bottom (RD-A06-F-3)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
06/12/79	14	44.0		300	7.2	50	0	29	6	0.100	0.90	2.900	0.150	0.060	
07/30/79	8 •	16.0		260	9.0	60	22	23	6	0.010	1.60	0.220	0.110	0.010	
08/16/79	8	12.0		250	7.5		0	17	8	0.230	1.40	0.010	0.110	0.010	
10/26/79	15	15.0		264	7.6	90	0	20	2	0.070	0.80	0.300	0.060	0.010	
06/24/80	9	8.0		302	8.0	102	0	23	2	0.200	1.20	0.200	0.080	0.010	
09/02/80	13	10.0		265	7.8	130	0	11	4	0.114	1.20	0.001	0.080	0.002	
Count		6		6	6	6	6	6	6	6	6	6	6	6	
Minimum		8.0		250	7.2	50	0	11	2	0.010	0.80	0.001	0.060	0.002	
Maximum		44.0		302	9.0	130	22	29	8	0.230	1.60	2.900	0.150	0.060	
Average		17.5		274	7.9	86.4	3.7	20.5	4.7	0.121	1.18	0.605	0.098	0.017	
Standard deviation		13.3		22.0	0.6	32.3	9.0	6.1	2.4	0.082	0.30	1.131	0.032	0.021	

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, μmho/cm - micromho per centimeter, mg/L -- milligrams per liter, blank spaces - no data

Table 13a. Water Quality Characteristics for the Current Study in Otter Lake at Station 1 Surface (RD-A06-F-1)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolphthalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/11/96	1	3.9	64	327	7.7	125	0	6	2	0.070	0.82	0.350	0.018	0.006	46
04/17/96	1	3.3	58	332	7.9	125		4	1	0.210	1.31	0.400	0.019	0.001	44
05/09/96	1	6.6	42	325	7.8			8	2	0.410	1.10	0.430	0.029	0.013	49
05/22/96	1	7.6	24	304	8.2			7	2	0.020	0.71	1.690	0.015	0.015	48
06/05/96	1	25.0	58	327	7.4	120	0	9	3	0.030	0.56	1.870	0.036	0.007	45
06/17/96	1	3.3	38	299	8.5			21	6	0.010	0.50	1.840	0.025	0.006	47
07/03/96	1	1.6	54	321	8.8	110	10	4	2	0.040	0.62	2.100	0.012	0.002	47
07/15/96	1		53	296	8.5			4	2	0.010	0.86	1.780	0.020	0.005	47
08/15/96	1	5.7	36	289	8.6	80	10	4	1	0.010	0.70	0.750	0.022	0.004	45
08/19/96	1	8.1	31	274	8.8			10	5	0.010	0.74	0.620	0.023	0.003	46
09/09/96	1	21.0	48	257	8.2			36	12	0.340	1.20	0.060	0.123	0.025	48
09/24/96	1	2.8	42	275	8.3			6	5	0.050	1.40	0.080	0.023	0.003	52
10/02/96	1	5.3	54	305	8.3	110	0	5	2	0.070	0.62	0.060	0.020	0.004	47
11/20/96	1	4.6	48	296	7.8	120		7	4	0.560	1.10	0.150	0.018	0.007	47
01/23/97	1	2.5	117	210	8.0	95		2	1	0.120	0.46	0.220	0.005	0.002	47
02/11/97	1	3.5	88	269	8.0	125		10	2	0.120	0.32	9.100	0.079	0.065	41
03/19/97	1	9.5	54	301	7.8	123		5	1	0.150	0.85	0.440	0.019	0.005	51
04/18/97	1	9.5	66	320	7.9	105	0	5	4	0.090	0.74	0.730	0.017	0.003	51
05/13/97	1	3.5	74	302	8.0			6	2	0.100	0.52	0.850	0.014	0.010	46
06/06/97	1	6.1	90	335	7.9	104	0	6	2	0.080	0.75	0.820	0.016	0.006	46
07/09/97	1	5.8	46	300	8.4	110	12	8	5	0.160	0.81	0.190	0.029	0.006	47
08/08/97	1	1.1	40	308	8.2	114	8	8	4	0.210	0.36	0.010	0.027	0.004	49
10/03/97	1	6.7	48	323	7.9	100	0	5	2	0.300	0.52	0.010	0.017	0.005	46
Count		22	23	23	23	15	10	23	23	23	23	23	23	23	23
Minimum		1.1	24	210	7.4	80	0	2	1	0.010	0.32	0.010	0.005	0.001	41.0
Maximum		25.0	117	335	8.8	125	12	36	12	0.560	1.40	9.100	0.123	0.065	52.0
Average		6.7	55.3	300	8.1	111.1	4.0	8.1	3.1	0.138	0.76	1.067	0.027	0.009	47.0
Standard deviation		5.8	21.0	28.7	0.4	12.9	5.2	7.1	2.4	0.144	0.29	1.878	0.025	0.013	2.4

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 13b. Water Quality Characteristics for the Current Study in Otter Lake at Station 1 Bottom (RD-A06-F-1)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolphthalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/11/96	44	2.7		315	*1.1*	120		6	*2*	0.070	0.56	0.380	0.016	0.004	46
04/17/96	42	5.6		333	7.8	117		7	3	0.010	1.23	0.380	0.025	0.004	44
05/09/96	46	6.8		336	7.3			6	2	0.060	0.81	0.630	0.029	0.007	49
05/22/96	46	13.0		330	7.2			10	1	0.530	0.68	0.440	0.040	0.020	48
06/05/96	43	28.0		329	7.1	130		12	3	0.230	0.60	0.770			45
06/17/96	45	38.0		350	7.1			35	8	1.000	1.40	0.120	0.169	0.042	47
07/03/96	45	17.0		347	7.3	130		17	5	1.100	1.40	0.180	0.144	0.048	47
07/15/96	44			359	7.1			74	16	0.320	2.70	0.010	0.499	0.349	47
08/15/96	43	28.0		362	7.0	150		40	12	1.400	1.70	0.010	0.270	0.227	45
08/19/96	44	34.0		386	7.1			66	16	1.800	2.50	0.020	0.492	0.412	46
09/09/96	46	19.0		385	7.0			44	18	0.080	1.30	0.010	0.112	0.018	48
09/24/96	44	6.1		379	7.0			46	14	2.500	2.20	0.030	0.463	0.404	52
10/02/96	45	15.0		400	7.2	160		36	26	2.500	4.40	0.010	0.384	0.322	47
11/20/96	45	4.3		297	7.7	119		8	5	0.580	1.00	0.140	0.023	0.002	47
01/23/97	45	3.1		309	7.7	180		4	1	0.220	0.67	0.310	0.008	0.002	47
02/11/97	39	3.7		320	7.7	107		5	4	0.300	0.97	0.280	0.040	0.015	41
03/19/97	49	7.9		301	7.8	122		11	1	0.170	0.82	0.530	0.024	0.004	51
04/18/97	49	11.0		323	7.5	90		16	5	0.240	0.96	0.680	0.030	0.006	51
05/13/97	44	3.9		309	7.4			11	3	0.330	0.77	0.650	0.024	0.011	46
06/06/97	44	25.0		346	7.0	110		17	4	0.570	1.40	0.520	0.058	0.016	46
07/09/97	45	25.0		358	7.1	126		5	2	1.400	1.83	0.010	0.115	0.095	47
08/08/97	47	7.1		364	7.0	160		38	12	2.700	2.90	0.010	0.268	0.225	49
10/03/97	44	7.8		390	7.0	100		6	3	0.300	0.33	0.010	0.020	0.006	46
Count		22		23	23	15		23	23	23	23	23	22	22	23
Minimum		2.7		297	7.0	90		4	1	0.010	0.33	0.010	0.008	0.002	41.0
Maximum		38.0		400	7.8	180		74	26	2.700	4.40	0.770	0.499	0.412	52.0
Average		14.2		345	7.3	128.1		22.6	7.2	0.800	1.44	0.267	0.148	0.102	47.0
Standard deviation		10.9		30.2	0.3	24.7		20.6	6.8	0.852	0.96	0.263	0.169	0.146	2.4

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, μmho/cm - micromho per centimeter, mg/L -■ milligrams per liter, blank spaces - no data

Table 13c. Water Quality Characteristics for the Current Study in Otter Lake at Station 2 Surface (RD-A06-F-2)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (/mho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/17/96	1	5.9	24	350	8.3	113		22	6	0.010	1.39	1.160	0.063	0.015	25
05/09/96	1	12.0	15	324	7.6			15	4	0.180	0.98	1.830	0.075	0.045	31
05/22/96	1	18.0	24	304	8.0			12	3	0.070	0.69	1.920	0.064	0.027	31
06/05/96	1	31.0	36	320	7.6	110	0	12	2	0.010	0.52	2.500	0.048	0.008	31
06/17/96	1	6.1	38	289	8.8			12	5	0.010	0.39	1.060	0.030	0.006	31
07/03/96	1	4.1	48	317	8.8	110	10	9	6	0.040	0.52	2.200	0.015	0.002	30
07/15/96	1		48	296	8.5			8	5	0.030	0.78	1.890	0.026	0.005	31
08/15/96	1	7.9	36	292	8.8	100	10	13	6	0.010	0.82	0.700	0.023	0.003	31
08/19/96	1	2.1	32	275	9.0			9	6	0.010	0.85	0.680	0.025	0.003	30
09/09/96	1	24.0	34	254	8.6			34	12	1.000	1.60	0.010	0.105	0.071	30
09/24/96	1	3.0	39	277	8.2			10	7	0.010	0.86	0.060	0.034	0.007	30
10/02/96	1	5.5	48	304	8.5	100	0	6	2	0.070	0.81	0.060	0.031	0.004	29
11/20/96	1	4.5	42	296	7.9	120		9	5	0.490	1.00	0.160	0.029	0.010	29
01/23/97	1	2.7	117	210	8.2	128		1	1	0.190	0.55	0.300	0.010	0.002	29
02/11/97	1	3.6	85	308	8.0	85		30	6	0.260	1.26	3.200	0.326	0.254	30
03/19/97	1	15.0	44	302	7.8			12	3	0.160	0.85	0.920	0.038	0.011	31
04/18/97	1	12.0	60	321	7.8	110	0	8	3	0.100	0.72	0.810	0.019	0.004	31
05/13/97	1	3.7	66	305	8.1			6	2	0.290	0.59	0.910	0.019	0.007	31
06/06/97	1	4.4	90	338	8.0	100	0	6	4	0.100	1.70	0.820	0.017	0.006	31
07/09/97	1	4.0	44	303	8.5	94	14	11	7	0.180	0.94	0.180	0.031	0.007	31
08/08/97	1	4.2	38	313	8.3	106	12	8	5	0.200	0.69	0.010	0.036	0.006	30
10/03/97	1	7.2	46	324	8.0	100	0	9	4	0.420	0.43	0.010	0.022	0.006	29
Count		22	23	23	23	14	10	23	23	23	23	23	23	23	23
Minimum		2.1	15	210	7.6	85	0	1	1	0.010	0.39	0.010	0.010	0.002	25.0
Maximum		31.0	117	350	9.0	128	14	34	12	1.000	1.70	3.200	0.326	0.254	31.0
Average		8.4	48.2	302	8.2	106.9	4.6	11.7	4.6	0.169	0.86	0.946	0.048	0.023	30.1
Standard deviation		7.5	23.1	29.3	0.4	11.4	6.0	7.6	2.4	0.225	0.35	0.906	0.064	0.053	1.3

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L -- milligrams per liter, blank spaces - no data

Table 13d. Water Quality Characteristics for the Current Study in Otter Lake at Station 2 Bottom (RD-A06-F-2)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolphthalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/17/96	23	6.3	24	354	8.0	117		26	6	0.010	1.60	1.120	0.077	0.007	25
05/09/96	29	9.8	15	328	7.4			21	4	0.240	1.20	1.750	0.106	0.048	31
05/22/96	29	12.0	24	326	7.3			12	2	0.320	0.60	0.880	0.049	0.026	31
06/17/96	29	24.0	38	338	7.2			21	4	0.100	0.52	1.060	0.068	0.034	31
07/15/96	29		48	334	7.1			36	6	0.280	0.86	0.790	0.060	0.007	31
08/19/96	28	8.3	32	366	7.3			20	8	0.520	1.10	0.010	0.096	0.044	30
08/19/96	30														
09/09/96	28	2.3	34	356	7.2			10	7	0.180	1.10	0.080	0.035	0.006	30
09/24/96	28	6.4	39	362	7.1			18	6	1.000	1.80	0.020	0.062	0.020	30
11/20/96	27	4.2		296	7.7	119		9	5	0.480	1.00	0.160	0.036	0.009	29
01/23/97	27	2.2	117	309	7.7	162		2	1	0.200	0.62	0.330	0.013	0.005	29
01/23/97	29														
02/11/97	28	2.9	85	321	7.7	103		6	2	0.260	0.83	0.320	0.023	0.004	30
03/19/97	29	8.7	44	302	7.8	121		15	4	0.210	0.92	0.890	0.041	0.011	31
05/13/97	29	4.2	66	308	7.5			11	2	0.230	0.74	0.770	0.018	0.006	31
Count		12	12	13	13	5		13	13	13	13	13	13	13	13
Minimum		2.2	15.0	296	7.1	103		2	1	0.010	0.52	0.010	0.013	0.004	25.0
Maximum		24.0	117.0	366	8.0	162		36	8	1.000	1.80	1.750	0.106	0.048	31.0
Average		7.6	47.2	331	7.5	124.4		15.9	4.4	0.310	0.99	0.629	0.053	0.017	29.9
Standard deviation		6.0	29.1	23.5	0.3	22.2		9.1	2.2	0.248	0.38	0.526	0.029	0.016	1.7

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 13e. Water Quality Characteristics for the Current Study in Otter Lake at Station 3 Surface (RD-A06-F-3)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/11/96	1	3.3	24	346	8.4	115	10	20	7	0.010	1.34	1.580	0.070	0.009	15
04/17/96	1	6.5	18	361	8.6	119		34	8	0.010	1.77	1.700	0.092	0.012	9
05/09/96	1	400.0	3	179	6.9			140	24	0.110	5.00	4.200	0.741		10
05/22/96	1	22.0	10	292	7.6			34	6	0.260	0.91	4.600	0.158	0.098	10
06/05/96	1	39.0	10	342	7.2	110	0	44	10	0.010	0.64	6.400	0.138	0.071	9
06/17/96	1	6.9	21	294	8.7			28	14	0.010	0.87	4.400	0.089	0.010	9
07/03/96	1	14.0	20	319	8.8	110	10	25	9	0.060	0.92	2.900	0.077	0.004	8
07/15/96	1		18	281	8.7			30	14	0.020	0.96	1.740	0.110	0.012	9
08/15/96	1	7.2	18	269	9.0	100	20	28	14	0.010	0.93	0.100	0.109	0.015	9
08/19/96	1	5.1	17	266	9.6			30	20	0.010	1.80	0.060	0.243	0.043	9
09/09/96	1	16.0	18	272	8.6			46	16	2.600	3.40	0.020	0.433	0.431	8
09/24/96	1	5.2	16	279	8.6			26	11	0.010	0.10	0.010	0.127	0.034	8
10/02/96	1	11.0	16	306	8.9	100	10	18	13	0.010	1.40	0.020	0.112	0.018	8
11/20/96	1	6.9	30	290	8.4	119		11	7	0.040	0.75	0.050	0.036	0.011	8
01/23/97	1	12.0	6	281	8.0	122		74	16	0.080	1.30	1.560	0.488	0.289	8
02/11/97	1	3.2	14	319	7.9	105		5	2	0.280	1.15	0.330	0.017	0.005	9
03/19/97	1	9.0	15	356	7.6	105		36	8	0.190	1.27	5.930	0.141	0.079	9
04/18/97	1	10.0	18	365	8.5	120	10	20	6	0.050	1.20	3.000	0.072	0.009	9
05/13/97	1	4.0	24	327	8.8			18	10	0.070	0.97	1.770	0.063	0.016	9
06/06/97	1	4.3	24	364	8.3	112	9	12	6	0.090	1.00	0.830	0.075	0.014	9
07/09/97	1	5.2	18	309	8.4	92	9	26	12	0.150	1.59	0.010	0.092	0.016	8
08/08/97	1	7.0	18	314	8.4	no	10	21	12	0.250	1.20	0.010	0.126	0.015	9
10/03/97	1	6.9	16	323	8.3	100	5	26	8	0.290	1.00	0.010	0.146	0.024	7
Count		22	23	23	23	15	10	23	23	23	23	23	23	22	23
Minimum		3.2	3	179	6.9	92	0	5	2	0.010	0.10	0.010	0.017	0.004	7.0
Maximum		400.0	30	365	9.6	122	20	140	24	2.600	5.00	6.400	0.741	0.431	15.0
Average		27.5	17.0	307	8.4	109.3	9.3	32.7	11.0	0.201	1.37	1.793	0.163	0.056	8.9
Standard deviation		83.6	16.0	42.2	0.6	8.9	5.0	27.3	5.0	0.532	1.00	2.051	0.169	0.104	1.5

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 13f. Water Quality Characteristics for the Current Study in Otter Lake at Station 4 Surface (RD-A06-F-4)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolphthalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
05/09/96	1	110.0	7	300	7.3			112	16	0.250	1.40	3.500	0.231	0.099	27
05/22/96	1	18.0	10	290	7.5			28	6	0.270	0.96	4.100	0.155	0.100	26
06/05/96	1	40.0	12	309	7.2	110	0	42	10	0.010	0.61	4.600	0.134	0.067	26
06/17/96	1	9.6	24	294	8.7			22	12	0.060	0.65	3.600	0.048	0.008	26
07/03/96	1	7.7	28	302	9.0	90	10	7	3	0.060	0.96	2.600	0.046	0.002	24
07/07/96	1		26	291	8.6			9	6	0.050	0.99	2.000	0.059	0.010	25
08/15/96	1	8.2	30	292	8.7	110	10	10	6	0.010	0.84	0.500	0.067	0.008	26
08/19/96	1	5.3	29	280	8.5			10	2	0.010	0.87	0.470	0.081	0.010	26
09/09/96	1	15.0	28	278	7.7			9	2	0.640	1.10	0.010	0.025	0.006	25
09/24/96	1	4.1	24	283	7.9			14	6	0.030	0.10	0.100	0.081	0.019	26
10/02/96	1	11.0	24	308	8.1	110	0	13	10	0.180	1.00	0.100	0.055	0.019	24
11/20/96	1	7.2	30	296	7.9	119		14	11	0.290	0.90	0.190	0.037	0.009	24
01/23/97	1	2.0	72	298	7.8	149		5	2	0.090	0.63	0.210	0.024	0.003	25
02/11/97	1	3.5	64	311	7.9	102		3	1	0.280	0.99	0.390	0.015	0.005	26
03/19/97	1	12.0	22	310	7.6	114		24	4	0.190	1.19	2.750	0.121	0.073	27
04/18/97	1	8.7	26	352	8.4	115	10	19	4	0.050	0.92	2.800	0.056	0.010	25
05/13/97	1	3.9	33	325	8.7			22	5	0.160	0.74	1.730	0.061	0.009	25
06/06/97	1	4.2	28	356	8.2	100	8	13	5	0.100	1.30	0.860	0.077	0.016	25
07/09/97	1	6.1	30	320	8.4	100	12	12	6	0.220	1.02	0.230	0.041	0.011	25
08/08/97	1	4.0	22	317	7.7	110	0	12	5	0.280	0.95	0.010	0.105	0.013	23
10/03/97	1	6.7	14	326	7.5	90	0	26	6	0.320	0.83	0.290	0.088	0.020	24
Count		20	21	21	21	13	9	21	21	21	21	21	21	21	21
Minimum		2.0	7	278	7.2	90	0	3	1	0.010	0.10	0.010	0.015	0.002	23.0
Maximum		110.0	72	356	9.0	149	12	112	16	0.640	1.40	4.600	0.231	0.100	27.0
Average		14.4	27.8	307	8.1	109.2	5.6	20.3	6.1	0.169	0.90	1.478	0.077	0.025	25.2
Standard deviation		24.0	15.2	20.9	0.5	15.0	5.4	22.9	3.8	0.152	0.27	1.550	0.051	0.031	1.0

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, μmho/cm - micromho per centimeter, mg/L - milligrams per liter, blank spaces - no data

Table 13g. Water Quality Characteristics for the Current Study iin Otter Lake at Station 4 Bottom (RD-A06-F-4)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
05/09/96	24	150.0	7	286	7.2			168	28	0.260	1.90	4.100	0.323	0.116	27
05/22/96	24	32.0	10	291	7.1			36	4	0.380	0.92	3.700	0.201	0.084	26
06/17/96	24	20.0	24	313	7.1			12	4	0.010	0.56	4.900	0.093	0.057	26
07/15/96	26		26	299	7.9			24	3	0.090	0.96	2.000	0.085	0.014	26
08/19/96	23	5.2	29	285	7.7			21	5	0.030	0.80	0.480	0.091	0.015	26
09/09/96	25	2.4	28	288	7.4			8	5	0.260	1.20	0.120	0.026	0.004	25
09/24/96	24	4.3	24	286	7.7			24	5	0.050	0.66	0.120	0.086	0.021	26
11/20/96	22	3.9		296	7.9	110		13	7	0.230	0.81	0.200	0.042	0.004	24
01/23/97	23	2.3	72	315	7.6	183		9	3	0.150	0.60	0.210	0.028	0.004	25
02/11/97	24	3.2	64	330	7.5	102		3	3	0.290	0.88	0.330	0.011	0.004	26
03/19/97	25	12.0		312	7.6	116		22	6	0.190	1.14	2.760	0.117	0.073	27
05/13/97	23	3.7	33	330	8.2			22	9	0.120	1.00	1.580	0.046	0.015	25
Count		11	10	12	12	4		12	12	12	12	12	12	12	12
Minimum		2.3	7	285	7.1	102		3	3	0.010	0.56	0.120	0.011	0.004	24.0
Maximum		150.0	72	330	8.2	183		168	28	0.380	1.90	4.900	0.323	0.116	27.0
Average		21.7	31.7	303	7.6	127.8		30.2	6.8	0.172	0.95	1.708	0.096	0.034	25.8
Standard deviation		43.6	20.9	16.8	0.3	37.3		44.3	6.9	0.116	0.36	1.760	0.088	0.038	0.9

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L -- milligrams per liter, blank spaces - no data

Table 13h. Water Quality Characteristics for the Current Study iin Otter Lake at Station 1 Middle (RD-A06-F-1)

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transparency (inches)*	*Conductivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/L as $CaCO_3$)*	*Total suspended solids (mg/L)*	*Volatile suspended solids (mg/L)*	*Ammonia nitrogen (mg/L)*	*Total Kjehldahl nitrogen (mg/L)*	*Nitrate/ nitrite (mg/L)*	*Total phosphorus (mg/L)*	*Dissolved phosphorus (mg/L)*	*Total depth (feet)*
04/17/96	22	5.8	58	332	7.9	118		10	3	0.010	1.24	0.400	0.026	0.002	42
05/09/96	24	5.7	42	328	7.6			4	1	0.140	0.94	0.650	0.029	0.013	49
05/22/96	24	9.2	24	319	7.4			12	2	0.190	0.68	1.170	0.047	0.030	48
06/17/96	30	12.0	38	331	7.1			11	2	0.010	0.33	1.090	0.024	0.009	47
07/15/96	32		53	338	7.2			10	3	0.300	0.95	0.450	0.027	0.006	47
08/19/96	30	34.0	31	355	7.3			7	3	0.280	0.75	0.010	0.019	0.005	46
09/09/96	30	20.0	48	352	7.7			26	16	0.270	1.00	0.060	0.090	0.018	48
09/24/96	34	5.7	42	357	7.1			12	6	1.100	1.40	0.020	0.073	0.041	52
11/20/96	23	5.1		297	7.7	115		6	3	0.640	0.97	0.150	0.024	0.007	47
01/23/97	23	2.0	117	308	7.8	172		2	1	0.220	0.67	0.310	0.009	0.002	47
02/11/97	20	2.9	88	319	7.7	110		7	4	0.270	0.80	0.280	0.041	0.015	41
03/19/97	27	8.3		301	7.8	119		9	4	0.160	0.79	0.490	0.023	0.060	51
05/13/97	24	2.7	74	303	8.0			8	2	0.080	0.55	0.850	0.015	0.006	46
Count		12	11	13	13	5		13	13	13	13	13	13	13	13
Minimum		2.0	24	297	7.1	110		2	1	0.010	0.33	0.010	0.009	0.002	41.0
Maximum		34.0	117	357	8.0	172		26	16	1.100	1.40	1.170	0.090	0.060	52.0
Average		9.5	55.9	326	7.6	126.8		9.5	3.8	0.282	0.85	0.456	0.034	0.016	47.0
Standard deviation		9.2	27.4	20.6	0.3	25.5		5.8	3.9	0.294	0.28	0.387	0.023	0.017	3.0

Notes: NTU - nephelometric turbidity units, $CaCO_3$ - calcium carbonate, µmho/cm - micromho per centimeter, mg/L -- milligrams per liter, blank spaces - no data

Table 14. Analyses of Differences at a 95 Percent Confidence Level iin **Means of the Current Study versus Historical Data (1977 to 1994)**

Parameter	*Station 1*		*Station 2*		*Station 3*
	Surface	*Bottom*	*Surface*	*Bottom*	*Surface*
Turbidity, NTU	↑	↑	↑	↓	↑
Secchi transparency, in.	=		=		↓
Conductivity, µmho/cm	=	=	↑		=
Total alkalinity, mg/L as $CaCO_3$	↑	=	↑	↑	↑
Suspended solids, mg/L					
Total	↑	↓	↑	↓	↑
Volatile	↑	↑	=	=	↑
Nitrogen, mg/L					
Ammonia	↑	↓	↑	↓	↑
Total Kjeldahl	↓	↓	=	↓	↑
Nitrate/nitrite	=	↓	↓	=	=
Phosphorus, mg/L					
Total	=	=	=	↓	↑
Dissolved	↓	=	=	↓	↑

Notes: ↑ - indicates the current mean is greater than historical mean
↓ - indicates the current mean is less than historical mean
= indicates no significant difference between the two means
NTU - nephelometric turbidity unit
µmho/cm - micromho per centimeter
$CaCO_3$ - calcium carbonate

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

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

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

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

Impoundment of running water alters its physical, chemical, and biological characteristics. The literature is replete with detailed reports on the effects of impoundments on various water quality parameters (Kothandaraman and Evans, 1982, 1983a, b; Raman et al., 1996; Raman and Twait, 1994). The physical changes in the configuration of the water mass following impoundment reduce reaeration rates to a small fraction of those of free-flowing streams. When 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 temperatures, the bacterial decomposition of the bottom organic sediments exerts a high rate of oxygen demand on the overlying waters. When the rate of oxygen demand exceeds oxygen replenishment by molecular diffusion, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom. Hypolimnetic zones of artificial impoundments also were found to be anaerobic within a year of their formation (Kothandaraman and Evans, 1983a, b).

The isothermal and isodissolved oxygen concentration plots for Otter Lake at stations 1, 2, and 4 are shown, respectively, in figures 8, 9, and 10. Water depths at these stations were greater than 10 feet when the lakes typically exhibit the thermal stratification during summer months.

An examination of the isothermal and isodissolved oxygen profiles at station 1 (figure 8), which has a maximum depth of about 50 feet, indicates that the temperature and DO concentrations are nearly uniform from surface to bottom from November to April. Then the lake exhibits very typical stratification phenomenon. Stratification begins in late April to early May, intensifies, and reaches a peak quickly and remains so through the middle of October. The fall turnover occurs by the end of October. The maximum temperature gradient at station 1 was 17.6°C during July 1996.

Concomitant with the thermal stratification in the lake, DO depletion in the deeper waters intensified, became a mirror reflection of the thermal stratification phenomenon, and began to decrease in the bottom waters in April. Oxygen depletion reached a peak by early June and remained so through the end of September. The oxygen condition in the deeper waters improved gradually during October. The lake became uniform in DO when the fall turnover occurred in late October. There was no oxygen at depths below 15 feet from the surface during summer stratification. Any raw water withdrawal for water supply purposes near or below thermocline has serious implications. Water withdrawal from the anoxic zone is known to result in increased treatment costs and taste and odor problems because of the presence of products of anaerobic decomposition such as iron, manganese, ammonia, and other chlorine-demanding materials (Kothandaraman and Evans, 1982). During the period of thermal stratification, nearly 50 percent of the lake volume south of Emerson Airline Road was devoid of oxygen.

Generally the observations made for station 1 are true for station 2, which has a maximum water depth of 32 feet (figure 9). Oxygen depletion during summer stratification occurred at depths below 18 feet from the surface. Maximum temperature gradient observed at station 2 was 15.6°C during July 1996.

In contrast to station 2, station 4 (figure 10), which had a maximum water depth of 28 feet, exhibited much less temperature gradient and less severity of oxygen depletion in the deeper waters. The maximum observed temperature difference between the surface and bottom waters was 8.8°C (28.3-19.5°C) during July 1996 at station 4. Severe oxygen depletion (oxygen concentration less than 1.0 mg/L) in the near bottom waters was observed only three times during the summer, and these were interspersed with improved oxygen conditions. The reasons for the better oxygen conditions and much less severe thermal stratification at station 4 compared to station 2, which has a comparable maximum water depth, are the installation and continuous operation of a low energy mechanical (Garton-Quintero) destratifier. The road crossing the lake (Emerson Airline Road) essentially forms a barrier between stations 2 and 4 and prevents the propagation of the beneficial effects of destratification in the northern portion of the lake south of the Emerson Airline Road.

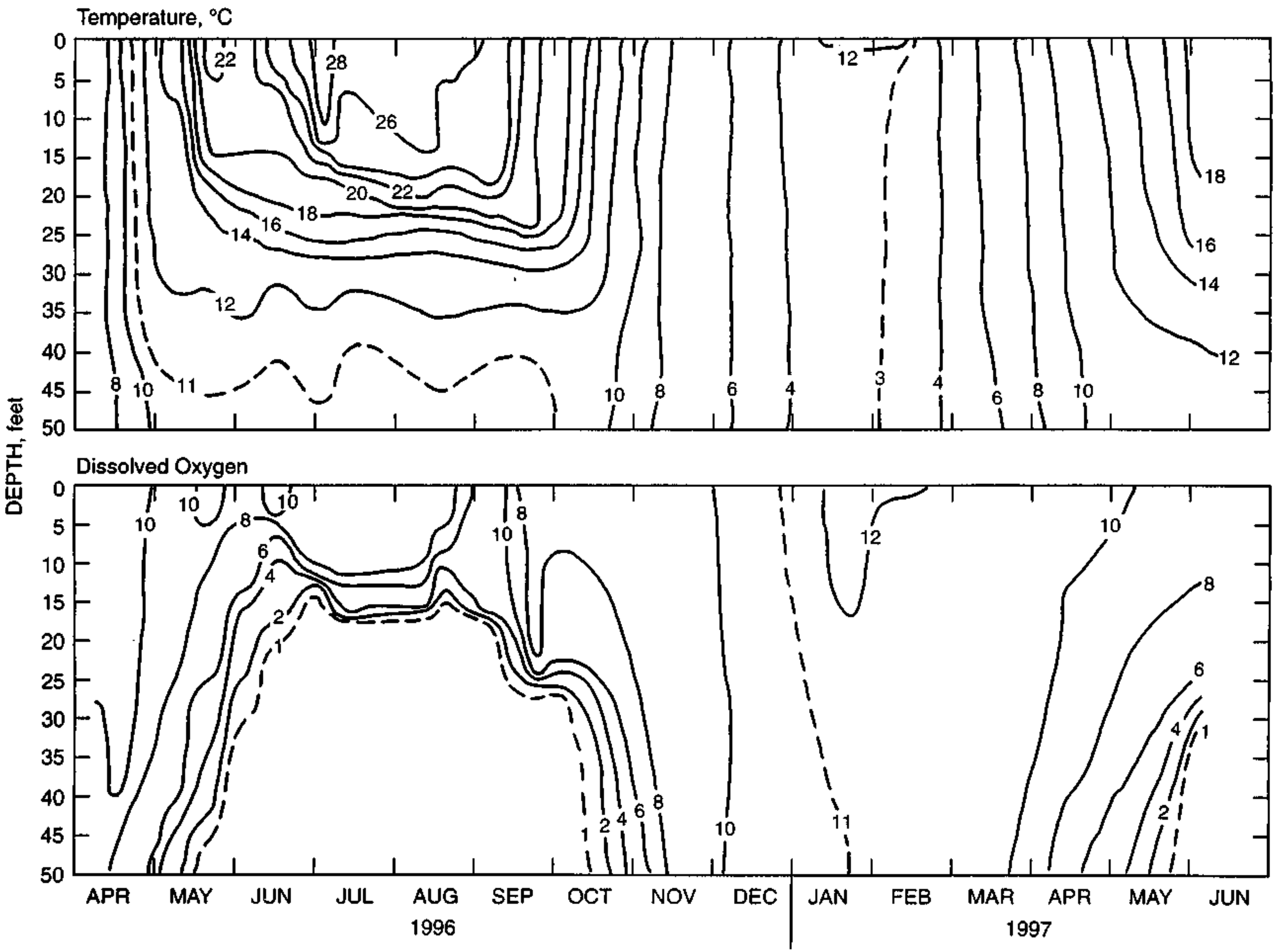


Figure 8. Isothermal and isodissolved oxygen plots for station 1

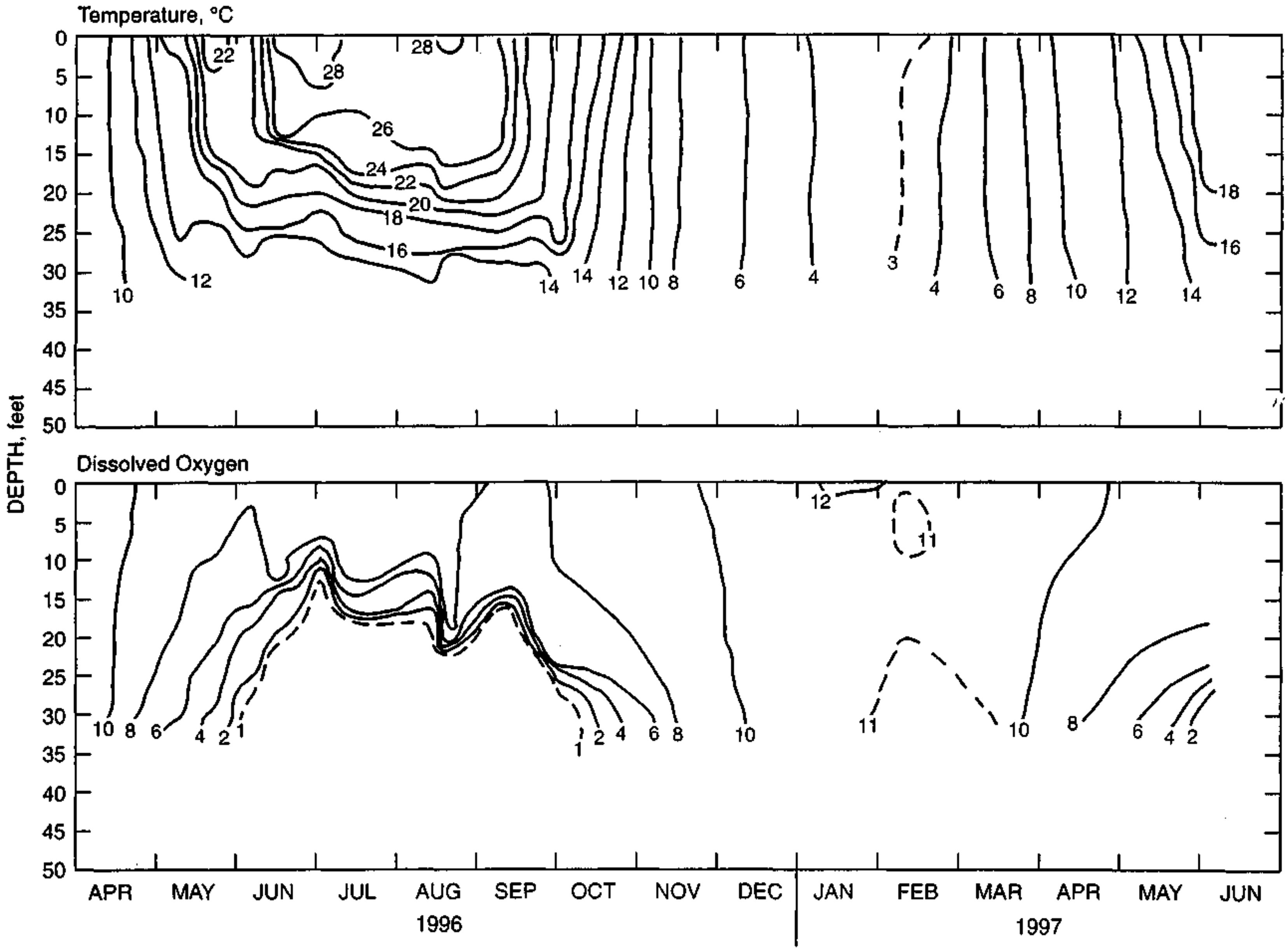


Figure 9. Isothermal and isodissolved oxygen plots for station 2

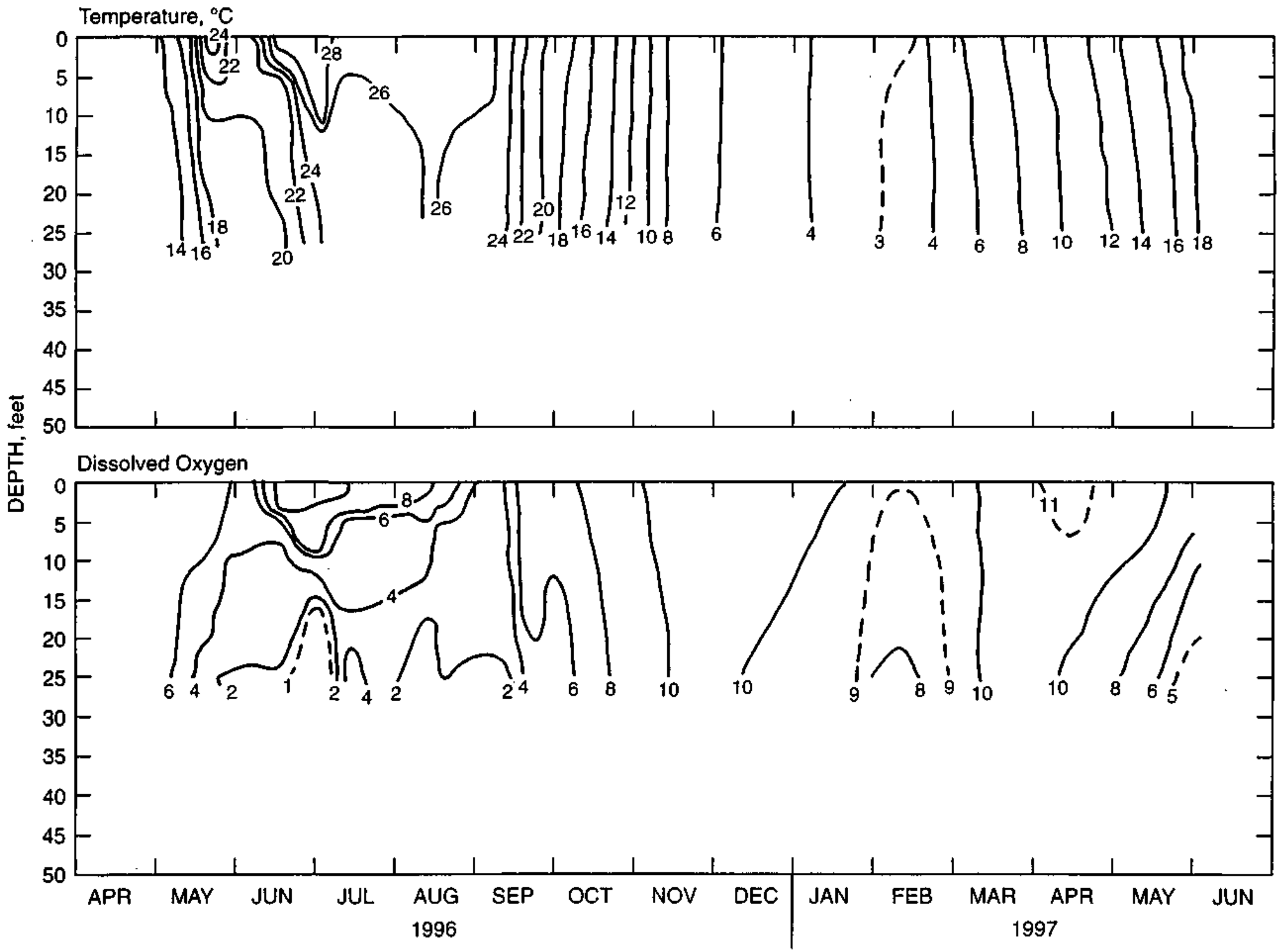


Figure 10. Isothermal and isodissolved oxygen plots for station 4

The DO and temperature profiles at stations 1, 2, 3, and 4 for selected dates are shown, respectively, in figures 11-14. Station 3, which is relatively shallow, exhibited minimal temperature gradient and very good oxygen conditions throughout the water column (figure 13). Observations made for temperature and DO conditions at stations 1, 2, and 4, as discussed for the isothermal and isodissolved oxygen plots, also can readily be discerned from temperature and DO profiles for these stations.

Percent DO saturation values were determined for the observed DO and temperature and are given in tables 15, 16, 17, and 18 for stations 1, 2, 3, and 4, respectively. Saturation DO values were computed using the formula (Committee on Sanitary Engineering Research, 1960):

$$DO = 14.652 - 0.410022T + 0.0079910T^2 - 0.000077774T^3$$

where

DO = the saturation dissolved oxygen, mg/L

T = water temperature, °C

The computed DO percent saturation values in Otter Lake at stations 1, 2, 3, and 4 are included, respectively, in the tables 15, 16, 17, and 18. The highest percent saturation values observed at stations 1, 2, 3, and 4 were, respectively, 125, 154, 204, and 134. These highest values occurred in June for all four stations. The data presented in tables 15-18 bring out the fact that oxygen was depleted in the southern portion of the lake at a depth of about 15 feet below the surface during summer months. Oxygen conditions in the northern portion of the lake are better, and the destratifier improves the oxygen in the raw water intake location, thereby improving the raw water quality characteristics. However, with an adequately sized destratifier system, oxygen conditions at station 4 could be improved further.

Turbidity. Turbidity is an expression of the property of water that causes light to be scattered and absorbed by a turbidimeter; it is expressed as nephelometric turbidity units (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, plankton, and other microorganisms. Generally, turbidity in lake waters is influenced by sediment in runoff from a lake's watershed, shoreline erosion, algae in the water column, resuspension of lake bottom sediments by wind or wave action, by bottom-feeding fish, power boats, etc. Elevated turbidity values make the appearance of a lake less pleasing aesthetically.

During the current (1996-1997) study, the ranges of turbidity at stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were, respectively, 1.1-25, 2-34, 2.7-38, 2.1-31, 2.2-24, 3.2-400, 2-110, and 2.3-150 NTU. The means and ± standard deviations of turbidity at these stations were, respectively, 6.7 ± 5.8, 9.5 ± 9.2, 14.2 ± 10.9, 8.4 ± 7.5, 7.6 ± 6.0, 27.5 ± 83.6, 14.4 ± 24.0, and 21.7 ±43.6 NTU (table 13).

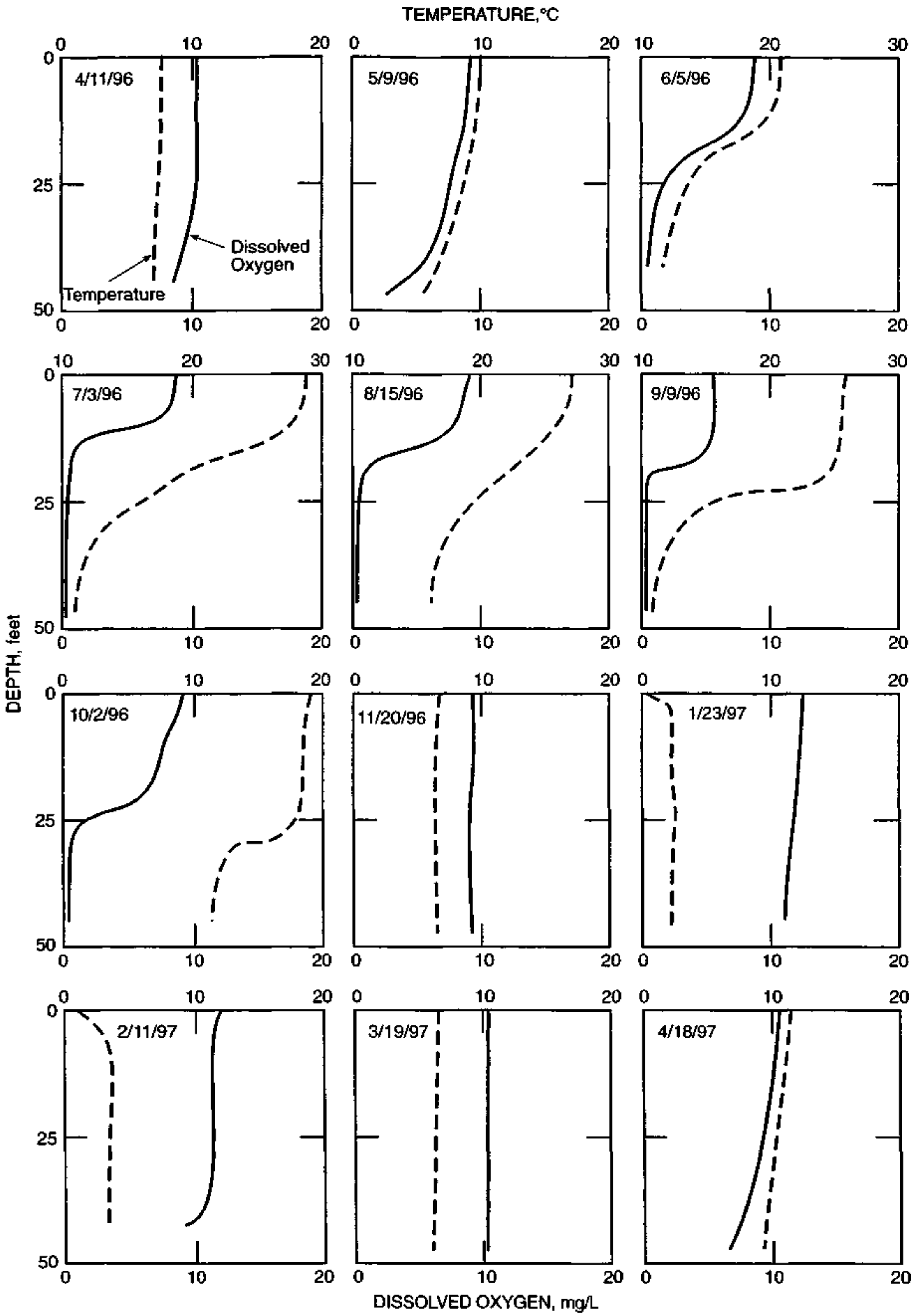


Figure 11. Temperature and dissolved oxygen profiles for station 1 on selected dates

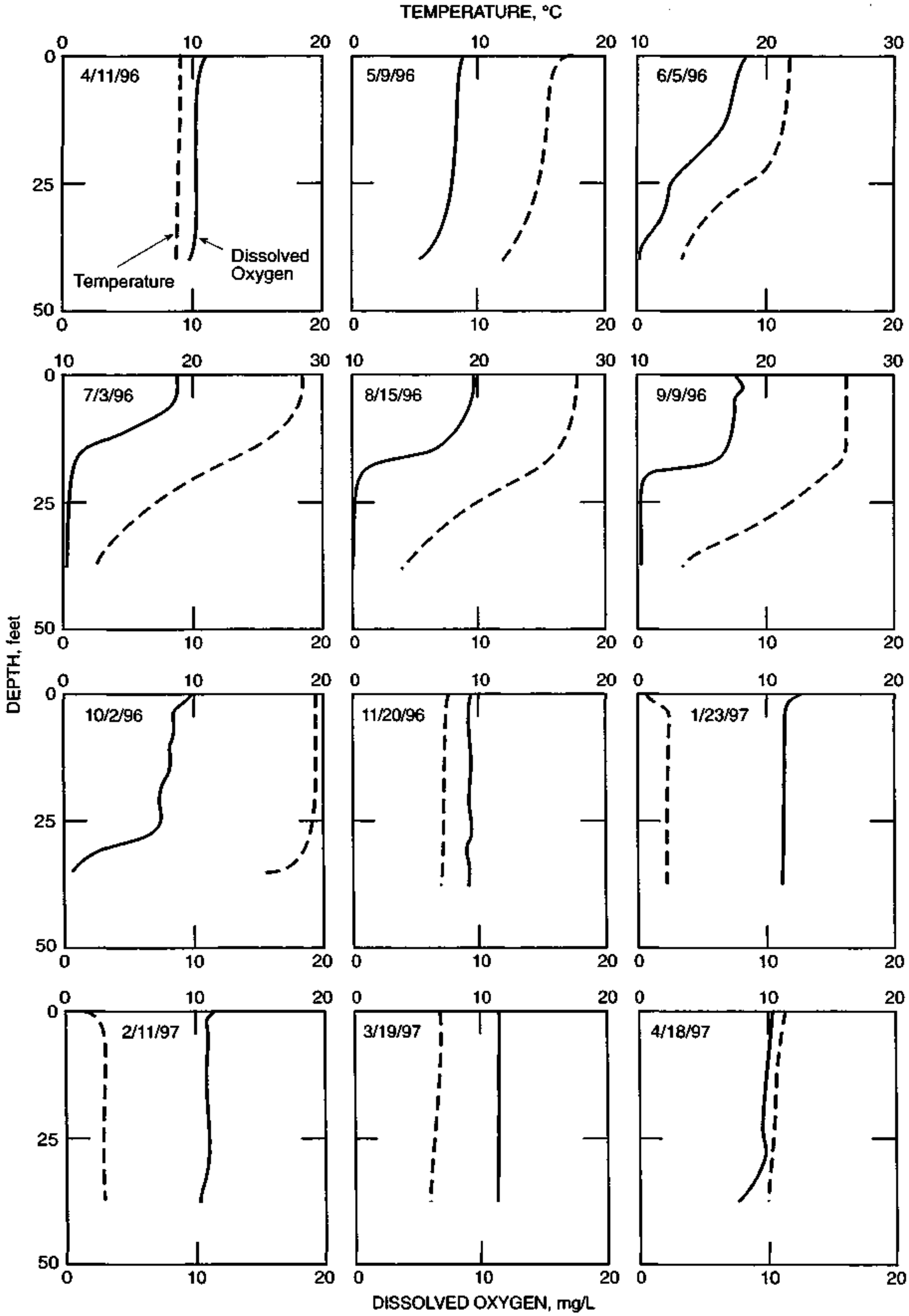


Figure 12. Temperature and dissolved oxygen profiles for station 2 on selected dates

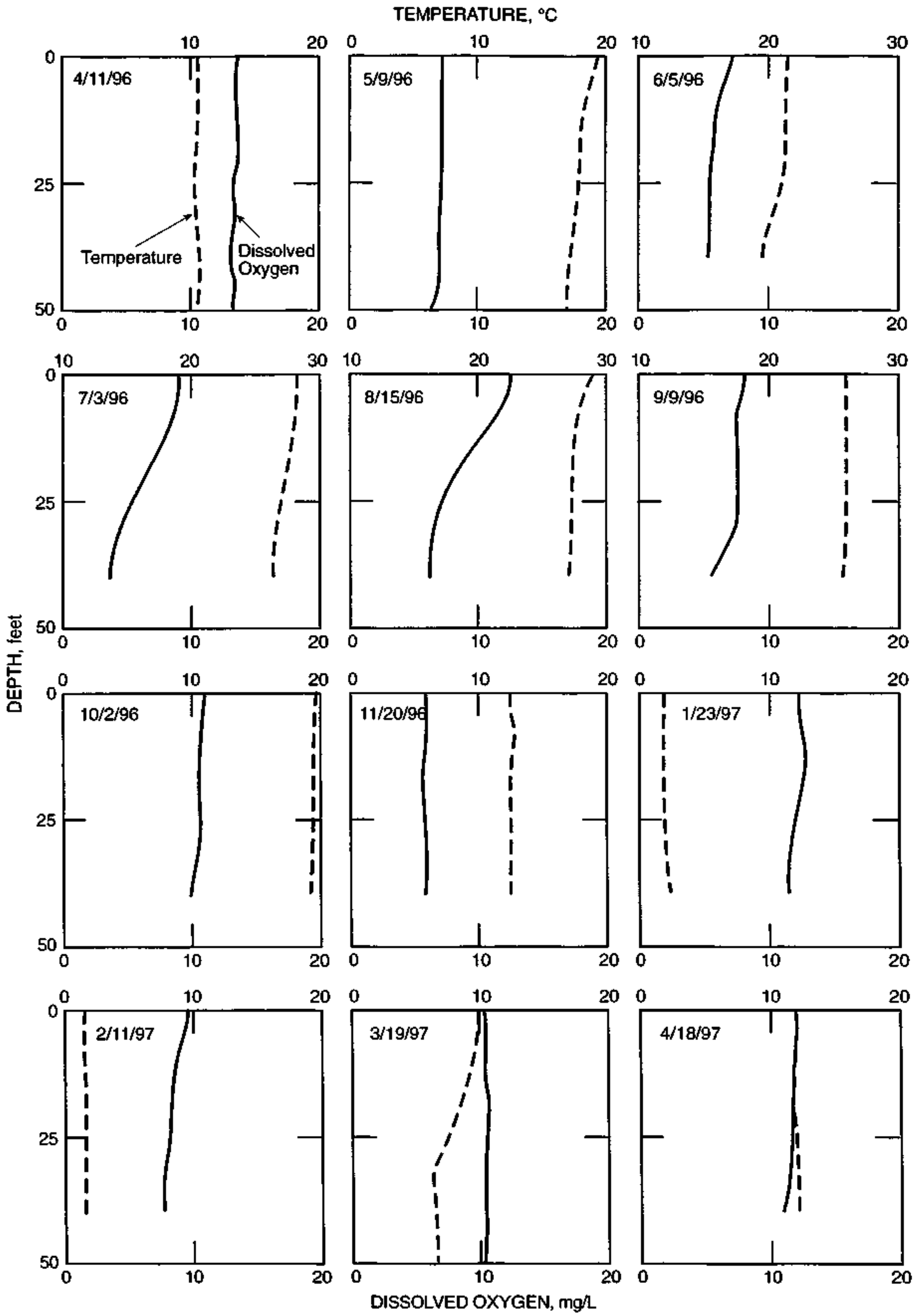


Figure 13. Temperature and dissolved oxygen profiles for station 3 on selected dates

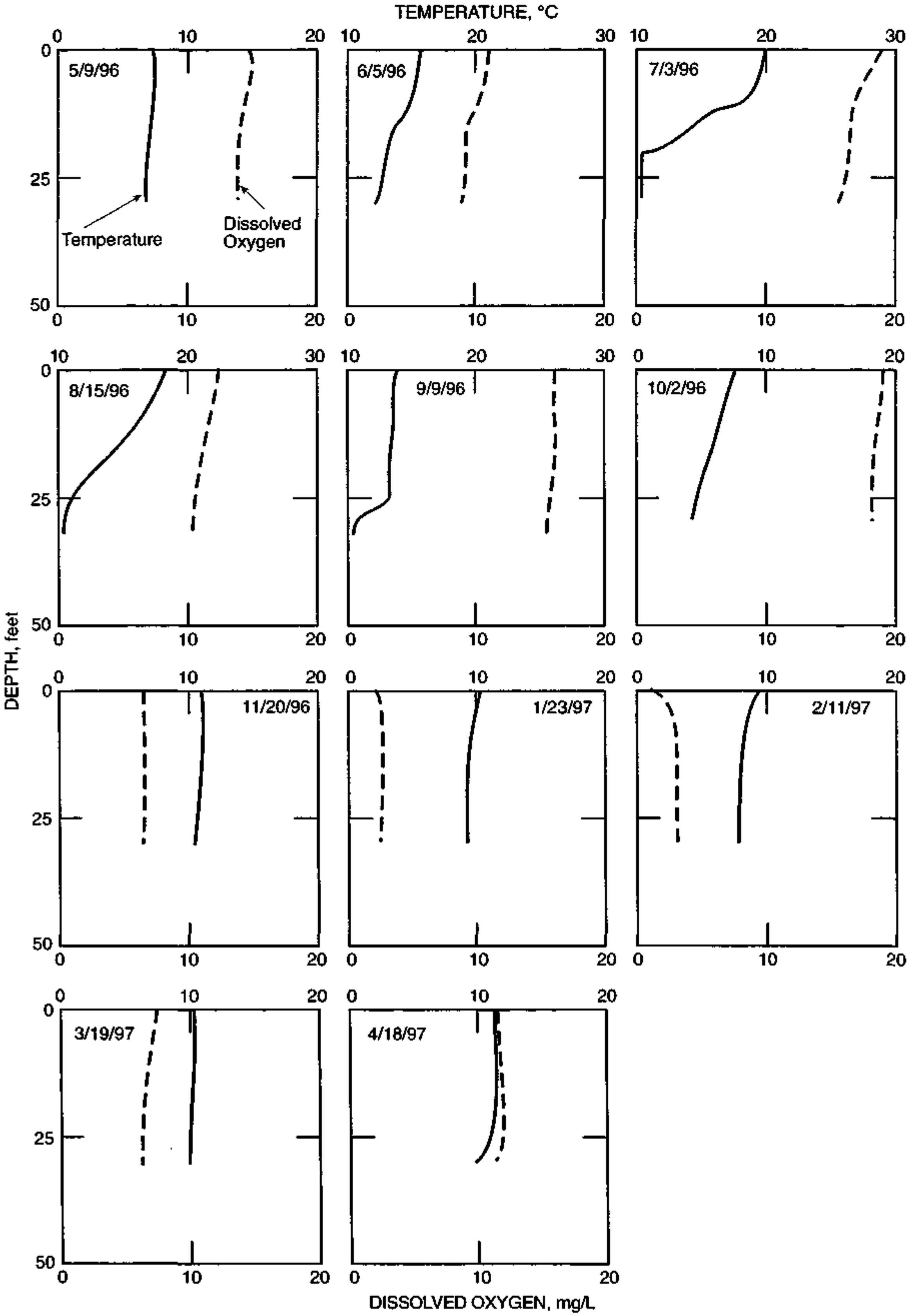


Figure 14. Temperature and dissolved oxygen profiles for station 4 on selected dates

Table 15. Percentage of Dissolved Oxygen Saturation in Otter Lake at Station 1

Depth (feet)	*4/11/96*	*4/17/96*	*5/9/96*	*5/22/96*	*6/5/96*	*6/17/96*	*7/3/96*	*7/15/96*	*8/15/96*	*8/19/96*
0	91	101			99		114		117	
1	91		94	125	99	125	113	104	117	111
2		100						104		110
3	89		94	119	97	124	112	104	117	110
4		99						104		109
5	87		94	116	89	85	111	104	108	110
6		99				73		104		82
7	87		90	107	89	60	110	103	106	82
8		98	87	102		53		103		78
9	87				85		110	103	102	75
10		98	80	96		45		101		66
11	87				83		78		88	
12		98	78	87		40		97		47
13	87				82		24		76	
14		98	78	87		31		62		22
15	87				45		4		52	
16		98	79	78		26		52		1
17	87				41		2		18	
18		97	79	71		22		1		0
19	86				27		1		8	
20		97	78	68		12		1		1
21	86				24		1		3	
22		97	78	62		5		1		1
23	86				21		1		3	
24		97	77	60		5		1		1
25	86				20		1		2	
26		97	76	55		5				0
27	5				17		1		2	
28		93	73	53		4		1		0
29	83				15		1		2	
30		92	72	48		1				0
31	80				9		1		2	
32		91	71	42		1		1		0
33	80				7			1	2	
34		90	69	39		1				0
35	75				4			1	2	
36		89	67	27		1		1		0
37	75				3			1	1	
38		89	62	25		1				0
39	75				3		1		1	
40		87	56	24		1		1		0
41	73				2			1	1	
42			54	19		0				0
43	72				2			1	1	
44			49	16		0		1		0
45	71							1	1	
46			30	11		0				0
47							1	1		
48				2		0				
49			22							
50										

Table 15. Concluded

Depth (feet)	*9/9/96*	*9/24/96*	*10/2/96*	*11/20/96*	*1/23/97*	*2/11/97*	*3/19/97*	*4/18/97*	*5/13/97*
0	70		98		87	87		98	101
1	70	91	96	80			93	94	101
2	70	92			85	86	93		
3	70	93	91	80				94	99
4	70	92					94		
5	70	93	88	80	89	84		93	99
6	70	93					93		
7	70	91	88	79				93	95
8	70	91							
9	70	91	85	80				93	92
10	70	91		79	90	84	93		
11			82					92	90
12	70								
13			77					91	86
14	70	90							
15			76	79	90	84	93	90	83
16	52	90							
17		90	75					90	82
18	1	90							
19			73					90	77
20	1	90		79	86	84	93		
21			71					89	75
22	0	89							
23			54					86	72
24	0	88							
25			28	79	84	84	93	85	57
26	0	14							
27			3					84	47
28	0	9							
29			2					83	21
30	0	7		79	83	85	93		
31			2					82	11
32	0	7							
33								81	5
34	0	6							
35				79	82	84	91	76	4
36	0	5							
37								74	4
38	0	4							
39								73	4
40	0	4		79	82	82	91		
41						74		69	4
42	0	3							
43								66	4
44	0	3							3
45				79	81		91	63	3
46	0	2							3
47				79				60	
48	0	2					90		
49								60	
50		2							

Note: Blank spaces - no data

Table 16. Percentage of Dissolved Oxygen Saturation in Otter Lake at Station 2

Depth (feet)	*4/11/96*	*4/16/96*	*5/9/96*	*5/22/96*	*6/5/96*	*6/17/96*	*7/3/96*	*7/15/96*	*8/15/96*	*8/19/96*
0	96	96			96		113		128	
1	96		90	102	96	154	112	113	126	126
2		95						113		125
3	94		87	119	91	143	112	113	125	122
4		94						114		120
5	94		87	109	90	137	112	116	119	119
6		93						116		118
7	93		86	95	86	135	103	116	114	116
8		93	82	92		134		113		116
9	93				84		70	112	110	116
10		92	84	91		130		105		116
11	92				78		16		93	
12		90	80	88		109		100		116
13	92				74		5		65	
14		88	81	85		43		94		113
15	92				72		2		18	
16		89	81	79		35		66		110
17	92				53		1		7	
18		86	80	70		29		2		101
19	92				41		1		3	
20		82	79	63		18		1		92
21	91				29		1		2	
22		80	76	57		7		1		2
23	91				25		1		2	
24		73	70	54		3		1		1
25	91	73			21		1		2	
26			68	52		1		1		1
27	90				17		1		2	
28			66	40		1		0		1
29	88				7		1	0	2	
30			64	31		1	1			1
31	82		48		3	1		0	2	

Table 16. Concluded

Depth (feet)	*9/9/96*	*9/24/96*	*10/2/96*	*11/20/96*	*1/23/97*	*2/11/97*	*3/19/97*	*4/18/97*	*6/6/97*
0			106		88	79		93	100
1	98	89	106	82			93	92	100
2	101	90			86	80	94		
3	104	89	98	82				92	99
4	96	89					93		
5	95	88	97	81	87	81		91	99
6	94	89					93		
7	93	86	93	81				91	98
8	96	85							
9	90	84	91	81				89	98
10	92	84			88	82	92		
11			89	81				89	98
12	89	81							
13			85					88	98
14	76	82							
15			84	80	87	82	92	87	95
16	2	80							
17			83					87	90
18	1	74							
19			83					87	85
20	1	69		80	84	82	91		
21			79					86	82
22	1	2							
23			76					85	74
24	1	1							
25			32	80	83	80	90	83	55
26	1	1							
27			17					82	28
28	1	1					90		
29			6	80				78	10
30	1	1			81	77	90		
31							89	71	5

Note: Blank spaces - no data

Table 17. Percentage of Dissolved Oxygen Saturation in Otter Lake at Station 3

Depth (feet)	*4/11/96*	*4/17/96*	*5/9/96*	*5/22/96*	*6/5/96*	*6/17/96*	*7/3/96*	*7/15/96*	*8/15/96*	*8/19/96*
0	124	115			80		117		166	167
1	124		83	102	75	204	115	136	165	161
2		114						136		
3	124		78	85	68	200	111	137	142	155
4		113						114		151
5	125		79	68	68	176	88	89	103	139
6		110						68		112
7	124		77	60	65	148	56	62	80	106
8		109	76	57		144	41	61		86
9	122	109		55	58			63	78	
10			68			137				
11	122									
12										
13	117									
14										
15	109									

Depth (feet)	*9/9/96*	*9/24/96*	*10/2/96*	*11/20/96*	*1/23/97*	*2/11/97*	*3/19/97*	*4/18/97*	*6/6/97*
0			121		88	69		110	123
1	101	105	120	101			91	110	120
2	97	105			92	58	90		
3	98	87	118	104			87	107	119
4	98	73			91	57	88		
5	97	70	116	101			84	105	113
6	93	0			86	55	83		
7	90	69	112	100			82	100	107
8	71		110	100	85	54	84		
9						51	82		95

Note: Blank spaces - no data

Table 18. Percentage of Dissolved Oxygen Saturation in Otter Lake at Station 4

Depth (feet)	*5/9/96*	*5/22/96*	*6/5/96*	*6/17/96*	*7/3/96*	*7/15/96*	*8/15/96*	*8/19/96*	*9/9/96*
0			63		131		101		
1	71	88	63	134	131	129	104	95	46
2						129		92	44
3	71	83	58	129	131	126	98	91	45
4						106		66	41
5	69	79	56	55	130	71	88	51	41
6						67		49	40
7	67	76	56	46	130	58	85	39	39
8	65	74		45		56		39	37
9			47		109	55	76	37	37
10	64	69		42		54		37	35
11			38		72		66		
12	64	57		41		54		31	37
13			35		46		50		
14	64	55		38		53		34	37
15			33		25		34		
16	63	52		38		52		34	37
17			32		7		26		
18	62	53		38		47		32	35
19			33		1		13		
20	60	45		38		48		32	40
21			29		1		13		
22	59	40		35		49		34	34
23			27		1		4		
24	58	36		35	1	50		31	7
25		29	22					1	2
26			13	12		51	1		

Table 18. Concluded

Depth (feet)	*9/24/96*	*10/2/96*	*11/20/96*	*1/23/97*	*2/11/97*	*3/19/97*	*4/18/97*	*6/6/97*
0		83		74	65		106	104
1	81	79	90			87	106	104
2	81			58	64	86		
3	80	77	87				106	103
4	79					86		
5	77	75	87	72	62		105	96
6	76					85		
7	74	71	87				101	82
8	73							
9	73	71	87				98	71
10	73		86	72	62	85		
11		68					96	62
12	73							
13		65					95	60
14	73							
15		58	87	72	60	84	94	59
16	73							
17		57					93	57
18	72							
19		54					93	54
20	69		87	70	60	83		
21		54					93	50
22	66		87					
23		51		68			81	47
24	62	49	86					
25	58				59	83		46
26					59			

Note: Blank spaces - no data

High turbidity at stations 3 and 4 occurred on May 9, 1996, due to a storm. The high values were caused by tributary inflow to station 3 and by the bisected roadway (Emerson Airline Road) at station 4. As expected, the ranges of turbidity at the deeper stations (stations 1 and 2) were less than those at stations 3 and 4. The maximum values for stations 1 and 2 were found on June 5, 1996. In the historical data in tables 12a-f., the values of maximum turbidity are less meaningful because storm event samples most likely were not collected. Nevertheless, comparisons of historical and current turbidity data suggest that the current mean turbidity at stations 1S, 1B, 2S, and 3S were higher than the historical means, respectively (table 14). At station 2B, the mean turbidity found during the recent study was less compared with historical means.

Secchi Disc Transparency. Secchi disc visibility is a measure of the lake's water transparency, which suggests the depth of light penetration into a body of water (its ability to allow sunlight penetration). Even though the 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. Because 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 in which 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 matters (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 suitable habitat for fish and other aquatic life, the lake's water quality and aesthetics, the state of the lake's nutrient enrichment, and problems and potential solutions for the lake's water quality and recreational use impairment.

Extensive measurements of Secchi disc transparency have been collected for stations 1-3 in Otter Lake since 1977. Secchi disc transparency was measured during the Illinois EPA Ambient Lake Monitoring program and this study (stations 1-4) (tables 12 and 13). In addition, it also was measured during the Volunteer Lake Monitoring Program (VLMP) (last part of the appendix) from 1982 to 1994, except 1983, 1992, and 1993. The statistical summary of the values of Secchi transparency collected by the VLMP, the ambient monitoring data (1977-1994, from table 12), the combined historical data (1977-1994), and the current study (1996-1997, from table 13) are presented in table 19.

During the study period, mean values observed for Secchi disc transparency at stations 1, 2, 3, and 4 were 55, 48, 17, and 28 inches, respectively (table 19). Stations 1 and 2 have the best Secchi disc transparency, with a range of 15 to 117 inches. The overall historical mean transparency for stations 1, 2, and 3 were, respectively, 55, 43, and 24 inches (table 19). The mean transparency for the current study at station 3 was significantly decreased from the historical value (table 14), but no difference was noted for stations 1 and 2.

Table 19. Statistical Summary of Secchi Disc Transparencies in Otter Lake

Station/ study period	*Number of observations*	*Secchi transparency, inches*			
		Minimum	*Maximum*	*Mean*	*Standard deviation*
Station 1					
Ambient, 1977-1994	28	18	94	49	22
VLMP, 1982-1994	73	16	92	58	17
Historical, overall	101	16	94	55	18
Current, 1996-1997	23	24	117	55	21
Station 2					
Ambient, 1977-1994	28	8	114	43	22
VLMP, 1982-1994	72	9	72	43	13
Historical, overall	100	8	114	43	16
Current, 1996-1997	23	15	117	48	23
Station 3					
Ambient, 1977-1994	28	4	36	23	9
VLMP, 1982-1994	72	3	41	24	9
Historical, overall	98	3	41	24	9
Current, 1996-1997	23	3	30	17	6
Station 4					
Current, 1996-1997	21	7	72	28	15

Note: VLMP - Volunteer Lake Monitoring Program

The Illinois EPA's Lake Assessment Criteria (IEPA, 1978) 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. The minimum recommended Secchi transparency set by the Illinois Department of Public 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, if it is not used for swimming.

Chemical Characteristics

Atrazine. Atrazine, an organic herbicide widely used on corn and soybeans, is slightly soluble in water. When soil and climate conditions are favorable, atrazine may be transported to surface waters by runoff or by leaching into ground water.

Atrazine has been shown to affect offspring of rats and the hearts of dogs. The U.S. Environmental Protection Agency (USEPA) has set the drinking water limit for atrazine concentration of 0.003 mg/L (or 3 µg/L) to protect the public against the risk of the adverse health effects. When atrazine or any other herbicide or pesticide is detected in surface or ground water, it does not mean that a human health risk exists. Treated (finished) water meeting the USEPA limit is considered safe with respect to atrazine with little or none of the health risks.

Maximum contaminant level (MCL) goals for water quality are set by the USEPA. The MCL goal is set at a concentration level such that it will have no adverse health effect. This concentration level is defined as the drinking water equivalent level (DWEL). The DWEL can be calculated as (Cotruvo and Vogt, 1990):

$$DWEL = \frac{(NOAEL)(70)}{(UF)(2)}$$

where

NOAEL = no observed adverse effect level, mg/kg/day
(70) = assumed weight of an adult, kg
UF = uncertainty factor (usually 10, 100, or 1,000)
(2) = assumed quantity of water consumed by an adult, L/day

The MCL goal can be determined as:

MCL goal = R_fD - contributions from (food + air)

where R_fD is called the reference dosage and is defined as the dosage that causes no ill effect for a chronic and/or a lifetime exposure. In fact, comprehensive data on the contributions from food and air generally are lacking. Therefore, in this case, the MCL goal is considered equal to the DWEL.

For the atrazine standard, UF is 1,000 and NOAEL is 0.086 mg/kg/d. Thus the USEPA standard of atrazine is derived as follows:

$$
\begin{aligned}
DWEL &= \frac{(NOAEL)(70)}{(UF)(2)} \\
&= \frac{(0.086\ mg/kg/d)(70\ kg)}{(1000)(2)} \\
&= 0.003\ mg/L \\
&= 3\ \mu g/L
\end{aligned}
$$

At the annual meeting of the American Chemical Society in March 1996, more than 60 scientists, from independent researchers to agricultural experts, presented results from a wide variety of research on atrazine. The symposium was the most comprehensive review of a herbicide ever conducted. The conclusion was that atrazine and simazine, used properly, have no unreasonable adverse effects on human health and the environment. Atrazine and simazine should remain available to growers without further restrictions (Ciba Crop Production, 1996).

Since the summer of 1993, monthly monitoring of atrazine for the raw and finished waters have been conducted through cooperation of the ADGPTVs Water Plant personnel and the Ciba-Giegy Company. Occasionally, the Illinois EPA also monitored the atrazine levels at the treatment plant's finished water. These observed data are presented in table 20. The results of a statistical analysis of these data also are given in table 20.

For the 135 observations collected (table 20), atrazine concentrations in the raw (lake) water ranged from 1 to 27 µg/L, with a mean of 6.0 µg/L and a standard deviation of 4.8 µg/L. High atrazine levels (>7 µg/L) were generally found during the summers (May-September) of 1993, 1995, and 1996. Nevertheless, early December 1996 and 1997 and late November 1997 samples had high atrazine concentrations.

On the basis of Ciba-Giegy data shown in table 20, atrazine levels in the finished waters were between 0.06 and 17 µg/L. Their average (169 samples) and standard deviation are 2.6 and 1.9 µg/L, respectively. Eighteen (31 out of 169 samples) percent of samples exceeded the recommended concentration of 3 µg/L. High values were observed during the summer of 1996. Since the improvement of the treatment process, high concentrations of atrazine in the treated water occurs sporadically, most likely during high atrazine levels in the raw waters.

The conventional water-treatment processes have some effect on atrazine removal: negative removal (five samples) and zero removal (four samples). With the exclusion of these nine samples, atrazine removal ranged from 7 to 98 percent, with a mean of 52 percent and a standard deviation of 21 percent (table 20).

Table 20. Atrazine Concentrations in Raw (Lake) and Finished Waters

Date	*Ciba-Geigy* Raw, µg/L	Finished, µg/L	Percent removal	*Illinois EPA finished, mg/L*
1993				
6/28	20.0	17.0	15	
7/6	9.0	6.0	33	
7/12	14.0	7.0	50	
7/19	5.0	5.0	0	
7/26	4.5	8.0	-78	
8/9	6.4	7.5	-17	
8/23	5.0	7.5	-50	
9/7	6.0	6.0	0	
9/20	5.0	5.0	0	
10/4	4.0	2.5	38	
10/18	3.5	2.6	26	
11/1	2.8	1.8	36	
11/15	4.0	2.4	40	
12/13	2.0	1.8	10	
12/27	2.2	1.8		
1994				
1/10	2.4	1.6	33	
1/24	2.2	1.7	23	
2/7	2.2	1.7	23	
2/21	3.2	1.8	44	
3/7		1.6		
3/23				1.3
6/21				5.0
7/27				5.1
9/19				4.1
10/25				4.2
12/20				2.8
1995				
1/3		3.0		
1/9	4.0	3.0	25	
1/17		3.0		
1/23	5.0	3.5	30	
1/30		1.6		
2/6	3.0	2.5	17	
2/13		2.0		
2/21	2.8	2.2	21	
2/27		2.2		
3/6		2.6		
3/13	3.2	2.6	19	
3/20		1.6		
3/21				
3/27	2.2	2.2	0	
4/3		1.8		1.2
4/10	2.6	2.0	23	
4/17		1.8		
4/24	2.2	1.8	18	

Table 20. Continued

Date	*Ciba-Geigy* Raw, µg/L	Finished, µg/L	Percent removal	Illinois EPA finished, mg/L
1995				
5/1	4.5	2.8	38	
5/8	3.0	2.0	33	
5/15	3.5	2.6	26	
5/22	6.5	3.8	42	
5/30	10.0	6.5	35	
6/5	10.0	5.0	50	
6/8				2.9
6/12	10.0	4.5	55	
6/19	7.5	2.5	66	
6/26	7.5	2.2	71	
7/3	7.0	2.8	60	
7/10	6.5	3.0	54	
7/17	6.0	2.0	67	
7/24	6.5	2.4	63	
7/31	5.0	1.8	64	
8/7		2.6		
8/14	6.0	1.6	73	
8/21		1.3		
8/28	5.0	1.9	62	
9/5		2.3		
9/11	7.0	2.5	64	
9/18		2.2		
9/25	7.0	1.7	76	
9/29				1.3
10/2		1.7		
10/9	6.0	1.0	83	
10/16		1.4		
10/23	5.0	1.2	76	
10/30		1.2		
11/6	5.0	1.4	72	
11/13		1.5		
11/20	7.5	1.8	76	
11/27		2.6		
12/4	5.0	2.5	50	
12/11		2.0		
12/18	5.0	2.2	56	
12/26		3.4		
12/28				0.7
1996				
1/2		0.9		
1/8	5.0	1.2	76	
1/15		1.1		
1/22	5.0	1.2	76	
1/29		2.6		
2/5		1.4		
2/12	4.5	1.4	69	
2/19		1.8		
2/26	4.5	1.5	67	

Table 20. Continued

Date	Ciba-Geigy Raw, µg/L	Ciba-Geigy Finished, µg/L	Ciba-Geigy Percent removal	Illinois EPA finished, mg/L
1996				
3/4		1.2		
3/11	5.0	1.4	72	
3/18		1.2		
3/19				0.48
3/25	4.0	1.2		
4/1		1.5		
4/8	5.0	1.2	70	
4/15		1.7		
4/22	5.0	1.6	68	
4/29		1.6		
5/6	17.0	7.0	59	
5/13	21.0	7.0	67	
5/20	25.0	4.5	82	
5/28	25.0	7.5	70	
6/3	21.0	6.0	71	
6/6				0.48
6/10	27.0	6.0	78	
6/17	18.0	7.0	61	
6/24	7.0	5.0	29	
7/1	12.0	4.0	67	
7/8	12.0	4.0	67	
7/15	14.0	5.0	64	
7/22	12.0	4.0	67	
7/29	11.0	3.5	68	
9/5				3.1
10/15				1.5
12/2	10.0	3.0	70	
12/9		2.5		
12/16	9.0	2.5	72	
12/23		2.0		
12/23		2.4		
1997				
1/6	5.4	2.1	61	
1/13	3.1	2.2	29	
1/20	4.8	2.3	52	
1/27	4.9	1.8	63	
2/2	3.8	2.5	34	
2/10	3.0	2.7	10	
2/24	4.1	2.1	49	
2/26	5.8	2.2	62	
3/10	3.1	1.3	58	
3/17	4.2	0.075	98	
3/18	3.2	1.1	66	
3/24	3.9	0.06	98	
3/31	4.3	0.065	98	

Table 20. Continued

Date	*Ciba-Geigy* Raw, µg/L	*Ciba-Geigy* Finished, µg/L	*Ciba-Geigy* Percent removal	*Illinois EPA finished, mg/L*
1997				
4/7	3.1	1.2	61	
4/21	3.2	1.3	59	
4/28	3.8	1.7	55	
5/5	3.6	1.4	61	
5/12	2.1	1.2	43	
5/19	4.5	1.5	67	
5/27	3.3	1.1	67	
6/2	2.6	1.4	46	
6/9	5.0	3.1	38	
6/23	1.0	2.1	-110	
6/23	6.5	2.1	68	
6/30	5.2	1.4	73	
7/7	5.2	2.1	60	
7/14	4.4	1.7	61	
7/21	4.2	1.6	62	
7/28	4.8	2.1	56	
8/4	4.8	2.9	40	
8/11	4.4	2.9	34	
8/18	4.9	1.6	67	
8/27	4.2	2.3	45	
9/1	7.0	1.7	76	
9/8	6.1	2.0	67	
9/15	2.7	0.8	70	
9/22	3.2	2.2	31	
9/29	1.8	1.2	33	
10/3	1.8	0.5	72	
10/13	4.6	3.0	35	
10/20	4.0	2.8	30	
10/27	5.8	2.2	62	
11/3	5.2	1.4	73	
11/10	2.8	1.6	43	
11/17	2.9	1.5	48	
11/24	10.0	4.0	60	
12/1	11.0	3.1	72	
12/6	6.0	1.8	70	
12/8	2.9	1.8	38	
12/15	3.7	2.3	38	
12/22	2.8	2.6	7	
12/29	3.2	2.1	34	

Table 20. Concluded

Date	Ciba-Geigy Raw, µg/L	Ciba-Geigy Finished, µg/L	Ciba-Geigy Percent removal	Illinois EPA finished, mg/L
1998				
1/5	2.6	1.9	27	
1/12	1.9	1.3	32	
1/19	2.6	1.5	42	
1/27	2.9	1.5	48	
2/2	6.0	1.8	70	
2/9	1.6	1.7	-6	
2/16	2.8	2.5	11	
2/23	3.8	2.4	37	
3/2	2.3	1.8	22	
For overall data:				
Number of observations	135	169	135	
Minimum	1.0	0.06	-110	
Maximum	27.0	17.00	98	
Mean	6.0	2.60	47	
Standard deviation	4.8	1.90	30	
Dates excluding negative removal:				
Number of observations	130	164	130	
Minimum	1.4	0.06	0	
Maximum	27.0	17.00	98	
Mean	6.0	2.50	50	
Standard deviation	4.8	1.80	23	
Data excluding negative and zero removal:				
Number of observations	126	160	126	
Minimum	1.8	0.06	7	
Maximum	27	17	98	
Mean	6.1	2.4	52	
Standard deviation	4.9	1.8	21	

Note: Blank spaces - no data

pH. The pH value, or hydrogen ion concentration, is a measure of the acidity of water; values below 7.0 indicate acidic water, and values above 7.0 indicate basic (or alkaline) water. A pH of 7.0 is exactly neutral. The pH values are influenced by the concentration of carbonate in the 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 also is consumed by the 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.

Generally 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 of the lakes can offset this acidic input by an abundance of natural buffering compounds in the lake water and the watershed. The Illinois Pollution Control Board or IPCB (IEPA, 1990) general-use water quality standard for pH ranges from 6.5-9.0, except for natural causes. Most Illinois lakes have a pH between 6.5 and 9.0.

During the current study, the range of pH values at the lake surface waters were 7.4-8.8, 7.6-9.0, 6.9-9.6, and 7.2-9.0 at stations 1, 2, 3, and 4, respectively (tables 13a, c, e, and f). Only one sample, taken on August 19, 1996, at station 3 (with a pH value of 9.6, table 13e) exceeded 9.0. Photosynthetic activity in Otter Lake appears to be much less compared to other Illinois lakes.

The pH values at the lake bottom water were found to be in a narrower ranges: 7.0-7.8, 7.1-8.0, and 7.1-8.2 at stations 1, 2, and 4, respectively (tables 13b, d, and g). Otter Lake pH values met the state standard of 6.5 to 9.0 for general-use water quality.

In table 12 the pH values at the three surface water sites ranged from 7.0-9.1 and from 6.2-9.0 in the bottom waters. Comparison of historical and current pH data indicates that the current pH values at station 1,2, and 3 are similar to the historical values.

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 a 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, Midwest lakes usually have a high alkalinity and thus are well buffered from the impacts of acid rain. Natural waters generally have a total alkalinity between 20 and 200 mg/L (APHA et al., 1992).

Total Alkalinity. During this study, the range of total alkalinity for surface water at stations 1S, 2S, 3S, and 4S were 80-125, 85-128, 92-122, and 90-149 mg/L as $CaCO_3$, respectively; their means were, respectively, 111.1, 106.9, 109.3, and 109.2 mg/L as $CaCO_3$ (tables 13 a, c, e, and f). Total alkalinity at all four stations are almost identical. For the near-bottom samples, the ranges at stations 1B, 2B, and 4B were 90-180, 103-162, and 102-183 mg/L as $CaCO_3$, respectively; and the means were 128.1, 124.4, and 127.8 mg/L as $CaCO_3$ (tables 13b, d, and g). Total alkalinity for bottom waters are similar at stations 1B, 2B, and 4B.

Historical data on total alkalinity (table 12) at stations 1S, 2S, 3S, 1B, 2B, and 3B ranged from 50-130, 40-120, 40-115, 40-170, 60-140, and 50-130 mg/L as $CaCO_3$; means were 92.6, 92.7, 88.8, 115.1, 97.1, and 86.4 mg/L as $CaCO_3$, respectively. Total alkalinity for surface waters at stations 1-3 also were similar.

As shown in table 14, the lake surface total alkalinity in the current study increased significantly from the past, as did that at station 2B. There is no difference at station 1B.

Phenolphthalein Alkalinity. Phenolphthalein alkalinity in lake waters generally was found only in summer with high pH periods and low in concentrations in the surface waters only, not the bottom waters. The highest phenolphthalein alkalinity observed was 20 mg/L as $CaCO_3$ at station 3S on August 15, 1996 (table 13e). Historical data show higher phenolphthalein alkalinity at stations 1S and 2S than the current results. The maximum values at these two stations were, respectively, 38 mg/L as $CaCO_3$ on May 24, 1982, and 40 mg/L as $CaCO_3$ on June 12, 1979 (tables 12a and c).

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 the soils in the drainage basin is the major factor determining the chemical constituents in the waters. The higher the conductivity reading, the higher the concentration of 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.

Conductivity in Otter Lake during the current study ranged from 179 micromhos per centimeter (µmho/cm) at station 3S on May 22, 1996, to 400 µmho/cm at station 1B on October 2, 1996 (tables 13a-h). The mean conductivity values for lake waters at stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were, respectively, 300, 326, 345, 302, 331, 307, 307, and 303 umho/cm. These values are typical of Illinois lake waters. The Illinois General Use Water Quality Standards for total dissolved solids is 1,000 mg/L, which is approximately equivalent to a conductivity of 1,700 µmho/cm. The observed conductivity values did not exceed this criterion.

For historical data, the lowest conductivity was 132 µmho/cm at station 1S on May 24, 1982. The highest conductivity observed was 443 µmho/cm at station 1B on August 2, 1994 (table 12a-f). The mean conductivity for the historical data at stations 1S, 1B, 2S, and 3S were 297, 341, 297, and 289 µmho/cm, respectively.

Comparing the current and historical data of conductivity for stations 1S, 1B, and 3S, no significant change with time could be discerned (table 14). However, conductivity at station 2S increased from the historical values.

Total Suspended Solids. Total suspended solids (TSS) are the portion of total solids retained by a filter ≤ 2.0 µm nominal pore size. Total solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at 103-105°C. Total solids include TSS and total dissolved solids, the portion that passes through the filter (APHA et al., 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 they mainly are 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 also may 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.

As shown in table 13e, highest TSS (140 mg/L) occurred during this study at station 3S on May 9, 1996, because of a storm event. The mean TSS at stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were 8.1, 9.5, 22.6, 11.7, 15.9, 32.7, 20.3, and 30.2 mg/L, respectively (table 13a-h). As expected, higher TSS were found in the bottom waters than the surface waters.

Referring to tables 12a-f for the historical data, the mean TSS values at stations 1S, 1B, 2S, 2B, 3S, and 3B were, respectively, 6.3, 17.7, 7.6, 23.3, 13.6, and 20.5 mg/L. The overall range of historical TSS values were between 1 and 66 mg/L. In comparison, the current TSS values for the surface water were higher than historical values for all three surface stations. The trend was inverse for the bottom waters (table 14).

On the basis of the Illinois Lake Assessment Criteria (IEPA, 1978), water with TSS > 25 mg/L is classified as having a high lake-use impairment; TSS between 15 and 25 mg/L indicates moderate-use impairment; TSS < 15 mg/L is considered to have minimal impairment. In this study, the number of samples that exceeded TSS levels of 25 mg/L were 4, 8, 35, 9, 15, 58, 16, and 17 percent of samples at stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B, respectively. At the same stations, the percent of samples having TSS values between 15 and 25 mg/L were 4, 0, 22, 4, 31, 15, 16, and 42, respectively. On the basis of TSS, waters at stations 1S and 2S might be considered as not impaired.

Volatile Suspended Solids. Volatile suspended solids (VSS) are the portion of TSS lost to ignition at 500 ± 50°C. The 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 resuspended from the lake bottom by bottom-feeding fish, wind action, or human activities can be major contributors of VSS and TSS.

The VSS levels in the surface and bottom samples at any given station ranged from 1 (most stations, various dates) to 28 mg/L (at station 4B on May 9, 1996) during the current study. Mean VSS ranged from a low 3.1 mg/L at station 1S to 11 mg/L at station 3S (table 13a-h).

Tables 12a-f reveal that the mean VSS at stations 1S, 1B, 2S, 2B, 3S, and 3B were, respectively, 2.3, 4.7, 3.8, 4.7, 5.3, and 4.7 mg/L. Comparing the historical and current data, the VSS increased at stations 1S, 1B, and 3S; but there are no differences in VSS at stations 2S and 2B (table 14).

Nitrogen. Nitrogen is generally found in surface waters in the form of ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and organic nitrogen. Organic nitrogen is determined by subtracting NH_3-nitrogen from the total Kjeldahl nitrogen (TKN) measurements. Organic nitrogen content can indicate the relative abundance of organic matter (algae and other vegetative matter) in water, but it 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 has stipulated (IEPA, 1990) that nitrate not exceed 10 mg/L nitrate-nitrogen or 1 mg/L nitrite-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 also can 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 the 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. With 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) cautions that the direct use of organic nitrogen by planktons has not been established definitely, citing that not 1 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. Vollenweider (1968) has stated that, in view of the fact there are always bacterial fauna active in nature, the question of the use of organic nitrogen sources is of more interest to physiology than to ecology.

Ammonia-Nitrogen. As shown in table 13a-h, during this study, the minimum ammonia-nitrogen (NH_3-N) concentration was 0.01 mg/L for the four routine surface water sampling stations. The maximum NH_3-N levels observed for stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were 0.56, 1.1, 2.7, 1.0, 1.0, 2.6, 0.64, and 0.38 mg/L, respectively. At the same stations, the mean ammonia concentrations were, respectively, 0.138, 0.282, 0.800, 0.169, 0.310, 0.201, 0.169, and 0.172 mg/L.

The Illinois General Use Water Quality Standards of NH_3-N vary according to water temperature and pH values, with the allowable concentration of NH_3-N decreasing as temperature and pH rise. High water temperatures and pH increase the toxicity of NH_3-N for fish and other aquatic organisms. The allowable concentration of NH_3-N for the lake waters varied from 1.5-13.0 mg/L, depending on the observed temperature and pH values. The observed data in Otter Lake showed that the NH_3-N values are well within the upper limit of the standards.

For historical data (table 12), the mean NH_3-N concentrations for stations 1S, 1B, 2S, 2B, 3S, and 3B were 0.059, 1.003, 0.111, 0.568, 0.101, and 0.121 mg/L, respectively. Based on the statistical comparison, NH_3-N values for surface waters in the current study were greater than the historical means. In contrast, mean NH_3-N values for bottom waters (1B and 2B) in the current study were less than the historical means (table 14).

Total Kjeldahl Nitrogen. During this study, TKN values found in Otter Lake ranged from 0.1 mg/L at station 4S on September 24, 1996, to 5.0 mg/L at station 3S on May 9, 1996. Results in tables 13a-h show that mean TKN levels at stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were 0.76, 0.85, 1.44, 0.86, 0.99, 1.37, 0.90, and 0.95 mg/L, respectively. The bottom waters have higher TKN than the surface waters.

For historical data, TKN ranged from 0.3 mg/L at station 1S on August 17, 1984 and station 2S on July 14,1989, to 3.8 mg/L at station 1B on August 17, 1989. Mean TKN concentrations for stations 1S, 1B, 2S, 2B, 3S, and 3B were, respectively, 0.78, 1.69, 0.90, 1.30, 1.15, and 1.18 mg/L (tables 12a-f). Mean TKN at station 3S in this study was significantly higher than the historical mean. At stations 1S, 1B, and 2B, mean TKN in the current study was less than the historical mean. The TKN means at station 2S were comparable.

An examination of the data for NH_3-N and TKN reveal that suspended matter in the water column was predominantly of organic origin (algae, zooplankton, bacteria, plant fragments, etc.). Organic nitrogen constituted more than 80 percent of the total Kjeldahl nitrogen determined for the four surface water samples.

Nitrate/Nitrite-Nitrogen. An examination of observed data during this study in tables 13a-h suggests that many samples, especially those collected in summer months, have low nitrate/nitrite-nitrogen (NO_3/NO_2) levels (at the detectable limit) of 0.01 mg/L. The highest value observed was 9.1 mg/L at station 1S on February 11, 1997. On the same date, a maximum value also was observed for station 2S, but not at station 3S. However, high NO_3/NO_2 (1.56 mg/L) was found at station 3S on January 23, 1997. At station 3S, high NO_3/NO_2 levels persist in May through early July 1996 (2.9-6.4 mg/L); with a maximum (6.4 mg/L) on June 5, 1996. Mean NO_3/NO_2 values for stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were 1.067, 0.456, 0.267, 0.946, 0.629, 1.793, 1.478, and 1.708 mg/L, respectively.

As can be seen in tables 12a-f, NO_3/NO_2 were not detected in many historical samples. A maximum NO_3/NO_2 concentration of 13 mg/L was found at both stations 1S and 2S on August 9, 1982. On this date, the NO_3/NO_2 concentration at station 3S was 0.66 mg/L.

Comparison of the current and historical mean NO_3/NO_2 data suggests that there are no significant differences at stations 1S, 2B, and 3S. Mean NO_3/NO_2 values for stations 1B and 2S of the current study were less than the historical means (table 14).

Phosphorus. The term total phosphorus (TP) represents all forms of phosphorus in water, both in particulate and dissolved forms, including three chemical types: reactive, acid-hydrolyzed, and organic. Dissolved phosphorus (DP) is the soluble form of TP (filterable 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, as is true of 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. Any condition that approaches or exceeds the limits of tolerance is said to be a limiting condition or a limiting factor.

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. However, the major portion of phosphate-phosphorus emitted from municipal sewer systems is in a dissolved form. This is also 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 the lake water may include the decomposition of aquatic plants and animals. Dissolved phosphorus is readily available for algae and macrophyte growth. However, the DP concentration 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 nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature.

To prevent biological nuisance, the IEPA (1990) stipulates, "Phosphorus as P shall not exceed a concentration of 0.05 mg/L in any reservoir or lake with a surface area of 20 acres (8.1 ha) or more or in any stream at the point where it enters any reservoir or lake."

Total Phosphorus. During this study period, the ranges of TP values observed were 0.005-0.123, 0.009-0.090, 0.008-0.499, 0.010-0.326, 0.013-0.106, 0.017-0.741, 0.015-0.231, and 0.011-0.323 mg/L for stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B, respectively. At these same stations, the mean TP concentrations were 0.027, 0.034, 0.148, 0.048, 0.053, 0.163, 0.077, and 0.096 mg/L, respectively (tables 13a-h). The maximum TP values at stations 2B, 3S, 4S, and 4B occurred on May 9, 1996. This might have been caused by a storm event. Maximum TP occurred at station 1S (0.123 mg/L) on September 9, 1996. On this date, TP value at station 2S was also relatively high (0.105 mg/L).

In this study, the number (percent) of samples collected from stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B exceeding the 0.05 mg/L TP standard were 2 (9%), 2 (15%), 11 (50%), 5 (22%), 6 (46%), 23 (92%), 12 (63%), and 6 (50%), respectively. High TP concentrations were observed in stations 3 and 4.

Tables 12a-f show that the range of historical TP concentrations in Otter Lake were between 0.001 and 0.544 mg/L. The mean TP values for stations 1S, 1B, 2S, 2B, 3S, and 3B were, respectively, 0.033, 0.145, 0.046, 0.119, 0.089, and 0.098 mg/L.

Statistical analyses suggest that the current TP values for station 3S were higher than the historical results, indicating a water quality impairment at the upper end of Otter Lake. For two other stations (1 and 2), it showed either improvement (station 2B) or no change (table 14).

Dissolved Phosphorus. Dissolved phosphorus usually followed the same pattern as TP. During the study period, DP concentrations in Otter Lake waters ranged from 0.001 mg/L at station 1S on April 17, 1996, to 0.431 mg/L at station 3S on September 9, 1996. On this latter date, DP contributed 99.5 percent of TP. Mean DP values for stations 1S, 1M, 1B, 2S, 2B, 3S, 4S, and 4B were 0.009, 0.016, 0.102, 0.023, 0.017, 0.056, 0.025, and 0.034 mg/L, respectively (tables 13a-h).

For the historical data shown in tables 12a-f, DP concentrations in many samples were 0.001 mg/L. The highest DP concentration observed was 0.431 mg/L at station 1B on August 2, 1994. Mean DP concentrations for stations 1S, 1B, 2S, 2B, 3S, and 3B were, respectively, 0.014, 0.091, 0.022, 0.049, 0.029, and 0.017 mg/L.

Comparisons of the current DP results and the historical results indicate trends similar to those for TP. Current mean DP for station 3S was significantly higher than the historical mean. For stations 1S and 2B, current mean DP were less than the historical means. Mean DP for stations 1B and 2S were not significantly different.

Chlorophyll. All green plants contain chlorophyll *a*, which constitutes approximately 1 to 2 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 a 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) contains only chlorophyll *a*, but both the green algae (Chlorophyta) and the euglenoids (Euglenophyta) contain chlorophyll *a* and *c.* Chlorophyll *a* and *c* also are present in the diatoms, yellow-green and yellow-brown (Chrysophyta), as well as 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 samples, the indirect method of making such assessments was not used in this investigation.

The observed, mean, and range of values for chlorophyll *a* and other pigments are given in tables 21a-g for the current study and historical survey. The mean concentrations of chlorophyll *a* (corrected) in the lake (stations 1-4) during the current study and in three stations (stations 1-3) during the historical survey were 12.01, 17.84, 61.48, 30.16, 21.7, 22.98, and 38.33 µg/L. Mean chlorophyll values for stations 1 and 2 in the current study were less compared to the historical values. However, at station 3, chlorophyll *a* values were significantly greater.

It can be seen from tables 21a-g that chlorophyll *a* concentration at each station has a peak in April or May, then a dip in June and July, and reaches its annual maximum in August. During this study, the maximum values of corrected chlorophyll *a* for stations 1, 2, 3, and 4 were 31.84 (8/15/96), 52.1 (4/17/96), 198.92 (8/19/96), and 64.32 µg/L (7/15/96), respectively. Historical maximum values of corrected chlorophyll *a* for stations 1, 2, and 3 were 79 (7/30/79 and 8/16/79), 87.1 (8/14/91), and 160.2 µg/L (8/14/91), respectively.

An examination of the data in tables 21a-g suggests that chlorophyll *b* and *c* and pheophytin *a* in Otter Lake were found to be generally low. They were, respectively, about 9-22, 7-18, and 4-8 percent of chlorophyll *a* concentration.

Metals in Water. Results of metal analyses for lake waters for both 1979 and the current study are presented in tables 22a-d. In 1979 samples were analyzed only for four metals: copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Fourteen metal analyses were performed in the current study. In general, with some exceptions, aluminum, copper, silver, and zinc were found to be less than the detectable values. Metals data do not indicate any discernible trend.

The IPCB (IEPA, 1990) stipulated chemical constituents concentrations for secondary contact and indigenous aquatic life standards as follows: barium, 5 mg/L; copper, 1.0 mg/L; iron, 2.0 mg/L; manganese, 1.0 mg/L; silver, 1.1 mg/L, and zinc, 1.0 mg/L. Unfortunately, many laboratory detection limits are much greater than the standards.

Table 21a. Chlorophyll Concentrations for the Current Study in Otter Lake at Station 1 (RD-A06-F-1)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
04/11/96	8.82	8.16	0.59	0.89	0.67
04/17/96	10.14	10.32	0.65	0.00	0.00
05/09/96	7.40	5.87	1.35	1.82	2.35
06/05/96	10.34	8.64	0.76	0.57	2.36
06/17/96	16.00	15.49	2.37	1.52	0.21
07/03/96	14.50	14.30	2.21	0.00	0.00
07/15/96	12.35	13.35	2.61	0.00	0.00
08/15/96	32.33	31.84	1.92	0.00	0.00
08/19/96	24.93	24.56	2.02	1.64	0.00
08/19/96	27.61	25.10	2.66	1.95	2.94
10/02/96	18.60	18.33	1.51	1.23	0.00
11/20/96	3.84	3.74	0.46	0.48	0.00
01/23/97	5.16	4.54	0.92	1.30	0.88
02/11/97	6.56	5.87	0.74	0.45	0.85
03/19/97	11.69	11.75	2.02	2.09	0.00
04/18/97	5.32	6.23	0.09	0.00	0.00
05/13/97	3.50	2.67	0.39	0.85	1.25
06/06/97	4.56	5.41	0.79	0.03	0.00
Count	18	18	18	18	18
Minimun	3.50	2.67	0.09	0.00	0.00
Maximun	32.33	31.84	2.66	2.09	2.94
Average	12.43	12.01	1.34	0.82	0.64
Standard deviation	8.54	8.31	0.84	0.76	0.97

Table 21b. Chlorophyll Concentrations for the Current Study in Otter Lake at Station 2 (RD-A06-F-2)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
04/11/96	9.32	9.15	1.50	1.83	0.00
04/17/96	54.00	52.10	3.06	2.88	0.32
05/09/96	9.69	8.01	3.32	3.28	2.74
06/05/96	16.07	15.40	1.97	1.37	0.41
06/17/96	28.34	27.23	5.12	1.25	0.80
07/03/96	14.60	15.82	2.59	0.00	0.00
07/15/96	14.56	13.35	3.45	0.31	1.60
08/15/96	33.74	33.23	2.97	0.67	0.00
08/19/96	36.68	35.24	3.42	2.07	0.64
09/09/96	38.73	33.82	5.34	2.87	6.68
10/02/96	22.92	24.08	4.17	2.17	0.00
11/20/96	7.47	6.94	0.62	1.15	0.53
01/23/97	4.66	4.27	1.50	1.70	0.59
02/11/97	5.60	5.87	1.12	1.08	0.00
03/19/97	15.05	13.88	2.65	3.13	1.44
04/18/97	8.66	9.79	1.09	0.00	0.00
05/13/97	6.88	6.94	0.89	1.23	0.00
06/06/97	5.72	6.08	0.78	0.00	0.00
Count	18	18	18	18	18
Minimun	4.66	4.27	0.62	0.00	0.00
Maximun	54.00	52.10	5.34	3.28	6.68
Average	18.48	17.84	2.53	1.50	0.88
Standard deviation	14.21	13.46	1.45	1.08	1.63

Table 21c. Chlorophyll Concentrations for the Current Study in Otter Lake at Station 3 (RD-A06-F-3)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
04/11/96	87.80	84.55	3.87	11.35	0.80
04/17/96	77.93	78.32	4.73	4.76	0.00
06/05/96	5.46	6.47	1.03	0.00	0.00
06/17/96	83.51	82.77	26.34	2.50	0.00
07/03/96	48.19	48.06	8.17	1.29	0.00
07/15/96	51.32	46.99	9.07	0.89	5.34
08/15/96	139.16	134.22	26.06	5.47	3.18
08/19/96	202.85	198.92	45.65	11.99	0.13
09/09/96	75.86	66.75	14.04	5.75	12.68
10/02/96	98.13	89.52	14.68	6.03	10.52
11/20/96	44.50	41.82	3.03	6.78	2.32
11/20/96	39.16	40.05	8.83	7.66	0.00
02/11/97	6.47	6.68	4.22	4.54	0.00
03/19/97	14.55	9.61	37.57	0.00	6.84
04/18/97	46.24	47.72	4.08	4.74	0.00
05/13/97	60.46	60.52	8.85	7.15	0.00
06/06/97	60.35	58.41	7.67	2.11	0.58
10/03/97	14.46	5.34	15.48	27.01	17.09
Count	18	18	18	18	18
Minimun	5.46	5.34	1.03	0.00	0.00
Maximun	202.85	198.92	45.65	27.01	17.09
Average	64.24	61.48	13.52	6.11	3.30
Standard deviation	48.97	48.25	12.55	6.25	5.19

Table 21d. Chlorophyll Concentrations for the Current Study in Otter Lake at Station 4 (RD-A06-F-4)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
05/22/96	4.51	4.01	0.85	0.00	0.67
06/17/96	24.50	23.50	4.60	1.25	0.80
07/03/96	42.69	42.52	10.81	0.00	0.00
07/07/96	42.38	38.45	12.57	0.50	5.66
07/15/96	67.10	64.32	10.29	3.57	1.94
08/19/96	48.33	44.06	8.69	4.80	5.47
09/09/96	47.97	41.83	8.70	3.35	8.63
10/02/96	18.96	17.80	3.90	0.83	1.30
11/20/96	21.52	19.36	1.63	3.11	2.60
01/23/97	8.08	6.41	1.39	2.06	2.56
02/11/97	6.22	5.34	1.90	1.99	1.39
03/19/97	9.24	6.41	3.63	5.06	4.81
04/18/97	38.26	40.35	3.02	*AAA*	0.00
05/13/97	61.91	60.88	6.90	6.81	0.00
06/06/97	39.24	37.19	3.51	1.29	1.53
Count	15	15	15	15	15
Minimun	4.51	4.01	0.85	0.00	0.00
Maximun	67.10	64.32	12.57	6.81	8.63
Average	32.06	30.16	5.49	2.60	2.49
Standard deviation	20.37	19.92	3.84	2.05	2.54

Table 21e. Chlorophyll Concentrations for the Historical Record through March 1996 in Otter Lake at Station 1 (RD-A06-F-1)

Sample date	*Chlorophyll a (μg/L)*	*Chlorophyll a corrected (μg/L)*	*Chlorophyll b (μg/L)*	*Chlorophyll c (μg/L)*	*Pheophytin a (μg/L)*
05/22/79	12.50	12.00	0.34	1.72	0.67
06/12/79	17.80	17.80	1.30	0.37	0.00
07/30/79	83.00	79.00	1.00	8.00	2.00
08/16/79	86.00	79.00	1.00	4.00	5.00
09/25/79	15.00	13.00	1.00	1.00	2.00
10/26/79	9.00	6.00	3.00	6.00	5.00
06/24/80	7.00	7.30	0.80	0.00	0.00
09/02/80	22.10	15.00	1.30	1.90	11.60
05/24/82	8.06	7.54	0.91	3.70	0.84
08/09/82	6.52	7.04	0.49	1.01	0.00
05/17/84	16.57	13.49	3.32	6.75	4.76
08/17/84	10.72	10.03	1.85	2.51	0.77
04/18/89	12.75	10.84	1.70	1.42	2.71
06/07/89	7.11	7.42	0.86	0.89	0.00
07/14/89	6.00	6.21	1.06	1.51	0.00
08/17/89	24.27	23.99	2.51	0.86	0.00
10/13/89	16.10	16.09	1.76	1.93	0.00
04/25/91	17.40	17.80	1.86	4.04	0.00
06/10/91	9.27	9.42	1.52	0.34	0.00
07/05/91	7.04	8.07	1.60	0.43	0.00
08/14/91	47.06	51.11	2.64	0.82	0.00
10/07/91	15.78	15.75	3.86	1.34	0.00
04/21/94	76.32	72.98	14.19	14.15	3.03
08/02/94	11.76	13.69	2.64	2.48	0.00
10/13/94	21.65	21.82	4.08	5.03	0.00
Count	25	25	25	25	25
Minimun	6.00	6.00	0.34	0.00	0.00
Maximun	86.00	79.00	14.19	14.15	11.60
Average	22.67	21.70	2.26	2.89	1.54
Standard deviation	23.87	22.74	2.68	3.18	2.70

Table 21f. Chlorophyll Concentrations for the Historical Record through March 1996 in Otter Lake at Station 2 (RD-A06-F-2)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
05/22/79	12.90	12.50	0.93	0.21	0.39
06/12/79	27.50	26.00	2.12	3.60	2.19
07/30/79	93.00	87.00	1.00	8.00	4.00
08/16/79	69.00	64.00	1.00	4.00	5.00
09/25/79	21.00	19.00	1.00	2.00	2.00
10/26/79	11.00	17.00	7.00	9.00	1.00
06/24/80	9.60	9.60	1.60	0.00	0.00
09/02/80	18.80	15.50	0.80	0.40	5.10
08/09/82	10.43	10.35	0.40	0.18	0.00
05/17/84	5.63	5.60	0.10	0.65	0.00
08/17/84	12.81	12.23	1.36	1.59	0.40
04/18/89	18.79	18.53	3.34	4.25	0.00
06/07/89	6.27	6.13	0.68	0.29	0.00
07/14/89	10.65	10.24	0.00	0.60	2.73
08/17/89	33.18	32.86	2.15	0.93	0.00
10/13/89	12.23	12.53	1.20	1.41	0.00
04/25/91	22.22	20.44	3.34	5.00	2.18
06/10/91	10.07	11.35	2.47	0.55	0.00
07/05/91	9.71	10.84	2.66	0.66	0.00
08/14/91	78.03	87.07	4.38	1.12	0.00
10/07/91	25.37	23.52	5.48	1.02	2.29
10/07/91	9.09	9.29	3.62	4.91	0.00
08/02/94	13.76	14.48	1.92	1.26	0.00
10/13/94	15.24	15.35	1.93	0.88	0.00
Count	24	24	24	24	24
Minimun	5.63	5.60	0.00	0.00	0.00
Maximun	93.00	87.07	7.00	9.00	5.10
Average	23.18	22.98	2.10	2.19	1.14
Standard deviation	23.25	22.99	1.72	2.49	1.66

Table 21g. Chlorophyll Concentrations for the Historical Record through March 1996 in Otter Lake at Station 3 (RD-A06-F-3)

Sample date	*Chlorophyll a (µg/L)*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	*Pheophytin a (µg/L)*
06/21/77	4.45	4.24	0.34	0.00	0.28
06/12/79	5.23	4.88	1.14	0.00	0.65
07/30/79	21.00	19.00	1.00	1.00	2.00
08/16/79	41.00	29.00	1.00	3.00	17.00
09/25/79	62.00	54.00	4.00	7.00	10.00
10/26/79	18.00	13.00	2.00	6.00	6.00
06/24/80	25.90	23.40	2.60	0.00	4.00
09/02/80	33.50	31.90	1.50	3.20	2.10
05/24/82	15.00	12.76	2.13	4.44	3.76
08/09/82	42.14	38.74	2.34	2.10	4.97
08/09/82	3.66	3.88	0.52	1.57	0.00
08/17/84	43.94	40.67	1.80	4.15	3.13
04/18/89	69.59	67.01	7.45	7.28	1.15
06/07/89	35.28	34.33	1.70	3.25	0.00
07/14/89	40.52	40.94	1.99	2.03	0.00
08/17/89	89.20	89.87	5.14	0.64	0.00
08/17/89	41.77	42.10	9.85	2.83	0.00
04/25/91	56.10	56.33	5.38	5.22	0.00
06/10/91	24.43	25.78	4.42	1.07	0.00
07/05/91	46.58	50.43	9.38	2.48	0.00
08/14/91	140.33	160.20	7.40	0.76	0.00
10/07/91	34.82	35.91	7.60	0.60	0.00
10/07/91	11.69	10.68	13.09	19.43	3.03
08/02/94	39.72	35.94	7.14	9.03	5.03
10/13/94	32.61	33.17	10.69	9.02	0.00
Count	25	25	25	25	25
Minimun	3.66	3.88	0.34	0.00	0.00
Maximun	140.33	160.20	13.09	19.43	17.00
Average	39.14	38.33	4.46	3.84	2.52
Standard deviation	29.44	32.62	3.65	4.24	3.95

Table 22a. Metals Concentrations in Otter Lake at Station 1 during 1979 and Current Study

	1979						*Current*			
	5/22	*6/12*	*7/30*	*8/16*	*9/25*	*10/26*	*8/19/96*	*1/23/97*	*8/19/96*	*1/23/97*
Metal	*Surface*						*Surface*		*Middle*	
Aluminum							100 k	100 k	120	100 k
Barium							48	40	68	53
Boron							17	25	21	24
Calcium							26	26	38	35
Cobalt										
Copper	5 k	5 k	5 k	50	30	5 k	10 k	10 k	10 k	25
Iron	270	120	60	70	120	100	50 k	50 k	230	50 k
Magnesium							14	11	15	14
Manganese	30	20	20	30	40	290	15 k	15 k	1200	52
Potassium							3.6	3.0	3.4	3.2
Silver							3 k	3	3 k	3 k
Sodium							7.8	6.2	7.9	8.2
Strontium							68	80	130	110
Zinc	5 k	5 k	5 k	20	40	10	100 k	100 k	100 k	100 k
	Bottom						*Bottom*			
Aluminum							560	100 k		
Barium							82	54		
Boron							16	21		
Calcium							39	35		
Cobalt										
Copper	5 k	5 k	5 k	20	5 k	5 k	10 k	10 k		
Iron	610	660	2000	900	480	180	3900	50 k		
Magnesium							15	15		
Manganese	270	470	2000	1900	3500	430	2800	84		
Potassium							3.3	3.2		
Silver							3 k	3		
Sodium							8.1	8.2		
Strontium							140	110		
Zinc	5 k	5 k	5 k	10	10	10	100 k	100 k		

Table 22b. Metals Concentrations in Otter Lake at Station 2 during 1979 and Current Study

	1979						*Current*			
	5/22	*6/12*	*7/30*	*8/16*	*9/25*	*10/26*	*8/19/96*	*1/23/97*	*8/19/96*	*1/23/97*
Metal	*Surface*						*Surface*		*Middle*	
Aluminum							100 k	100 k		
Barium							50	33		
Boron							15	15		
Calcium							27	21		
Cobalt										
Copper	5 k	5 k	20	20	10	5 k	10k	10k		
Iron	210	200	80	70	110	170	50 k	50 k		
Magnesium							14	8.9		
Manganese	20	20	20	30	70	410	15 k	15 k		
Potassium							3.5	1.8		
Silver							3 k	4		
Sodium							7.9	5.1		
Strontium							72	65		
Zinc	80	5 k	5 k	5 k	10	10	100 k	100 k		
	Bottom						*Bottom*			
Aluminum							290	100 k		
Barium							70	54		
Boron							15	25		
Calcium							39	35		
Cobalt										
Copper	5 k	5 k	5 k	5 k	5	5 k	10k	10 k		
Iron	600	890	1200	340	1600	130	1000	87		
Magnesium							15	14		
Manganese	480	120	1400	910	3400	300	1400	29		
Potassium							3.3	2.9		
Silver							3 k	3 k		
Sodium							7.9	8.2		
Strontium							140	110		
Zinc	5 k	5 k	5 k	5 k	10	30	100 k	100 k		

Table 22c. Metals Concentrations in Otter Lake at Station 3 during 1979 and Current Study

	1979						*Current*			
	5/22	*6/12*	*7/30*	*8/16*	*9/25*	*10/26*	*8/19/96*	*1/23/97*	*8/19/96*	*1/23/97*
Metal	*Surface*						*Surface*		*Middle*	
Aluminum							110	1300		
Barium							48	71		
Boron							33	17		
Calcium							27	27		
Cobalt							11	10k		
Copper	5k	10	5k	5k	5k	5k	10k	10 k		
Iron	660	780	400	390	370	410	180	1600		
Magnesium							13	10		
Manganese	70	50	50	90	170	210	58	130		
Potassium							3.3	5.2		
Silver							3k	3k		
Sodium							7.7	5.8		
Strontium							120	78		
Zinc	5k	5k	5 k	5 k	10	10	100 k	100 k		
	Bottom						*Bottom*			
Aluminum										
Barium										
Boron										
Calcium										
Cobalt										
Copper		20	20	10		5k				
Iron		1200	510	440		420				
Magnesium										
Manganese		80	3500	100		210				
Potassium										
Silver										
Sodium										
Strontium										
Zinc		30	5k	5k		10				

Table 22d. Metals Concentrations in Otter Lake at Station 4, 1996-1997

	Current			
	8/19/96	*1/23/97*	*8/19/96*	*1/23/97*
Metal	*Surface*		*Middle*	
Aluminum	100 k	100 k		
Barium	53	55		
Boron	21	19		
Calcium	27	36		
Cobalt	10 k	10 k		
Copper	10 k	10 k		
Iron	160	72		
Magnesium	14	15		
Manganese	68	58		
Potassium	3.5	2.9		
Silver	3 k	3		
Sodium	7.7	8.2		
Strontium	84	100		
Zinc	100 k	100 k		

	Bottom	
Aluminum	300	100 k
Barium	78	55
Boron	22	20
Calcium	28	36
Cobalt	14	10 k
Copper	10k	10k
Iron	450	94
Magnesium	14	15
Manganese	150	77
Potassium	3.7	3.1
Silver	3 k	3 k
Sodium	7.7	8.2
Strontium	81	100
Zinc	100 k	100 k

Notes: All units are in mg/L
A k indicates values below the detection level
Blank space means that the analysis was not made

Biological Characteristics

Macrophytes are commonly called aquatic vegetation (or weeds). The macrophytes consist principally of aquatic vascular flowering plants, including 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 habitats and hiding places for many small fish (fingerlings, bluegill, sunfish, etc.). They also provide food, shade, and oxygen for aquatic organisms; block water movement (wind wave); and use 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 and benthic invertebrates); causes fish kills; produces taste and odor in water due to decomposition of dense weed beds; blocks water movement and retards heat transfer, creating vertical temperature gradients; and destroys aesthetic value to the extent of decreasing the economic values of properties surrounding a lake. Under these circumstances, aquatic plants often are referred to as weeds.

The macrophytes survey was conducted on August 16, 1996, by the Illinois EPA. The survey results are plotted in figure 15. Five species of macrophytes were observed in Otter Lake at shallow areas of lake arms. They are *Phalaris* sp. (canary reed grass), *Salix* sp. (willow), *Potamogeton nodosus* (American pondweed), *Scirpus validus* (soft-stem bulrush), and *Phragmites communis* (giant weed grass). Canary reed grass and willow were found in the north basin, especially where water levels had become shallow due to siltation. Sporadic patches of American pondweed were observed in the south one-half of the south basin, generally in water depth of 6 feet or less.

However, during a 1989 macrophyte survey by the Illinois EPA, ten species were recorded all around the lake shorelines (IEPA field data, A. Jo Walkenbach, personal communication, 1998). Aquatic macrophytes observed were *Dianthera americana* (water willow), *Potamoogeton nodosus, Scirpus validus, Ceratophyllum demersum* (coontail), *Typa* spp. (cattail), *Jussiaea repens* var. *glabrescens* (creeping waterprimrose), *Cyperus strigosus* (lean sedge), *Ruppia maritima* (widgon grass), *Najas minor* (brittle naiad), and *Sagittaria* spp. (arrowhead). A significant decrease in the macrophyte community has been found in Otter Lake since 1989.

Comparison of Water Quality between Stations 2 and 4

Observed data during the 1996-1997 study for stations 2S and 4S were subjected to the Student *t*-tests for determining whether there are significant differences in the two means of water quality parameters for these two stations. The results of the *t*-tests are presented in table 23.

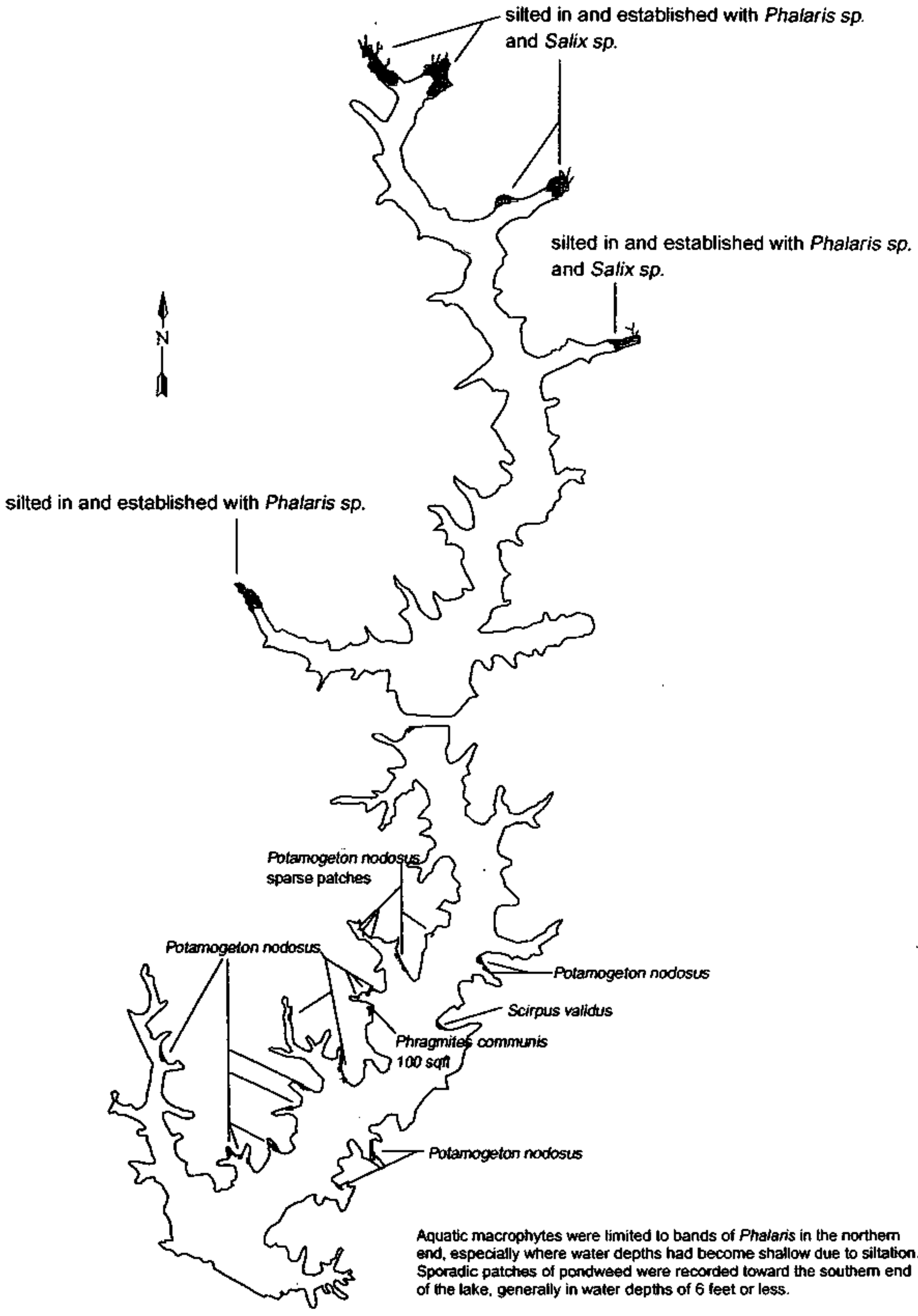


Figure 15. Aquatic vegetation at Otter Lake, 1996

Table 23. Analyses of Differences in Water Quality Parameters between Stations 2S and 4S, 1996-1997

Parameters	*Mean values*		*Degree of freedom*	*t values*		*95th percentile significant difference*
	Station 2S	*Station 4S*		*$t_{0.975}$*	*Calculated*	
Turbidity, NTU	8.4	14.4	38	2.03	2.72	yes
Secchi transparency, in.	48	28	40	2.02	-8.53	yes
Conductivity, µmho/cm	302	307	37	2.03	-23.15	yes
Total alkalinity, mg/L as $CaCO_3$	107	109	24	2.06	0.90	no
Suspended solids, mg/L						
Total	12	20	40	2.02	4.87	yes
Volatile	5	6	40	2.02	4.15	yes
Nitrogen, mg/L						
Ammonia	0.17	0.17	40	2.02	0.89	no
Total kjeldahl	0.86	0.90	40	2.02	1.90	no
Nitrate/nitrite	0.95	1.48	40	2.02	3.62	yes
Phosphorus, mg/L						
Total	0.048	0.077	40	2.02	4.43	yes
Dissolved	0.023	0.025	40	2.02	0.12	no
Chlorophyll *a*, µg/L	17.8	30.2	31	2.04	5.87	yes

Notes: $t_{0.975}$ - critical value for the *t* distribution with 95th percentile confidence level at the specified degree of freedom

$CaCO_3$ - calcium carbonate

NTU - nephelometric turbidity units

There are no significant differences in total alkalinity, ammonia-nitrogen, total Kjeldahl nitrogen, and dissolved phosphorus concentrations between stations 2S and 4S.

The mean values of turbidity, total and volatile suspended solids, nitrate/nitrite-nitrogen, total phosphorus, and chlorophyll *a* for station 4S are significantly greater than those for station 2S, with a 95 percentile confidence level. The mean values of Secchi disc transparency and conductivity for station 4S are significantly less than those for station 2S. It can be concluded that water quality at station 2S is significantly better than that at station 4S. On the basis of mean TSS and Secchi disc transparency, station 2S was considered as minimal impairment; and station 4S was moderate use impairment. The mean TP value of station 2S met the 0.05 mg/L standard, station 4S did not.

Similarly, data obtained during the 1996-1997 study for stations 2B and 4B also were subjected to the *t*-tests. The results of the *t*-tests are listed in table 24. The table indicates no statistical difference in the concentrations of conductivity, total alkalinity, and total Kjeldahl nitrogen in stations 2B and 4B.

The mean concentrations of turbidity, total and volatile suspended solids, nitrate/nitrite-nitrogen, and total and dissolved phosphorus for station 4B are significantly higher than those for station 2B at the 95th percentile confidence level. This is mostly the case for surface waters at these two stations also. Only ammonia-nitrogen mean concentrations at station 2B are greater than those at station 4B. In spite of the destratifier near station 4, water quality at station 2 is better than at station 4. On the basis of mean TSS values, station 2B was classified as moderate impairment, and station 4B was high impairment. Neither station met the TP standard.

Surface Inflow and Outflow Water Quality

Tributary inflow and spillway outflow water quality also were monitored, especially during the storms. The results of these samplings are presented in table 25. The ranges of parameters monitored also are included in table 25. Average values were not determined. It can be noticed from the table that, in storm waters (5/8/96), conductivity, pH, and nitrate/nitrite-nitrogen values decreased from the normal levels; total and volatile suspended solids, ammonia, total Kjeldahl nitrogen, and total phosphorus increased significantly. As expected, the water quality data for the outflow (table 25) is in the ranges of station 1S (table 13a).

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. These indices have been based on Secchi disc transparency; nutrient concentrations;

Table 24. Analyses of Differences in Water Quality Parameters between Stations 2B and 4B, 1996-1997

Parameters	*Mean values*		*Degree of*	*t values*		*95th percentile*
	Station 2B	*Station 4B*	*freedom*	$t_{0.975}$	*Calculated*	*significant difference*
Turbidity, NTU	7.6	22	21	2.08	2.54	yes
Conductivity, µmho/cm	331	303	6	2.45	-1.44	no
Total alkalinity, mg/L as $CaCO_3$	124	128	7	2.37	0.22	no
Suspended solids, mg/L						
Total	16	30	23	2.07	2.71	yes
Volatile	4	7	23	2.07	2.91	yes
Nitrogen, mg/L						
Ammonia	0.31	0.17	23	2.07	-4.23	yes
Total kjeldahl	0.99	0.95	23	2.07	-0.63	no
Nitrate/nitrite	0.63	1.71	23	2.07	5.06	yes
Phosphorus, mg/L						
Total	0.053	0.096	23	2.07	4.00	yes
Dissolved	0.017	0.034	23	2.07	3.48	yes

Notes: $t_{0.975}$ - critical value for the *t* distribution with 95th percentile confidence level at the specified degree of freedom.

$CaCO_3$ - calcium carbonate

NTU - nephelometric turbidity units

Table 25. Water Quality Characteristics for Inflow (Tributary) and Outflow of Otter Lake, 1996-1997

Date	Time	*Turbidity, NTU*	*Conductivity, µmho/cm*	*pH*	*Total alkalinity, mg/L as $CaCO_3$*	*Suspended solids. mg/L*		*Nitrogen, mg/L*			*Phosphorus, mg/L*	
						Total	*Volatile*	*Ammonia*	*NO_2/ NO_3*	*Total Kjeldahl*	*Total*	*Dissolved*
Tributary	(RDF 02)											
4/17/96	17:45	3.7	570	8.8		12	2	0.01k	9.6	1.00	0.051	
4/29/96	17:20	76	380	7.8		368	48	0.21	14.2	2.50	0.774	
5/8/96	11:15	4000 L	160	7.2		216	85	0.22	4.3	63.00	1.090	
	13:30	4000 L	150	7.2		1125	130	0.27	4.0	66.00	1.550	
	15:40	4000 L	130	7.2		1400	190	0.18	2.8	66.00	1.810	
5/9/96	08:00	5.7	390	7.3		244	32	0.20	14.0	1.90	0.440	
5/22/96	16:05	16.0	520	8.8		18	2	0.30	14.0	0.43	0.037	
6/17/96	00:01	4.8	519	8.0		9	1k	0.01k	14.3	0.29	0.050	
2/11/97	08:00	2.9				4	3	0.28	0.33	0.88	0.010	0.005
	13:30	23				54	8	0.27	11.00	0.99	0.224	
2/27/97	10:55	390	321	8.2		240	24	0.27	9.00	2.40	0.805	
	13:00	450	334	8.1		210	24	0.23	9.79	2.10	0.673	
2/28/97	16:50	63			72	108	14	0.16	12.55	1.00	0.220	
3/19/97	16:00	12	527	7.7	116	13	3	0.01	12.62	0.49	0.038	
5/13/97	16:17	3.8	447	8.7		6	2	0.01	8.00	0.58	0.014	
Number of observations		15	12	12	2	15	15	15	15	15	15	1
Maximum		400	570	8.8	16	1400	190	0.30	14.3	66.0	1.810	
Minimum		2.9	130	7.2	72	4	1k	0.01k	2.8	0.29	0.010	
Outflow	(RDF 01)											
4/29/96	18:00	23	350	8.2		19	5	0.24	0.46	0.76		0.058
5/8/96	12:15	41	320	7.6		14	4	0.11	0.58	0.73	0.031	
	14:50	5	326	7.8		17	5	0.09	0.60	0.74	0.025	
2/27/97	11:40	12	314	8.2		7	3	0.22	0.32	0.84	0.012	
Number of observations		4	4	4	0	4	4	4	4	4	3	1
Maximum		41	350	8.2		19	5	0.24	0.60	0.84	0.031	
Minimum		5	314	7.6		7	3	0.09	0.32	0.73	0.012	

Notes: $CaCO_3$ - calcium carbonate, k = less than detection value, L - greater than stated value, NO_2/NO_3 - nitrite plus nitrate, NTU - nephelometric turbidity units, µmho/cm - micromho per centimeter

Storm event occurred on May 8, 1996

hypolimnetic oxygen depletion; and biological parameters, including chlorophyll *a*, species abundance, and diversity.

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. 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 micrograms per liter (µg/L), and TP in micrograms per liter 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 Otter Lake were calculated for each station using equations 1-3, based on Secchi disc transparency, TP, and chlorophyll *a* concentrations of both the historical and the current study data. The TSI results, range and average of TSI values, and trophic state are listed in table 26. Categorizing the trophic state of each station or of the lake were accomplished using mean TSI values and the information provided in table 27.

Lakes are generally classified by limnologists into one of four trophic states: oligotrophic, mesotrophic, eutrophic, or hypereutrophic. 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 growth 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.

Table 26. Statistical Summary of Trophic State Index (TSI) and Trophic State of Otter Lake

	Station 1		*Station 2*		*Station 3*		*Station 4*
TSI/ Trophic state	*1979-1994*	*1996-1997*	*1979-1994*	*1996-1997*	*1979-1994*	*1996-1997*	*1996-1997*
SD-TSI							
Minimum	47.4	44.3	44.7	44.3	61.3	63.9	51.3
Maximum	71.3	89.7	82.9	92.9	92.9	112.9	102.9
Mean	56.7	55.8	58.6	57.7	67.7	72.3	65.3
Trophic state	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Hypereutrophic	Eutrophic
TP-TSI							
Minimum	41.5	27.3	44.1	37.3	47.3	45.0	43.2
Maximum	77.4	73.5	84.3	87.6	87.1	99.4	82.6
Mean	54.4	52.0	59.2	60.0	68.9	77.2	66.2
Trophic state	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Hypereutrophic	Eutrophic
CHL-TSI							
Minimum	48.2	40.2	47.5	44.8	43.9	47.0	44.2
Maximum	73.5	64.6	74.4	69.4	80.4	82.5	71.4
Mean	60.8	55.0	61.3	58.9	66.4	71.0	64.0
Trophic state	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Hypereutrophic	Eutrophic
Overall							
Mean	57.3	54.3	59.7	58.9	67.7	73.5	65.2
Trophic state	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Hypereutrophic	Eutrophic

Notes: CHL - chlorophyll *a*
SD - Secchi disc transparency
TP - total phosphorus
TSI - trophic state index

Table 27. Quantitative Definitions of Lake Trophic States

Trophic state	*Secchi disc transparency (in.)*	*Secchi disc transparency (m)*	*Chlorophyll a (µg/L)*	*Total phosphorus, lake surface (fig/L)*	*Trophic State Index*
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

The mean TSI values shown in table 26 suggest that values calculated using the three parameters fall within a narrow range for each station and for each study period. The overall average TSI values for stations 1, 2, 3, and 4 using the average of mean SD-TSI, TP-TSI, and CHL-TSI, during the current study, were 54.3, 58.9, 73.5, and 65.2, respectively. During the period of 1979-1994, the overall average TSI values for stations 1, 2, and 3 were, respectively, 57.3, 59.7, and 67.7. These values indicate that the lake waters could be classified as eutrophic, except for the portion at station 3 during 1996-1997 that falls in the hypereutrophic category (table 26). Only in the upper end (station 3) of Otter Lake, the trophic state has worsened from eutrophic to hypereutrophic condition. Lake transparency decreased at station 3 and total phosphorus and chlorophyll *a* values increased significantly during the current investigation compared to the historical data. These factors contribute to the change in the trophic state of the shallow portion of the lake.

When considering the results of the TSI calculations, one should keep in mind the assumptions on which the Carlson formulae are based: Secchi disc transparency is a function of phytoplankton biomass, phosphorus is the factor limiting algal growth, and total phosphorus concentration is directly correlated with algal biomass. These assumptions will not necessarily hold when suspended solids other than algal biomass are a major source of turbidity; short retention times prohibit a large algal standing crop from developing; or grazing by zooplankton affects algal populations.

Lake-Use Support Analysis

Definition

An analysis of Otter Lake's use support was carried out using a methodology developed by the Illinois EPA (1996). The degree of support identified for each designated use indicates the ability of the lake to: support a variety of high-quality recreational activities, such as boating, sport fishing, swimming, and aesthetic enjoyment; support healthy aquatic life and sport fish populations; and 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, 1990). 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 was established for the protection of aquatic life as well as 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.

Lakes that folly support designated uses still may 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 shows 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. Because most lakes are multiple-use bodies of water, a lake can folly 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 by the Illinois EPA (1996);

The primary criterion in the aquatic-life use assessment is an Aquatic Life Use Impairment Index (ALI); in the recreation use assessment, the primary criterion is a Recreation Use Impairment Index (RUI). 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. The 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 a lake.

The assessment of swimming use for primary-contact recreation was based on available data using two criteria: Secchi disc transparency depth data and Carlson's TSI. The swimming use rating reflects the degree of attainment of the "swimmable goal" of the Clean Water Act. A rating of "nonsupport" for swimming does not mean 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.

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 lake uses assessed. Values assigned to each use-support attainment category were summed and averaged, then used to assign an overall lake-use attainment value for the lake.

Otter Lake-Use Support

Support of designated uses in Otter Lake was determined based on Illinois' use-support assessment criteria. Table 28 presents basic information and assessed use-support information for stations 1 and 2. The use-support analysis results for both stations 1 and 2 are similar, except for recreation use. Station 2 is classified as partial/minor. Except for this, all other type of uses are assessed as full use. For overall use, waters at stations 1 and 2 of Otter Lake during 1996-1997 can be classified as full and full/threatened, respectively.

Sediment Characteristics

Lake sediment can act both as sinks and as potential pollution sources (for pollutants such as phosphorus and metals) affecting lake water quality. Its metal and/or organic chemical toxicities can directly affect the presence of aquatic animals and plants on the lake bottom. Lake sediments, if and when dredged, should be carefully managed to prevent surface water and ground-water contamination.

Sediment monitoring is becoming increasingly important as a tool for detecting pollution loadings in lakes and streams because: (1) Many potential toxicants are easier to assess in sediments as they accumulate at levels far greater than those normally found in the water column. (2) Sediments are less mobile than water and can be used more reliably to infer sources of pollutants. (3) Nutrients, heavy metals, and many organic compounds can become tightly bound to the fine particulate silts and clays of the sediment deposits where they remain until they are released to the overlying water and made available to the biological community through physical, chemical, or bioturbation processes. Remedial pollution mitigation projects may include the removal of contaminated sediments as a necessary step (Indiana Department of Environmental Management, 1992).

Sediment Quality Standards

No regulatory agencies promulgate sediment quality standards, but sediment quality in Illinois generally is assessed using data by Kelly and Hite (1981). For their studies, Kelly and Hite collected 273 individual sediment samples from 63 lakes across Illinois during the summer

Table 28. Use-Support Assessment for Otter Lake,, 1996-1997

Use	*Station 1* Value	ALIpoints	*Station 2* Value	ALIpoints
Aquatic life use				
Mean trophic state index	54.3	40	58.9	40
Macrophyte impairment	<5%	10	<5%	10
Mean nonvolatile suspended solids	5 mg/L	0	7 mg/L	5
Total points:		50		55
Criteria points:		<75		<75
Use support:		Full		Full
	Value	*RUI points*	*Value*	*RUI points*
Recreation use				
Mean trophic state index	54.3	54	58.9	59
Macrophyte impairment	<5%	0	<5%	0
Mean nonvolatile suspended solids	5 mg/L	5	7 mg/L	5
Total points:		59		64
Criteria points:		<60		60<RUI<75
Use support:		Full		Partial/minor
	Value	*Degree of use support*	*Value*	*Degree of use support*
Swimming use				
Secchi depth < 24 in.	0%	Full	0%	Full
Fecal coliform > 200/100 mL	0%	Full	0%	Full
Mean trophic state index	54.3	Full	58.9	Full
Use support:		Full		Full
Drinking water supply		Full		Full
Overall use	5.0		4	
Use support:		Full		Full/threatened

Notes: ALI - aquatic life use impairment index
RUI - recreation use impairment index
No swimming allowed by ADGPTV Water Commission due to water supply concern

of 1979. On the basis of each parameter measured, they defined "elevated levels" as concentrations of one to two standard deviations greater than the mean value, and "highly elevated levels" as concentrations greater than two standard deviations from the mean. Recently, the Illinois EPA (J. Mitzelfelt, personal communication, 1996) revised classification of lake sediments as shown in table 29. It should be noted that, in this classification, lake sediment data are considered to be elevated based on a statistical comparison of levels found in a 20-year record and not on toxicity data. Therefore, elevated or highly elevated levels of parameters do not necessarily indicate a human health risk.

Nutrients and Metals

Available historical and current chemical data on sediments in Otter Lake are listed in tables 30 and 31. An examination of data in tables 30 and 31, shows that only the summer period total phosphorus and total Kjeldahl nitrogen concentration at stations 1 and 2 increased during the current study period when compared to historical values. Other parameters and heavy metals monitored at stations 1, 2, and 3 were comparable for both historical and current data.

Cadmium, mercury, and silver concentrations in Otter Lake sediments were negligible. During the current study, TP and TKN concentrations at stations 1 and 4 were generally higher than those at stations 2 and 3 (table 30). On the basis of the classification listed in table 29, TP at station 4 was considered as elevated, and TP at stations 1, 2, and 3 as normal for Illinois lakes. Classification of potassium at these four stations is the same as for TP. Although the January 23, 1997, sample for station 1 (table 30) has the highest TKN (7,806 mg/kg), TKN in Otter Lake at the four sites monitored can be considered as normal.

Organic Compounds

Chlorinated hydrocarbon compounds consist of a group of pesticides that are no longer in use but are persistent in the environment. These compounds, such as PCBs, chlordane, dieldrin, and DDT present a somewhat unique problem in aquatic systems because of their potential for bioaccumulation in fish in the food web. Organochlorine compounds are relatively insoluble in water but highly soluble in lipids where they are retained and accumulate. Minute and often undetectable concentrations of these compounds in water and sediment may ultimately pose a threat to aquatic life, then possibly to human health.

Table 31 presents the historical and current observed concentrations of tested organochlorine compounds. An examination of table 31 indicates that almost all parameters assessed were below detection levels.

Table 29. Classification of Lake Sediments (revised 1996)

Parameters	*Detection limit**	*Low*	*Normal*	*Elevated*	*Highly elevated*
Phosphorus	0.1	<394	394-<1115	1115-<2179	≥ 2179
Total Kjeldahl-N	1.0	<1300	1300-<5357	5357-<11,700	≥ 11,700
Arsenic	0.5	<4.1	4.1-<14	14-<95.5	≥ 95.5
Barium	1.0	<94	94-<271	271-<397	≥ 397
Cadmium	0.1	n/a	<5	5-<14	≥ 14
Chromium	10	<13	13-<27	27-<49	≥ 49
Copper	1.0	<16.7	16.7-<100	100-<590	≥ 590
Iron	10	<16,000	16,000-<37,000	37,000-<56,000	≥ 56,000
Lead	0.1	<14	14-<59	59-<339	≥ 339
Manganese	10	<500	500-<1700	1700-<5500	≥ 5500
Mercury	0.1	n/a	<0.15	0.15-<0.701	≥ 0.701
Nickel	1.0	<14.3	14.3-<31	31-43	≥ 43
Potassium	1.0	<410	410-<2100	2100-<2797	≥ 2797
Silver	0.1	n/a	<0.1	0.1-<1	≥ 1
Zinc	10	<59	59-<145	145-<1100	≥ 1100
PCB	10	n/a	<10	10-<89	≥ 89
Aldrin	1	n/a	<1	1-<1.2	≥ 1.2
Dieldrin	1	n/a	<3.4	3.4-<15	≥ 15
DDT	10	n/a	<10	10-180	≥ 180
Chlordane	5	n/a	<5	5-12	≥ 12
Endrin	1	n/a	<1	n/a	≥ 1
Methoxychlor	5	n/a	<5	n/a	≥ 5
Alph-BHC	1	n/a	<1	n/a	≥ 1
Gamma-BHC	1	n/a	<1	n/a	≥ 1
HCB	1	n/a	<1	n/a	≥ 1
Heptachlor	1	n/a	<1	n/a	≥ 1
Heptachlor epoxide	1	n/a	<1	1-<1.6	≥ 1.6

Notes: * Amounts of metals and inorganics expressed as mg/kg; organics expressed as µg/kg
BHC - benzene hexachloride
DDT - dichloro-diphenyl trichloroethane
HCB - hexachlorobenzene
n/a - Data not available
PCB-• polychlorinated biphenyls

Source: J. Mitzelfelt, Illinois EPA, personal communication, 1996

Table 30. Characteristics of Sediments in Otter Lake

	Station 1							Station 2		
Parameters	*7/30/79*	*4/18/89*	*4/25/91*	*7/11/94*	*7/3/96*	*8/19/96*	*1/23/97*	*7/30/79*	*8/19/96*	*1/23/97*
Residue, %										
Total	34.5	57.3	26.5	23.8	22.1	23.8			22.8	26.3
Volatile	7.2	6.9	4.7	11.2	11.8	11	9.2	6.0	10.4	7.9
Phosphorus	540	568	357	910	961	974	893	530	1009	763
TKN	3000	1900	1250	2901	3630	5000	7806	2300	4855	3481
Arsenic	9.8	7	4	7	12	12	12.6	7.1	8	8.3
Barium		141	65	239	220	200	220		180	180
Cadmium	2.0	0.1 k	1 k	1 k	1 k	1 k	1 k	0.5 k	1 k	1 k
Chromium	28	15.2	11	23	23	24	21	25	23	18
Copper	44	17.6	7	26	27	26	26	27	26	25
Iron	35,000	28,600	12,000	38,000	36,000	35,000	33,000	29,000	31,000	26,000
Lead	40	8.7	15	26	21	20	21	30	21	20
Manganese	1800	1470	680	1700	1100	1200	1100	960	930	1100
Mercury	0.06	0.00	0.10	0.1 k	0.1 k	0.1 k	0.1 k	0.06	0.1 k	0.1 k
Nickel		18	13	27	25	25	24		24	21
Potassium		1197	1000 k	1900	1900	2100	2000		2000	1700
Silver		1 k	1 k	1 k	1 k	1 k	1 k		1 k	1 k
Zinc	120	50.5	34	81	75	74	69	99	80	67
Water depth, ft	49	46	45	46	47	46	47	30	30	29

Table 30. Concluded

Parameters	*Station 3* 7/30/79	4/18/89	4/25/91	7/11/94	7/3/96	8/19/96	1/23/97	*Station 4* 8/19/96	1/23/97
Residue, %									
Total	30.8	33.2	14.5	40.0	34.1	20.1	22.7		
Volatile	5.2	8.3	10.6	10.4	8.7	14.1	10.7		
Phosphorus	410	734	720	905	655		586	1228	1143
TKN	1900	2541	3140	2045	3922		2420	3767	4564
Arsenic	4.1	7.0	6.0	11.4	6		5.6	10	9.7
Barium		210	190	225	162		150	260	250
Cadmium	2.0	0.1	1 k	1 k	1 k		1 k	1 k	1 k
Chromium	23	21.7	24	20	18		15	26	28
Copper	23	23.6	17	24	22		19	29	27
Iron	21,000	31,000	25,000	30,000	22,500		19,000	35,000	29,000
Lead	20	6.7	26	22	16		15	20	21
Manganese	470	802	740	907	590		550	1600	1500
Mercury	0.05	0.00	0.20	0.1	0.1	0.1 k	0.1		
Nickel		19.9	23	22	17		15	24	21
Potassium		1741	2200	1700	1500		1400	2400	2300
Silver		1 k	1 k	1 k	1 k		1 k	1 k	1 k
Zinc	81	75.3	76	83	66		57	91	77
Water depth, ft	10	15	17	15	8	26	25		

Notes: Blank spaces - no data
k indicates that values were below the detection level
TKN - total kjeldahl nitrogen
Units are mg/kg, unless specified otherwise

Table 31. Organic Characteristics of Sediment in Otter Lake

Organic compounds, µg/kg	*Station 1*					*Station 2*	*Station 3*				
	7/30/79	*4/18/89*	*4/25/91*	*7/11/94*	*7/3/96*	*7/30/79*	*7/30/79*	*4/18/89*	*4/25/91*	*7/11/94*	*7/3/96*
Total PCB	10k	10 k	10k	10 k	10k	10k	10k	10 k	10k	10k	10k
Aldrin	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1.4	1 k
Dieldrin	3.3C	1 k	1 k	2.5	2.6	9.2C	6.1C	1 k	4.1	7.0	3.6
Total DDT		10k	10 k	10k	10k			10k	10k	10k	10 k
O'P'-DDE		1 k	1 k					1 k	1 k		
P'P'-DDE		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
O'P'-DDD		1 k	1 k					1 k	1 k		
P'P'-DDD		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
O'P'-DDT		1 k	1 k					1 k	1 k		
P'P'-DDT		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
Chlordane											
Total	8.6C	5k	5k	5k	5k	18C	13C	5k	5k	5k	5k
Cis isomer		2k	2k	2k	2k			2k	2k	2k	2k
Trans isomer		2k	2k	2k	2k			2k	2k	2.4	2k
Endrin	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k	1 k
Methyoxychlor	5k					5k	5k				6k
Alpha-BHC		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
Gamma-BHC (Lindane)		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
Hexachlorobenzene		1 k	1 k	1 k	1 k			1 k	1 k	1 k	1 k
Hectachlor	10k	10k	10 k	10k	10k	10k	10k	10k	10k	10k	10k
Heptachlor epoxide	1 k	1 k	1 k	1 k	1 k	2.2C	2.1C	1 k	1 k	2.5	1.5

Notes: k indicates that values are below the detection level
BHC - benzene hexachloride
Blank spaces •- no data
C - calculated value
Cis isomer - the isomer with like groups close together
DDD - dichloro-diphenyl dichloroethane
DDE - dichloro-diphenyl dichlorethEne
DDT - dichloro-diphenyl trichloroethane
O'P' - O'P' refers to the positions of chlorines on the phenyl rings relative to the ethane
PCB - polychlorinated biphenyls
Trans isomer - the isomer with like groups far apart.

Lake Budgets

Hydrologic Budget

The hydrologic budget of Otter Lake, or any other lake system, takes the general form: storage change = inflows - outflows.

In general, inflows to the lake include direct precipitation, watershed runoff, ground-water inflow, and pumped input. Outflows include surface evaporation, discharge at the lake outlet, ground-water outflow, and withdrawals. For Otter Lake, pumped inputs are not a significant factor. However, all other factors must be considered in developing an effective hydrologic budget for the lake.

Data necessary for evaluating various parameters to develop a hydrologic budget for the lake were collected for a one-year period (April 1996-March 1997) during the diagnostic phase of the project. Table 32 presents monthly results of this monitoring.

Several elements of this budget analysis were evaluated on the basis of data collected during the monitoring period, including:

- Reservoir storage change on the basis of direct monitoring of the lake level during the study. Lake level data were collected by automatic water level recorder from April 20, 1996-July 9, 1997. Data were collected at 15-minute intervals and recorded at intervals of 6 hours or less.
- Spillway discharge also was analyzed on the basis of the lake level records. The general spillway rating equation $3.1*121*H^{1.5}$ was used. Where 3.1 is the weir coefficient for the spillway, 121 feet is the spillway length, and H is the height of water over the spillway.
- Direct precipitation was determined on the basis of the precipitation record at the Virden, Illinois, station of the U.S. Weather Service.
- Daily water supply withdrawals were obtained from the monthly reports of the water treatment plant.

Evaporation was estimated using average monthly values for Springfield and St. Louis as determined by Roberts and Stall (1967).

On the basis of these available, directly measured parameters, the following elements of the budget were determined,

Based on the water level record frequency:

- Changes in basin storage were estimated by multiplying the periodic change in lake stage from the water level record by the lake surface area to determine net inflow or outflow volume in acre-feet.
- Spillway discharge was calculated when water level exceeded the spillway elevation.

Table 32. Summary of Hydrologic Analysis for Otter Lake, April 1996 - March 1997

Date	*Storage change (acre-feet)*	*Direct precipitation (Virden)*		*Calculated inflow (acre-feet)*	*Monthly evaporation*		*Spillway discharge (acre-feet)*	*Water supply withdrawal (acre-feet)*
		(inches)	*(acre-feet)*		*(inches)*	*(acre-feet)*		
1996								
April	440.8	3.8	231	2,210	3.2	194	1,662	144
May	-288.8	5.6	341	5,536	4.7	284	5,735	147
June	-296.4	3.6	221	994	5.5	334	1,018	159
July	-98.8	2.6	158	290	6.1	373	0	175
August	-258.4	1.8	112	109	5.0	307	0	173
September	-334.4	1.8	108	-66	3.6	219	0	157
October	-273.6	1.2	76	-52	2.4	144	0	154
November	53.2	3.7	229	41	1.1	70	0	147
December	-106.4	0.4	23	62	0.6	36	0	156
1997								
January	296.4	2.1	131	363	0.6	36	0	161
February	1,193.2	4.0	243	2,010	0.9	55	850	155
March	-296.4	2.5	153	1,688	1.9	116	1,850	172
Totals April 1996 March 1997	30.4	33.2	2,027	13,186	35.5	2,168	11,114	1,900

These less than daily values were then combined into daily values that could be analyzed on a daily basis with:

- The volume of direct precipitation input to the lake based on the daily precipitation data at Virden. The precipitation depth was multiplied by the lake surface area to determine inflow volume.
- Water supply withdrawal rates were taken directly from the treatment plant record.
- Monthly evaporation rates were reduced to daily values by calculating an average daily value for each month. Daily lake surface evaporation volume was determined for the study period by multiplying the daily average evaporation depth by the lake surface area.
- Surface water inflow was not determined from direct measurements; instead it was determined by calculation of the determinate factors listed. The summation of daily inflow and outflow values generally left a calculated remainder that was allotted to surface water runoff.

Table 33 summarizes the hydrologic budget for the one-year monitoring period. During this period, 13.3 percent of the inflow volume to the lake was direct precipitation on the lake surface, 86.5 percent was watershed runoff, and 0.2 percent was due to storage change. Outflow volume was 14.3 percent evaporation, 73.2 percent spillway overflow, and 12.5 percent water supply withdrawal. A 0.2 percent increase in storage was observed and accounted for as an undefined inflow.

Sediment and Nutrient Budgets

Sediment and nutrient loading to the lake is determined on the basis of an analysis of three component factors. These factors are:

- Input to the lake from external sources such as watershed runoff, bank erosion, and precipitation.
- Export from the lake system at the spillway and water treatment plant withdrawal.
- Internal regeneration of nutrients from sources in the lake, mainly lake sediments.

These factors combine to form the total load of sediment and nutrients impacting the lake.

The sediment and nutrient budgets for inflows and outflows from the lake were developed using daily values from the hydrologic budgets and the sediment and nutrient analyses from the one-year monitoring program. The laboratory results from the water samples collected during the field monitoring were compared to flow conditions. Analysis for each sampling site was made on the basis of an annual average for the stable, in-lake conditions and by a linear regression analysis for the more volatile stream inflow site. The following list presents the methods used for calculation of the major nutrient inflows and outflows:

Table 33. Annual Summary of the Hydrologic Budget for Otter Lake, April 1996-March 1997

Source	*Inflow volume (acre-feet)*	*Outflow volume (acre-feet)*	*Inflow (percent)*	*Outflow (percent)*
Storage change	30.4		0.2	
Direct precipitation	2,027		13.3	
Surface inflow	13,185		86.5	
Spillway discharge		11,114		73.2
Evaporation		2,168		14.3
Water supply withdrawal		1,900		12.5
Totals	15,242	15,182		

Note: Blank spaces - not applicable

Watershed inflow concentrations in milligrams per liter were calculated by regression analysis with daily flow volume (Qw) in acre-feet. These concentrations were weighted by the daily discharges at each site to determine nutrient loading by source. The results of this analysis are summarized in table 34:

Sediment	0.746107 * Qw
Total nitrogen	0.00608643 * Qw + 10.9835
Total phosphorus	0.0007433101 * Qw + 0.0921313

Spillway discharge concentrations by annual average:

Sediment	7.8
Total nitrogen	1.967
Total phosphorus	0.0217

Water treatment plant intake concentrations by annual average:

Sediment	25.4
Total nitrogen	2.727
Total phosphorus	0.0867

Precipitation chemistry concentrations (Lin et al., 1996)

Total nitrogen	1.54
Total phosphorus	0.167889

Lakeshore bank erosion nutrient input was calculated on the native soil nutrient contents from the county soil survey:

Sediment	To be discussed in a later section (Bank Erosion Evaluation)
Total nitrogen	0.0015 milligrams per kilogram of eroded sediment
Total phosphorus	0.0005 milligrams per kilogram of eroded sediment.

The results of this analysis are also presented in table 34.

The third factor in analyzing the total sediment and nutrient loading to the lake is internal regeneration of nutrients from the sediments. Internal regeneration of phosphorus in the lake from deposited sediments was estimated on the basis of maximum range values of 5 grams/meter^2/year (g/m^2/year) under aerobic conditions and 20 g/m^2/year under anaerobic conditions as recommended by the USEPA (1980). Nitrogen regeneration from lakebed sediments is not included in this analysis.

The sediment input from the watershed of 7,257 tons represents an annual yield of 0.56 tons per acre from the watershed. This input of sediment is only slightly offset by the discharge of 183.2 tons of sediment at the spillway and through the raw water withdrawals by the water treatment plant.

Table 34. Annual Summary of Sediment and Nutrient Budget for Otter Lake, April 1996-March 1997

Water flows	*Sediment load*	*Total nitrogen*	*Total phosphorus*
Annual nutrient inflows (tons)			
Watershed surface drainage yield	7,257	268.7	8.99
Direct precipitation on the lake		4.2	0.46
Lakeshore erosion	1,654	2.5	0.83
Total	8,911	275.4	10.28
Annual nutrient inflows (percent of total)			
Watershed surface drainage yield	81.4	97.6	87.5
Direct precipitation on the lake		1.5	4.4
Lakeshore erosion	18.6	0.9	8.1
Annual outflow (tons)			
Outflow at spillway	117.8	29.7	0.06
Withdrawn with water supply	65.4	7.0	0.22
Total	183.2	36.7	0.28
Annual outflows (percent of total)			
Outflow at spillway	64.3	81.0	21.4
Withdrawn with water supply	35.7	19.0	78.6
Total outflow as a percent of total inflow	2.1	13.3	2.7
Internal regeneration of phosphorus (tons)			6.14
For combined loading (percent)			37.4

Note: Blank spaces - not applicable

Total nitrogen input to the lake was 275.4 tons, of which 268.7 tons originated from the watershed and 6.7 tons originated from direct precipitation and bank erosion sources. This total of 275.4 tons was offset by 36.7 tons of nitrogen discharged at the spillway and withdrawn at the water treatment plant. This results in an annual accumulation (1996-1997) of about 240 tons of nitrogen in the lake that may be subject to annual regeneration.

Total phosphorus input to the lake was 10.28 tons, of which 8.99 tons originated from watershed runoff and 1.29 tons came from precipitation and bank erosion. Spillway and water treatment plant phosphorus removal from the lake was 0.28 tons. The analysis of internal regeneration of phosphorous estimated that 6.14 tons of phosphorus per year regenerated in Otter Lake from the sediments. This combined with the phosphorus input gives a total load of 16.4 tons of phosphorus per year available in Otter Lake. Of this total phosphorus loading to the lake, 37.4 percent is a result of internal regeneration.

Over 80 percent of sediment input to the lake and 97.6 and 54.7 percent, respectively, of the nitrogen and phosphorus loading to the lake (loading to the lake includes internal regeneration from the sediments) originates in the watershed. Just over 2 percent of the sediment input, 13 percent of the nitrogen input, and 1.7 percent of the phosphorus input to the lake exits the lake in flow over the spillway or through the water treatment plant.

Hydrographic Survey

The 1997 survey was conducted to develop a hydrographic map of Otter Lake. Cross sections were laid out at 30 lines across the lake and surveyed using a Trimble Global Positioning System receiver and an Odom Hydrographic Systems DF3200 dual frequency depth sounder. Survey transect lines were distributed longitudinally along the lake axis to define changes in depth within the pool area. Additional depth data were collected in contouring runs that approximately followed lines of constant depth in loops around the lake. The locations of all depth soundings made for this survey are shown in figure 16.

Data collected during the field survey were processed and plotted using the ISWS's GIS. Depth contours for the lake, shown in figure 17, were developed from the survey depth files. Initial contours were generated by computer. These contours were modified manually in the GIS. Surface areas for these contours were used for the depth-volume analyses in table 35.

Bank Erosion Evaluation

An evaluation of bank erosion conditions for Otter Lake was made in June 1998. For this evaluation, a visual inspection was made of the accessible shoreline of the lake. Each section of the bank was rated on the basis of Illinois EPA guidelines (IEPA, 1994) as follows:

- minimal, 0-3 vertical feet of eroded bank;
- moderate, 3-8 vertical feet of eroded bank;
- severe, over 8 vertical feet of eroded bank.

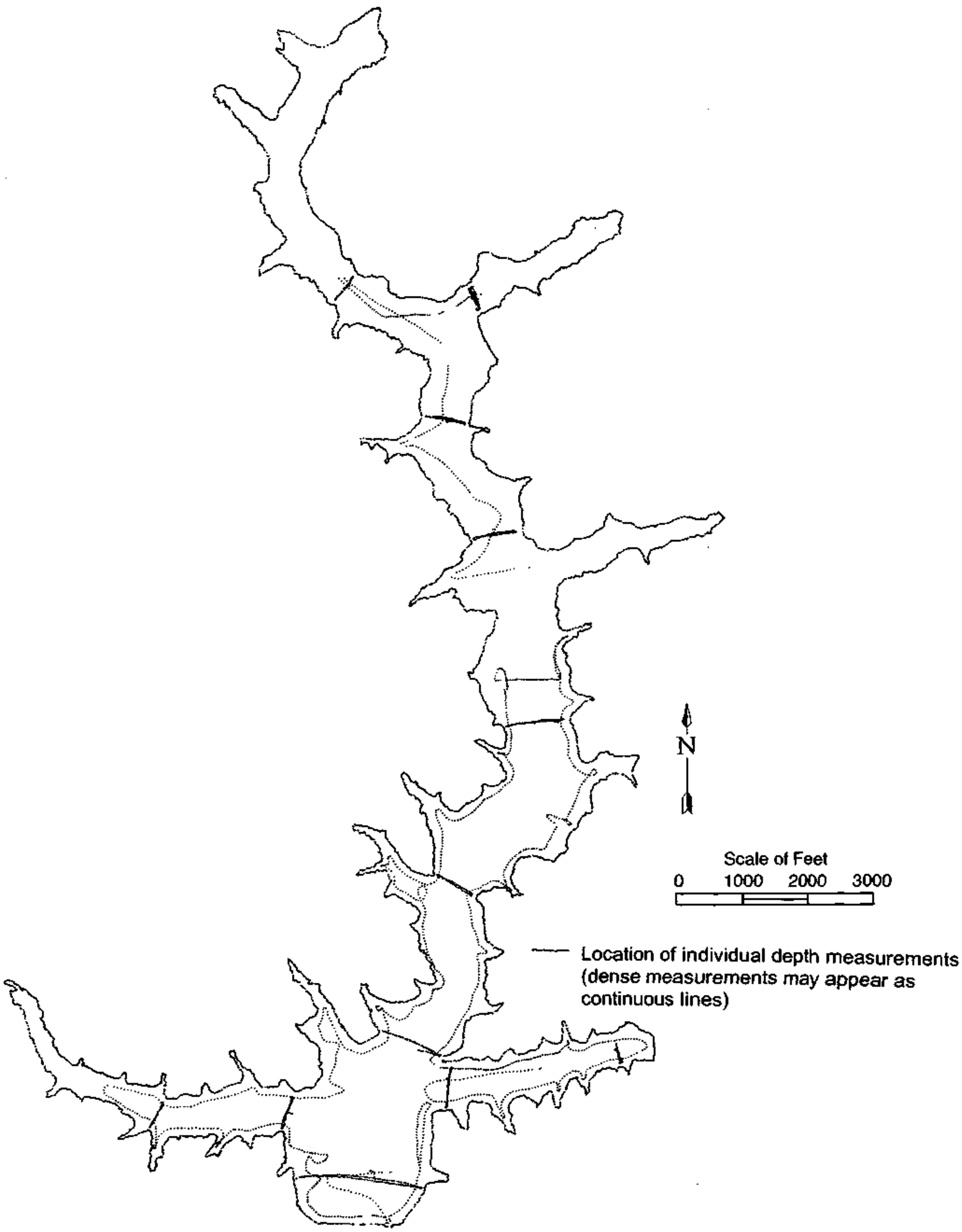


Figure 16a. Plan of the 1997 hydrographic survey of Otter Lake (north basin)

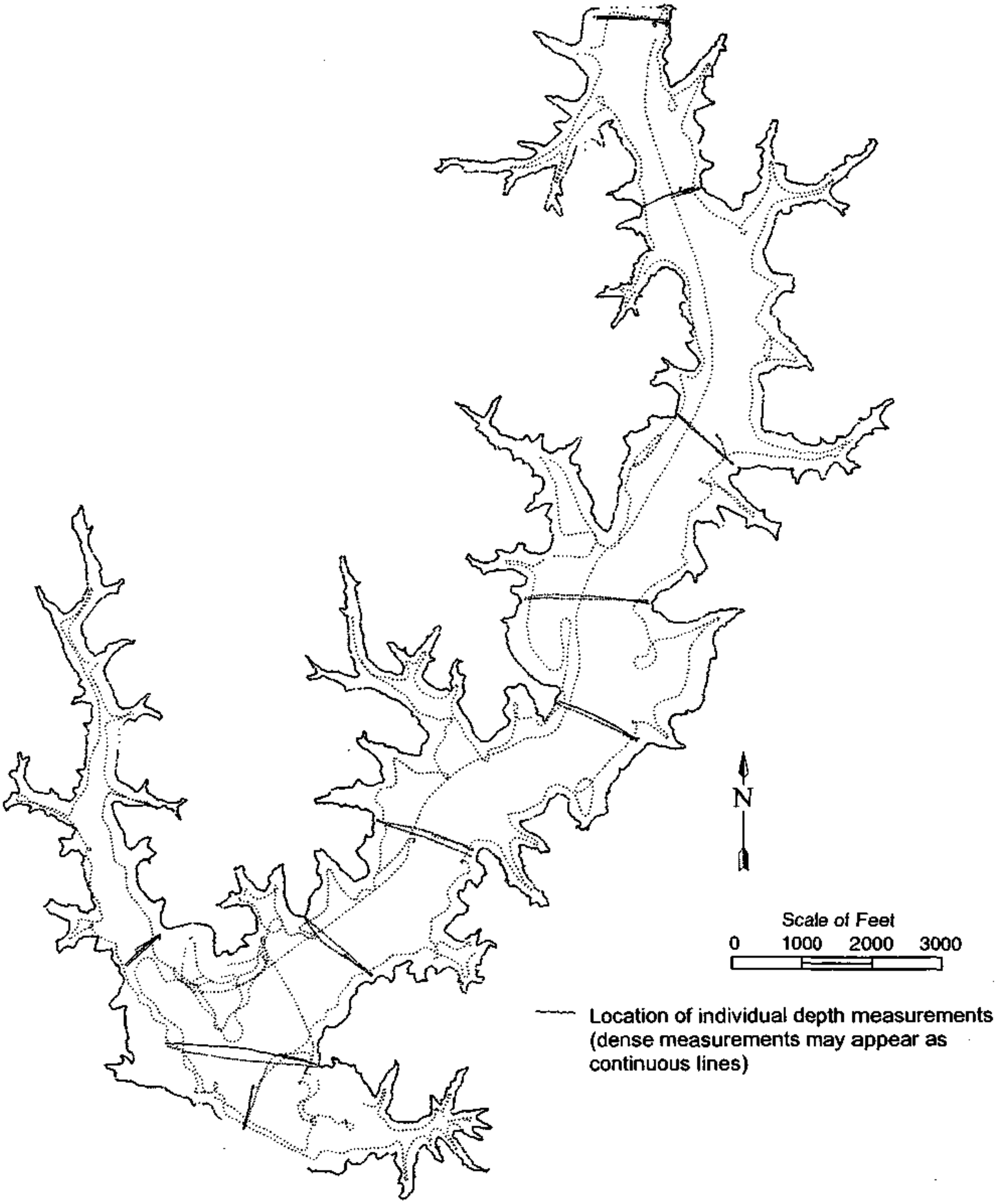


Figure 16b. Plan of the 1997 hydrographic survey of Otter Lake (south basin)

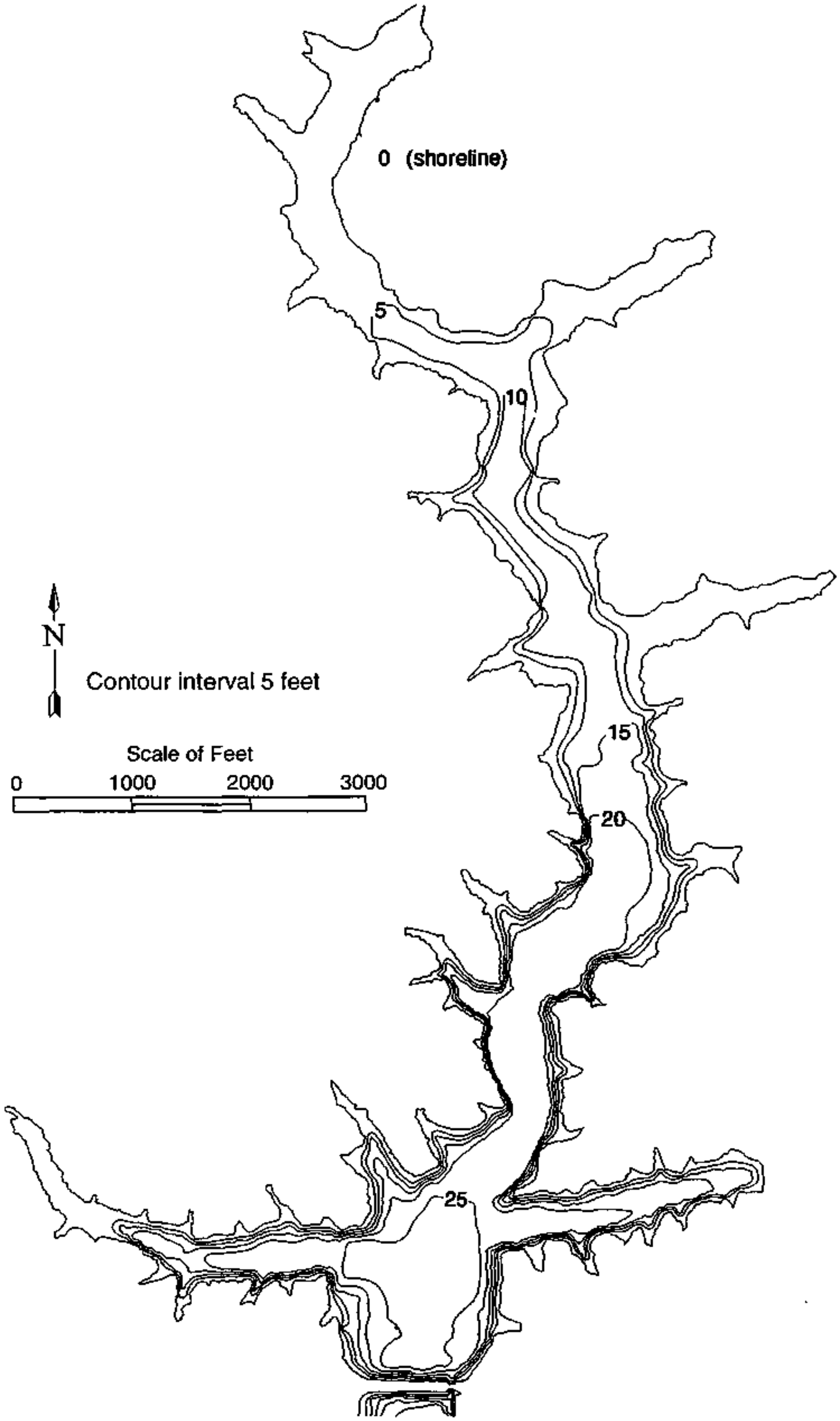


Figure 17a. The 1997 bathymetric survey for Otter Lake (north basin)

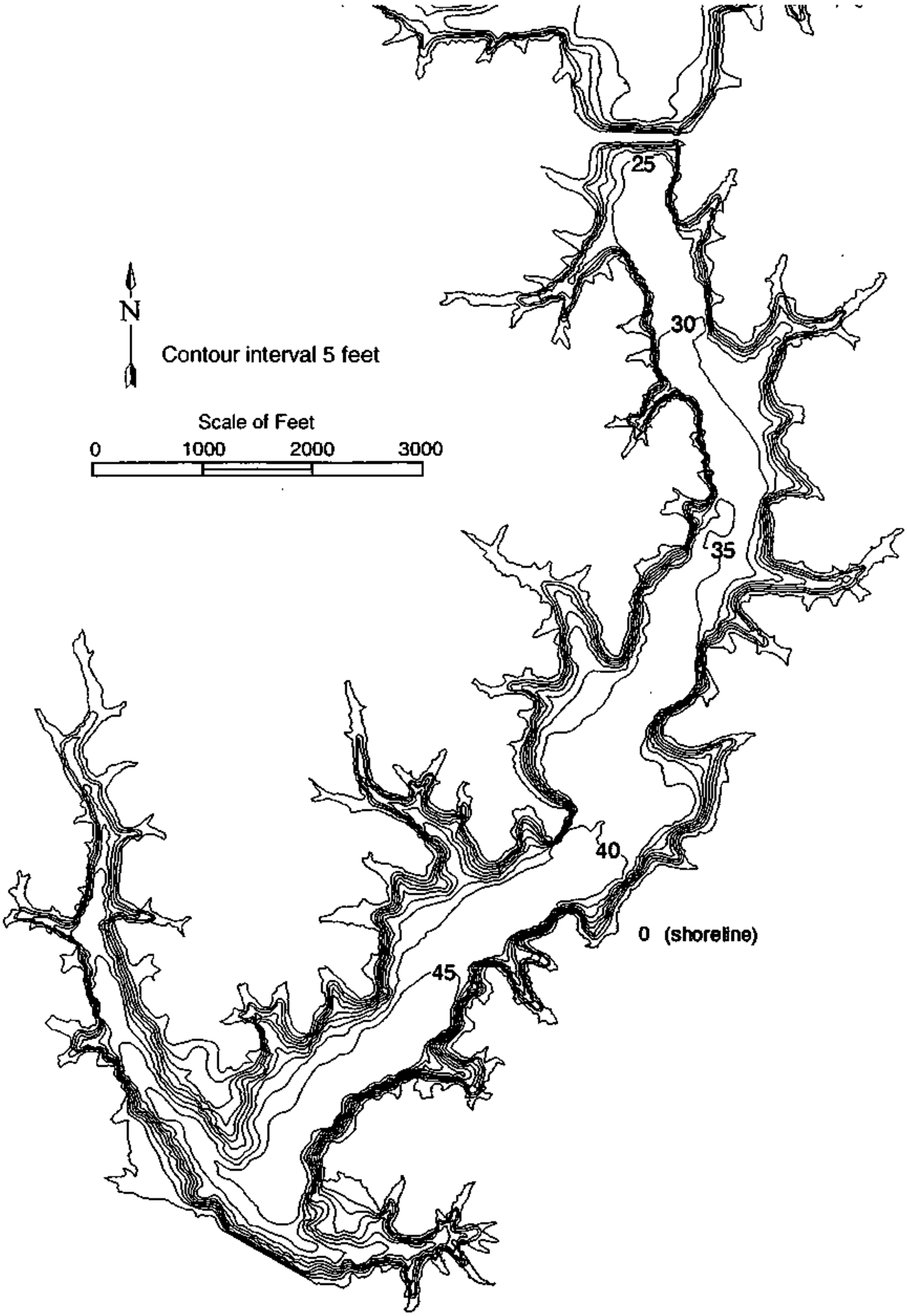


Figure 17b. The 1997 bathymetric survey for Otter Lake (south basin)

Table 35. Stage versus Volume and Area for Selected Elevations at Otter Lake, 1997

	Full basin		*North basin*		*South basin*		*Available basin*	
Depth below spillway crest (feet)	*Surface area (acres)*	*Volume (acre-feet)*	*Surface area (acres)*	*Volume (acre-feet)*	*Surface area (acres)*	*Volume (acre-feet)*	*Surface area (acres)*	*Volume (acre-feet)*
0	*134*	13,763	306	3,507	428	10,202	734	7,103
5	537	10,599	190	2,279	347	8,269	537	3,939
10	472	8,077	155	1,417	317	6,609	155	1,417
15	400	5,898	114	748	287	5,101	114	748
20	339	4,051	82	261	257	3,741	82	261
25	250	2,583	22	15	228	2,530	22	15
30	175	1,524			175	1,524		
35	128	769			128	769		
40	66	293			66	293		
45	28	65			28	65		

Notes: Full basin refers to all of Otter Lake

North basin refers to the lake volume and area north of Emerson Airline Road

South basin refers to the lake volume and area south of Emerson Airline Road

Available basin refers to the portion of the basin accessible to the present intake structure. This would be all of the north basin and the portion of the south basin to a depth of 10 feet

Blank spaces - not applicable

The results of this evaluation are shown in figures 18 and 19.

On the basis of this evaluation, the lineal length and eroded volume were determined as follows:

Erosion class	*Eroded length (feet)*	*Eroded volume (acre-feet)*	*Eroded tonnage (tons)*
Minimal	121,621	6.28	456
Moderate	33,342	12.25	889
Severe	5,139	4.25	308
Totals	160,102	22.8	1,653

Lake Sedimentation Survey

A lake sedimentation survey of Otter Lake was conducted in June 1998. This survey was conducted separately from the hydrographic survey conducted in October 1997. The results of the two are not directly comparable due to differences in the methods of analyses.

The sedimentation survey was conducted by surveying water depth only along the transect lines shown in figure 20. Sediment thickness was measured at a minimum of three points on each cross section in the north basin of the lake. In the south basin of the lake, water depth exceeding 35 feet in most areas precluded the measurement of sediment thickness. Sediment thickness was measured at only a few points near the road causeway, and a sediment thickness of 1 foot was assumed for all unmeasured transects.

The cross-sectional areas and widths of these transects were analyzed using the standard U.S. Department of Agriculture, Natural Resource and Conservation Service standard range survey calculation (USDA-SCS, 1968). The results of this analysis are presented in tables 36a and 36b. Table 36a presents the full results of the 1998 sedimentation survey for Otter Lake and the annual sedimentation rates for delivery to the lake as well as delivery from the watershed. Table 36b presents a summary of the results of the volume analysis for each surveyed segment of the lake.

Table 36a shows that Otter Lake has had an average annual volume loss of 36.5 ac-ft per year. In terms of delivery rates from the 20.3 sq mi watershed of the lake, 122 cubic feet of sediment were lost on average from each acre of land in the watershed. Similarly, 23,804 tons of sediment have been deposited in the lake each year for an average of 1.8 tons per acre of watershed area.

As shown in table 36b, sedimentation volume loss in the south basin of the lake (sections 1 through 8 in figure 20) are less than 5 percent over the 30-year period since construction of the lake. Annual sedimentation rates for these sections of the lake are less than 0.15 percent per year, corresponding to a half-life for this area of the lake of over 300 years.

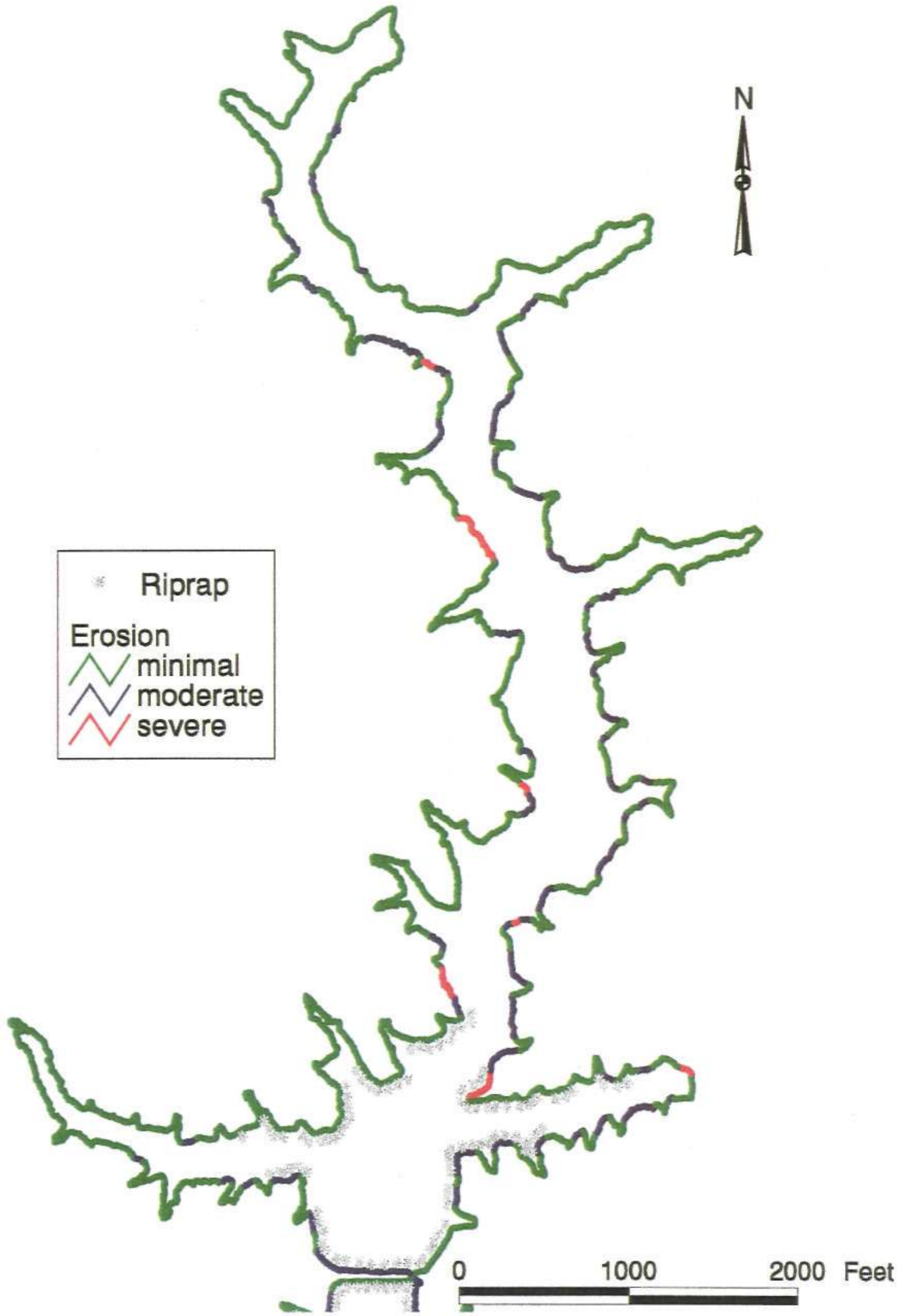


Figure 18. Otter Lake shoreline erosion condition survey (north basin), 1998

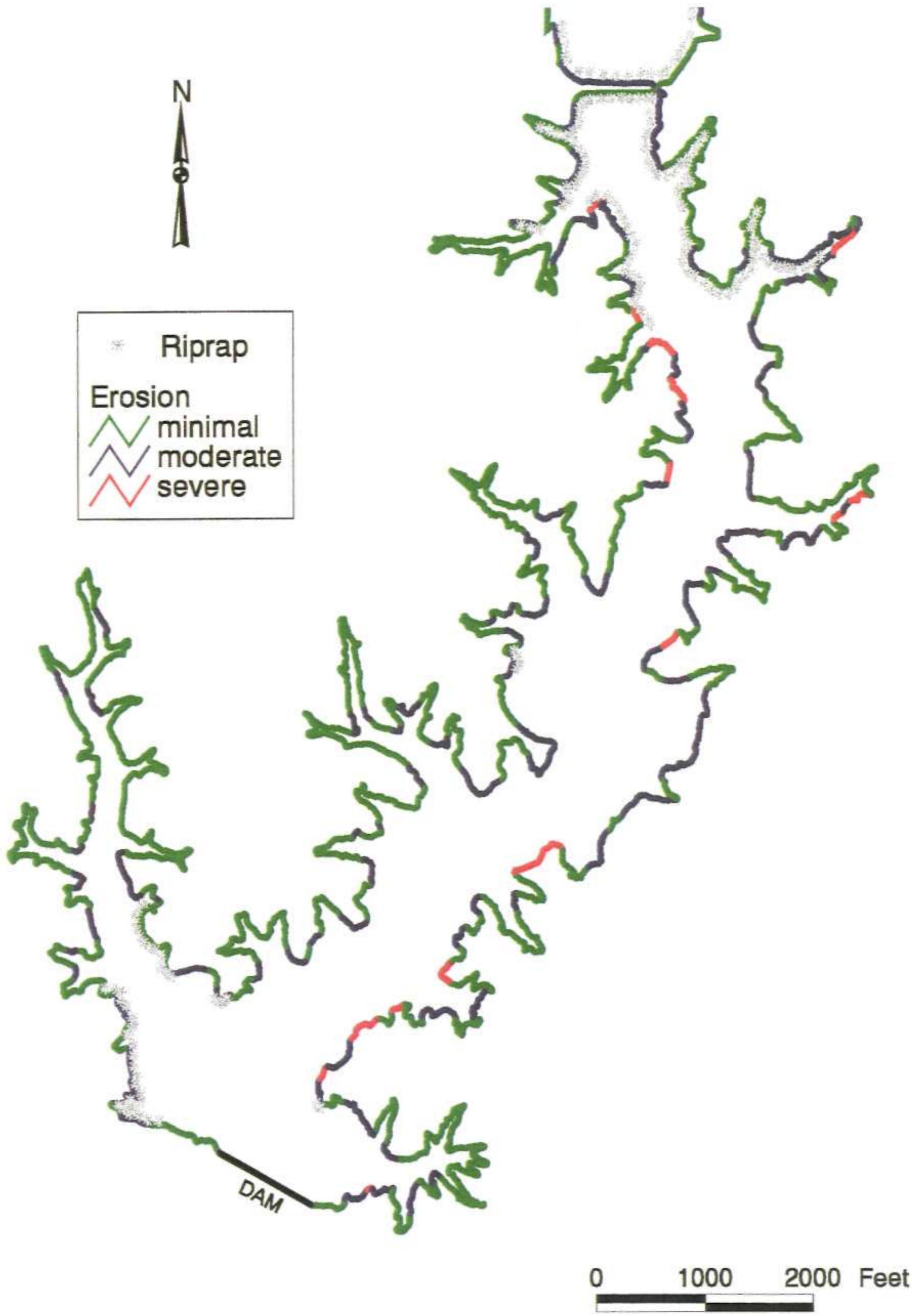


Figure 19. Otter Lake shoreline erosion condition survey (south basin), 1998

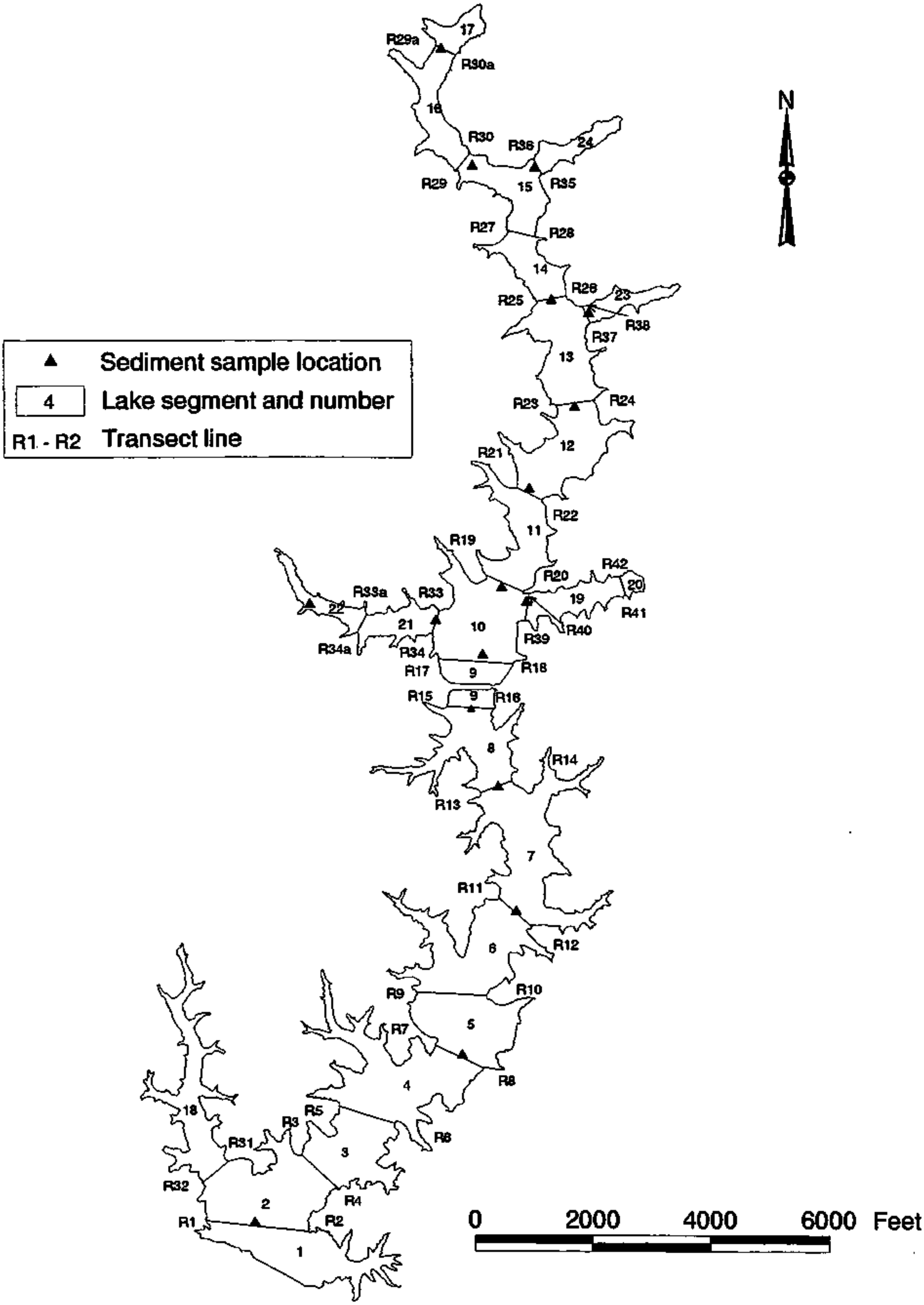


Figure 20. Plan of the 1998 lake sedimentation survey

Table 36a. Sedimentation Rate Analyses for Otter Lake and Its Watershed

Reservoir Capacity and Capacity Loss Analysis

Analysis in units of ac-ft

Period	*Capacity*	*Capacity loss*	*Annual capacity loss rate*
1968	16,137		
1968-1998	15,043	1,094	36.5

Analysis in units of million gallons

Period	*Capacity*	*Capacity loss*	*Annual capacity loss rate*
1968	5,258		
1968-1998	4,901	356	11.9

Note: Capacity shown is for the sedimentation survey conducted at the end of the period.

Computed Annual Sediment Delivery Rates from the Watershed

Period	*Acre-feet*	*Acre-feet per square mile*	*Cubic feet per acre*	*Tons*	*Tons per acre*
1968-1998	36.5	1.8	122	23,804	1.8

Note: Total watershed area is 20.3 square miles.

Capacity Loss Rates (percent) Relative to the Original Lake Capacity

Period	*Per period*	*Annual loss*
1968-1998	6.8	0.23

Table 36b. Otter Lake Sedimentation Evaluation, 1998

Section number	*1998 water volume* Section volume (acre-feet)	*1998 water volume* Cumulative volume (acre-feet)	*1998 sediment volume* Section (acre-feet)	*1998 sediment volume* Cumulative (acre-feet)	*1968 water volume* Section (acre-feet)	*1968 water volume* Cumulative (acre-feet)	*1968-1998 Percent volume loss* Section	*1968-1998 Percent volume loss* Cumulative	*1968-1998 Percent per year* Section	*1968-1998 Percent per year* Cumulative
1	1,233.9	1,233.9	43.3	43.3	1,277.3	1,277.3	3.4	3.4	0.11	0.11
2	1,479.4	2,713.4	52.4	95.7	1,531.9	2,809.1	3.4	3.4	0.11	0.11
3	1,325.2	4,038.6	35.5	131.2	1,360.7	4,169.8	2.6	3.1	0.09	0.10
4	1,817.1	5,855.7	64.1	195.3	1,881.2	6,051.0	3.4	3.2	0.11	0.11
5	1,224.8	7,080.4	39.3	234.6	1,264.1	7,315.0	3.1	3.2	0.10	0.11
6	1,296.8	8,377.2	52.2	286.8	1,349.0	8,664.0	3.9	3.3	0.13	0.11
7	1,396.4	9,773.6	58.6	345.5	1,455.0	10,119.0	4.0	3.4	0.13	0.11
8	758.5	10,532.1	29.3	374.8	787.8	10,906.8	3.7	3.4	0.12	0.11
9	366.2	10,898.3	25.9	400.7	392.1	11,299.0	6.6	3.5	0.22	0.12
10	878.4	11,776.7	121.1	521.8	999.5	12,298.5	12.1	4.2	0.40	0.14
11	515.3	12,291.9	66.5	588.3	581.8	12,880.3	11.4	4.6	0.38	0.15
12	607.6	12,899.5	68.2	656.5	675.7	13,556.0	10.1	4.8	0.34	0.16
13	505.0	13,404.5	92.6	749.1	597.6	14,153.6	15.5	5.3	0.52	0.18
14	189.9	13,594.4	58.3	807.4	248.2	14,401.8	23.5	5.6	0.78	0.19
15	174.7	13,769.1	63.0	870.4	237.7	14,639.5	26.5	5.9	0.88	0.20
16	82.1	13,851.2	56.0	926.4	138.1	14,777.6	40.6	6.3	1.35	0.21
17	6.9	13,858.1	23.4	949.8	30.3	14,807.9	77.1	6.4	2.57	0.21
18	543.5	14,401.6	39.0	988.8	582.4	15,390.4	6.7	6.4	0.22	0.21
19	245.0	14,646.6	29.3	1,018.0	274.2	15,664.6	10.7	6.5	0.36	0.22
20	14.8	14,661.4	4.7	1,022.7	19.5	15,684.1	24.0	6.5	0.80	0.22
21	201.6	14,863.0	26.3	1,049.0	227.8	15,911.9	11.5	6.6	0.38	0.22
22	84.4	14,947.4	15.5	1,064.5	99.9	16,011.8	15.5	6.6	0.52	0.22
23	57.4	15,004.8	12.1	1,076.6	69.6	16,081.4	17.4	6.7	0.58	0.22
24	38.6	15,043.4	17.2	1,093.8	55.8	16,137.2	30.9	6.8	1.03	0.23

The north basin of the lake exhibits higher sedimentation rates in the range of 0.40 to 2.57 percent per year. With the exception of the upstream extremities of the lake, annual sedimentation rates are less than 1.0 percent per year, with corresponding half-life values of more than 50 years (post-construction). Most of the lake, including the north basin, has at least a 70-year life expectancy.

Sedimentation of Boat Launch Cove

Discussion with staff of the ADGPTV Water Commission indicated that the most significant area of sedimentation impacting recreational use of the lake is the small cove adjacent to the boat launch area. This cove accumulated sediment at high rates over the life of the lake due to the discharge of filter backwash effluent from the water treatment plant. Corrections have been made to water plant facilities and operations to prevent recurrence of this problem.

Sedimentation from past discharges has reduced mobility of boats in the vicinity of the launch ramp and forced boaters to abandon the original dock structures in the sheltered cove. Public boat docks have been relocated to the more exposed site west of the launch ramps.

BIOLOGICAL RESOURCES AND ECOLOGICAL RELATIONSHIPS

Lake Fauna

Fish

Fisheries are very important in Otter Lake. In April 1991 a state record muskie was harvested from Otter Lake; another state record muskie was harvested from Otter Lake in September 1992; and a near record muskie was caught in Otter Lake in May 1993. Four fishing clubs use the lake for their competition fishing, and the state hopes to promote the lake for future fishing tournaments.

The upper half of the lake has higher levels of turbidity than the lower half, which result in less aquatic vegetation. In addition, high levels of turbidity also can be responsible for lower DO levels, decreased fish reproduction, increased fish diseases, and poor body condition of the fish. All these factors can contribute to a shift in the species composition from game fish to rough fish. The IDNR fisheries biologists report that there is little aquatic vegetation in the north end of the lake, and there are few crappie. Sediment deposition in the upper end has decreased the available fish habitat by blanketing potential spawning areas with silt. Continuing deterioration of Otter Lake will impact the viability of many of the species occurring in the lake, especially of those species, such as muskie, requiring relatively clean water and high DO levels. As fish populations are impacted due to the deterioration in the water quality in Otter Lake, the use of the lake for recreational fishing will decline.

Detailed and systematic records of the fisheries management efforts are available from the IDNR. These records provide details of periodic fish population surveys, installation of fish attractors, macrophyte surveys, herbicide applications, fish kills, fish stocking, etc. The annual reports summarize major activities, such as fish population surveys and stocking, and make recommendations for fisheries management for the following year.

Fish surveys were conducted by the Division of Fisheries of the IDNR April 9-11, 1996, September 23-24, 1996, and October 7, 1996. The spring survey consisted of trap nets and gill nets; the fall surveys involved daytime electrofishing. Twenty striped bass hybrids and 24 muskellunge, white crappie, and a channel catfish were collected during the spring survey. The fall shocking survey yielded sufficient numbers of all species sought. Overall, 2,409 fish and 16 species were collected during the 1996 fish surveys. Large mouth bass densities decreased slightly from the 1995 survey. Major game species included large mouth bass, bluegill, white crappie, channel catfish, muskellunge, and striped bass hybrids.

The Division of Fisheries of the IDNR stocked threadfin shad, muskie, and striped bass hybrids in the spring of 1997 to Otter Lake. In Otter Lake, these three species have been stocked on-and-off since 1981.

A fish kill was reported on May 23, 1997. The kill area was approximately halfway up the lake on the north side of Palmyra blacktop. The dead fish were found about 350 yards north of the no-wake buoys. The fish kill appeared to be localized in and around two large coves in the lake proper. According to the IDNR investigation, there was no sign of pollution. Fish mortality was most likely due to a bacterial infection (columnaris), which could have been brought on by low DO concentrations or fluctuations in water temperatures. Species identification was difficult due to the age of the kill (three-four days old).

Fish Flesh Analyses

The primary concern in fish flesh analyses is the possibility of the bioaccumulation of toxic substances such as mercury, organochlorine, and other organochemicals in fish, which may prove detrimental to higher forms of life in the food chain including humans, the ultimate consumers. In taking a preventive approach, the U.S. Food and Drug Administration (FDA) has adopted cancer-risk assessment guidelines as well as guidelines for other health effects. To protect the public from such long-term health effects, states have used the FDA guidelines to establish threshold concentrations for organics and metals in fish tissues above which an advisory will be issued that the fish should not be consumed. The federal action levels are:

Contaminants	*Federal action levels (parts per million)*
Heptachlor epoxide	0.3
PCBs	2.0
Chlordane	0.3
Total DDT	5.0
Dieldrin	0.3
Mercury	1.0

Fish flesh samples for analysis (carp fillets without skin) were collected by the IDNR on September 23, 1996, and analyzed by the Illinois EPA. The results of fish flesh analyses are given in table 37. Most of the organochlorine tests were below detection levels. Heptachlor epoxide, PCBs, chlordane, total DDT, and dieldrin concentrations were lower than the action levels.

Plants

This discussion of the plant and animal communities is adopted from the Otter Lake Ecosystem Plan (Macoupin County SWCD, 1995). The dominant plant species in the Otter Lake watershed are grain and forage plants. Corn and soybeans are the primary crops produced in the watershed. Wheat and, to a lesser extent, grain sorghum also are produced in the watershed.

Much of the strongly sloping agricultural lands are planted to permanent vegetative cover. Forage species are dominated by cool-season grasses and legumes. Tall fescue is the most abundant pasture grass. Various mixes of alfalfa, red clover, tall fescue, orchardgrass, smooth bromegrass, and timothy are typical of hay crops. Sorghum-sudan grass occasionally is used as a forage crop.

There are 35 acres of land in the watershed enrolled in the Conservation Reserve Program (CRP). Seven acres of the CRP are planted to wildlife cover, which is a mixture of cool-season grasses and legumes and shrubs. The remaining acreage is planted to cool-season grasses and legumes.

All of the timber in the watershed is confined to areas adjacent to water. Typical species include red, white, and black oaks; shagbark hickory; American elm; silver, red, and sugar maples; box elder; sycamore; hackberry; and persimmon. Nearly 80 percent of the timber is owned by the ADGPTV Water Commission and is immediately adjacent to the lake. Much of the timber in private ownership has been or is being grazed. The IDNR district forester has noted the absence of large contiguous tracts of timber in the watershed. Also noted was how effective the existing bald cypress trees were for controlling shoreline erosion.

Several species of plants listed as threatened or endangered are found in Macoupin County, but none has been specifically identified in the Otter Lake area.

Animals

Threatened and endangered animals; such as the Indiana Bat *{Myotis sodalis)* have been found in Macoupin County, but none has been identified specifically in the Otter Lake area. Pondhorn mussel *(Uniomerus tetralasmus)* has been found in a tributary of Otter Creek, approximately 1 mile from the Otter Lake dam, but not in the watershed. In addition to these species, a December 1992 report by the IDNR natural heritage biologist indicates that, although no evidence of nesting has been found, there are recent records of a Cooper's Hawk and a Barn Owl near Otter Lake during the breeding season. Both of these birds are on the list of endangered

Table 37. Results of Fish Flesh Analyses from Otter Lake

*Organics**	*Concentration*
Aldrin	0.01 k
Total chlordane	0.07
Total DDT and analogs	0.02
Dieldrin	0.04
Endrin	0.01 k
Total PCBs	0.01 k
Heptachlor	0.01 k
Heptachlor epoxide	0.01
Toxaphene	1.00 k
Methoxychlor	0.05 k
Hexachlorobenzene	0.01 k
Alpha-BHC	0.01 k
Gamma-BHC	0.01 k
Mirex	0.01 k
Lipid content, percent	3.1

Notes: *Unit - µg/g, unless specified
BHC - benzene hexachloride
DDT - dichlorodiphenyl trichloroethane
k - less than detectable level
PCBs - polychlorinated biphenyls

species in the State of Illinois. Bald Eagles, Ospreys, and Cormorants also have been observed as visitors in the watershed.

Livestock also are produced in the watershed. There are nine species in the watershed with permanent livestock herds. Hogs and cattle represent the majority of farm animals, but there are some sheep and exotic animals. The majority of hogs are produced in confinement systems, with the balance being feedlot/free-range. The cattle, sheep, and exotic species are primarily raised in a pasture/feedlot system. An estimated 12,000-13,000 animal units are produced in the watershed each year, but there have been no documented nitrate or bacterial problems in Otter Lake due to animal waste products.

PART 2: FEASIBILITY STUDY OF OTTER LAKE

INTRODUCTION

On the basis of the information obtained and the conclusions derived from the diagnostic portion of this lake restoration and protection study (see Part 1), a feasibility study was undertaken to investigate potential alternatives for restoring the environmental quality and enhancing the recreational and aesthetic value of Otter Lake. The feasibility portion of this Phase I study extends the diagnostic study. Its purposes are to identify and evaluate possible alternative techniques for restoring and/or protecting the lake water quality to maximize public benefits; to provide sufficient technical, environmental, socioeconomic, and financial information to enable decision-makers to select the most cost-effective techniques; and to develop a technical program for using the techniques selected.

Alternative methods to address various problems at Otter Lake have been identified and evaluated. The proposed restoration plan is presented for consideration as a Phase II project under the Clean Lakes Program. The anticipated benefits, cost estimates, and time schedule of the proposed lake restoration program also are presented.

EXISTING LAKE QUALITY PROBLEMS

On the basis of the detailed and systematic study of the lake ecology, which covered a period of more than 19 months, an assessment of the physical, chemical, and biological characteristics of the lake water and sediment was made. Additionally, factors affecting the lake's aesthetic and ecological qualities were assessed, and the causes of its use degradation were determined. The lake's hydraulic, sediment, and nutrient budgets were estimated using the data collected for precipitation, lake-level fluctuations, and the water quality characteristics of ephemeral runoffs into the lake after storm events.

The DO values in the lake surface water at all four sampling stations were very good throughout the current study period. The lake exhibits typical thermal stratification phenomenon (below 10-15 feet) during the springs through the summers as do other Midwestern lakes. Although DO at and near the lake surface only met the 5.0 mg/L standard at all stations, the summer DO stratification occurs.

No obnoxious algae was observed in the lake at any time. Aquatic vegetation (macrophytes) can be found in shallow areas along almost the full length of the lake. The growth of macrophytes was not extensive in density. The macrophyte beds did not impair recreational fishing but was beneficial for fisheries.

The chemical quality characteristics of parameters for which standards have been set in Illinois were generally within the stipulated limits, except atrazine. Ammonia-nitrogen was well within the upper limit of the standards. Total phosphorus levels for near surface waters exceeded the 0.05 mg/L for 9,26, 88, and 63 percent of the time at stations 1S, 2S, 3S, and 4S, respectively. For overall lake-use support, waters at stations 1 and 2 of Otter Lake during 1996-1997 were classified as full and full/threatened, respectively.

Based on the results of this diagnostic study, it is apparent that the major problems at Otter Lake have been identified as:

- shoreline erosion,
- deterioration of the boat launch and cove areas,
- watershed runoff-sediment, nutrients, and atrazine,
- siltation in the north end of the north basin,
- high atrazine concentration,
- summer stratification low DO levels,
- poor raw water quality for public water supply use.

Shoreline Erosion

Because most of the shoreline has steep slopes, there has been considerable shoreline erosion around the lake. It is estimated that more than 23 percent (figures 18 and 19) of the shoreline has been severely and moderately eroded mainly by wave action from wind and boats. Many portions of the shoreline had developed vertical banks (figure 21).

The shoreline erosion contributes sediment and turbidity to the lake, degrades the aesthetics of the lake, and threatens trees and valuable lakeshore property. Figure 22 shows the surrounding land types of the lake.

As stated previously, higher sedimentation rates (0.40-2.57 percent) occurred in the northern basin, and less than 0.15 percent of the annual sedimentation rate was found in the southern basin. Overall, the annual sedimentation rate for Otter Lake is less than 1.0 percent.

Deterioration of the Boat Launch and Cove Areas

The area immediately east of the only boat launching facilities on the lake has been severely negatively impacted by discharges from the filter rinse water system at the water treatment plant. The source of these discharges has been contained now, but the aesthetic condition of this high visibility location has been severely impaired by the deposition of filter rinse sediments. These deposits have reduced water depths, become exposed, accumulated debris, and developed a cover of brushy plants. Reduced water depths have severely impaired boat maneuverability adjacent to the boat launch ramp and docks.

Watershed Runoff

The soil, nutrients, and pesticides that have been washed from the watershed into the lake for years have impacted all uses of the lake. Watershed erosion and silt deposition have been a

Figure 21. Shoreline erosion

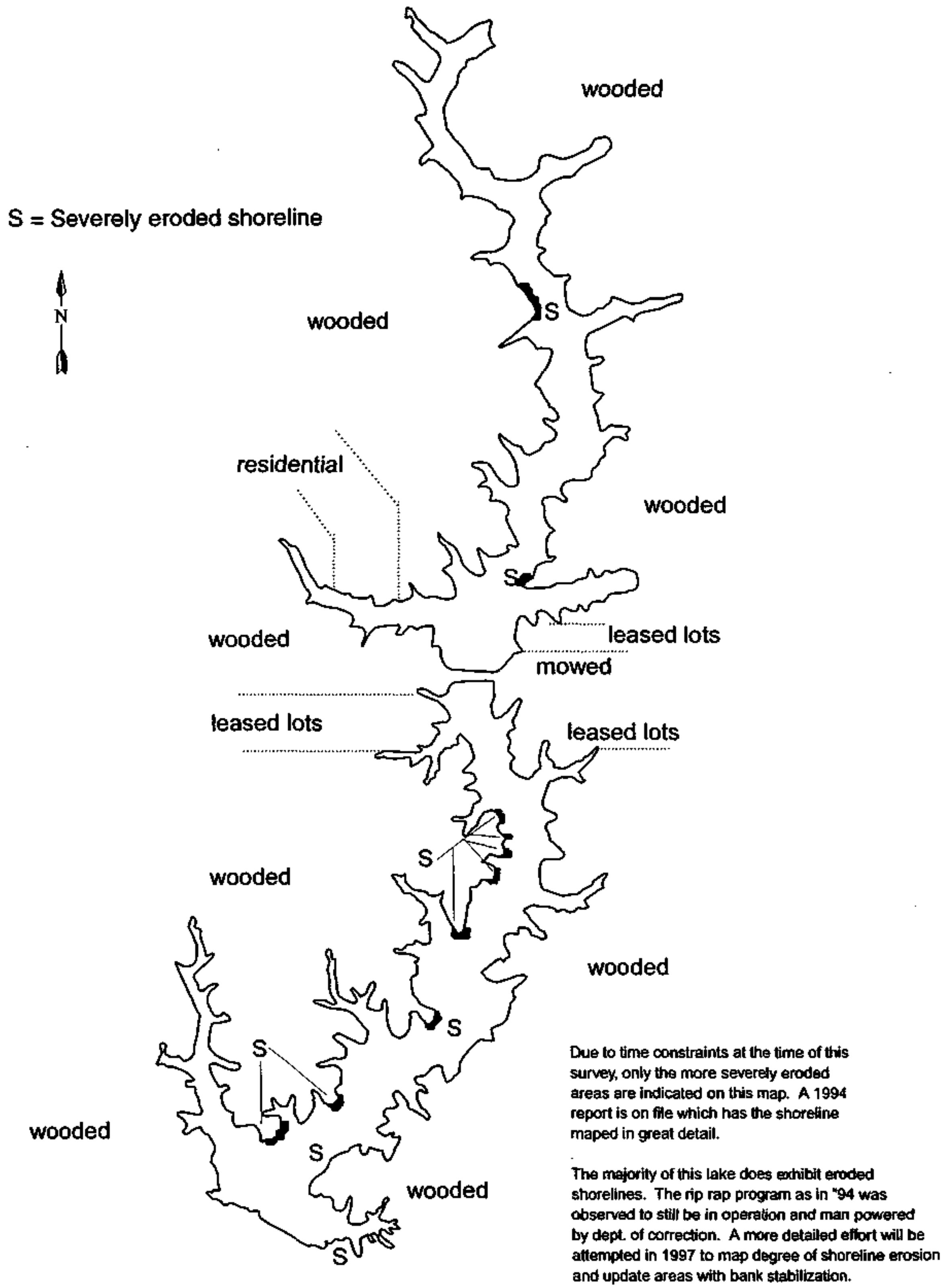


Figure 22. Surrounding land types and shoreline erosion estimates, 1996

problem at Otter Lake for a long time. Total erosion in the watershed has reduced the lake's surface by approximately 6 percent since its construction in 1968 (Macoupin County SWCD, 1993). Boaters on Otter Lake report difficulty in reaching the upper (north) end of the lake because of sedimentation.

The north end of the lake acts as a silt basin, trapping most of the soil particles and agricultural chemicals before they are transported to the south end of the lake. The upper (north end, station 3) area of the lake has higher levels of turbidity, total suspended solids, total nitrogen and phosphorus, with lower DO concentration and Secchi disc transparency. These conditions may result in less aquatic vegetation and adversely impact on aesthetic enjoyment of the lake. Also, these conditions decrease fish production and increase fish diseases and the poor body condition of the fish. These conditions also can contribute to a shift in the species composition from game fish (such as muskie) to rough fish (Macoupin County SWCD, 1993).

Siltation in the North End of the North Basin

Excess sedimentation in the headwater and poor water quality during storms caused the deterioration of the upper end of the lake. The trophic state condition at station 3 has deteriorated to a hypereutrophic condition.

During a storm event, high turbidity; low Secchi disc transparency, high total suspended solids, and total phosphorus; and high chlorophyll *a* occurred in the north portion of the lake, especially at station 3. The mean Secchi disc transparency at station 3 was 17 inches (<18 inches), which is considered as substantial lake-use impairment on the basis of the Illinois EPA's lake assessment criteria (IEPA, 1978). Based on water quality parameters monitored and historical data, the water quality at station 3 has deteriorated.

The turbid water may prevent light penetration, which in turn reduces the growth of phytoplankton that is essential in the food chain. The turbid water may be detrimental to fish on spawning beds and sight feeders. It also affects aesthetic conditions for recreational uses.

An estimated 14,130 tons of sediment is added to the lake annually from the watershed. Siltation reduces the storage volume of the lake, the habitat available for fish, and the growth of aquatic vegetation in areas. The contaminants in the sediment also contribute to degradation of the lake. The estimated nonpoint nutrient loading rates are 41 tons of nitrogen and 2.5 tons of phosphorus per year. The nutrients in the sediment from fertilizer used for farming redissolved in the lake water and affect water quality and lake biota.

High Atrazine Concentration

High atrazine concentrations (3.5-7.5 μg/L) were observed in the finished water from the treatment plant in May-July 1996. These values were due to high concentrations in the raw waters. During this period, the water treatment plant removed two-thirds of the incoming atrazine. The 1997-1998 results of the voluntary atrazine monitoring program (table 20) showed that all the finished water, except that sampled on December 1, 1997 (3.1 µg/L), have atrazine values less than 3.0 µg/L due to reduced atrazine in the raw (lake) waters.

Atrazine is still a potential problem. High concentrations (7-27 µg/L) of atrazine were observed through the fall of 1996 (table 20). Atrazine levels were subsequently reduced starting in January 1997 and continuing through March 1998.

Low Dissolved Oxygen Levels

The lake experiences summer (June-September) stratification. During the peak stratification period, the lake was anoxic at depths below 15 feet from the surface at stations 1 and 2. This condition is typical for Illinois lakes. No DO in the hypolimnion (deeper) water is detrimental to the fishery and subsequently results in the regeneration of phosphorus and nitrogen compounds from the lake sediment.

Poor Raw Water Quality for Water Works

As stated previously, poor water quality in the north basin was due to the watershed runoff. Poor raw water quality has had an adverse impact on the use of this lake (north basin) as a public water supply.

As noted in the diagnostic study, there are significant water quality differences between the north and south basins of Otter Lake. The water quality of the north basin at the existing raw water intake (station 4) is considerably poorer than that on the south side of Emerson Airline Road (station 2).

Treatment of water from the south basin of the lake will be less expensive than treatment of water from the north basin.

OBJECTIVES OF THE OTTER LAKE MANAGEMENT PLAN

The goal of the lake restoration plan for Otter Lake is to address the current problems identified previously and to protect, preserve, and enhance existing lake water quality and the beneficial uses of the lake. Beneficial uses include cultural uses such as public water supply, fishing, boating, and other recreational uses; and environmental uses such as water quality and habitat for fish and other wildlife.

The desirable water quality goals developed for this lake management plan based on water quality guidelines of the IEPA are:

- DO of at least 5 mg/L throughout the whole lake during the critical summer months,
- Secchi disc transparency of not less than 4 feet during summer months,
- total phosphorus of less than 0.05 mg/L at the time of the lake spring turnover,
- average annual suspended solids and turbidity values of less than 25 units,

- reduce nutrient loading to the maximum practicable extent,
- reduce soil erosion in the watershed to the maximum practicable extent,
- reduce atrazine concentrations.

The primary objectives of the proposed lake management program will be to improve the lake water quality and minimize the influx of sediments and nutrients from the watershed. The specific objectives are:

- protect the shoreline from erosion,
- reduce the amount of sedimentation in the lake through watershed land treatment,
- reduce the turbidity of the water in the lake,
- reduce the inflow of atrazine and nutrients into the lake through watershed land treatment and education,
- improve the raw water quality at the water treatment plant.

PROPOSED POLLUTION CONTROL AND RESTORATION SCHEMES

The pollution control and restoration measures may involve watershed management and best management practice (land treatments) for fanning and erosion control. In-lake treatment and control measures will involve shoreline stabilization, lake destratification, dredging, and relocation of the raw water intake. Specifically, the alternatives (nonaction and action) for pollution control and restoration measures are:

- reduce the amount of pollutants being delivered to the lake,
- reduce atrazine levels,
- improve lake water quality,
- perform shallow lake dredging,
- restore the boat launch cove,
- stabilize eroded shoreline areas and restore water depth in coves adjacent to the boat launch area,
- upgrade the existing destratifier in the north basin of the lake,
- install a new destratifier in the south basin of the lake,
- relocate the intake,
- conduct Phase II monitoring and prepare final report.

Reduce Pollutants being Delivered to the Lake

To reduce the pollutants (sediment and nutrients) being delivered to the lake, best management practices (BMPs) or land treatment should be carried out in the watershed. The following BMPs can be applied in the Otter Lake watershed: animal waste management, conservation tillage, contour farming, contour stripcropping, terraces, crop rotation, grassed waterways or filter strips, and runoff detention ponds.

Animal Waste Management

Animal wastes can be held temporarily in waste storage facilities until they can be used and safely disposed of. Storage structures can be constructed of reinforced concrete or coated steel. Wastes also can be stored in earthen ponds without runoff. The stabilized manure application rate should be adjusted to meet the phosphorus requirements. It should not be applied in winter or to poorly drained lands. Feedlot waste control costs approximately $7,500 per year for every 50 animals. Manure storage averages $2,844 for each storage facility (USEPA, 1990). In the Otter Lake watershed, the majority of hogs (7,500) are produced in confined systems.

Conservation Tillage

Conservation tillage is a farming practice that leaves stems or stalks and roots intact in the field after harvest. The purpose of this is to reduce water runoff and soil loss compared to conventional tillage in which the topsoil is turned over and mixed by a plow. The capital cost is high if new equipment is to be purchased. Conservation tillage reduces the number of times the top soil is mixed; for no-till, the topsoil is left essentially undisturbed.

Contour Farming

Under contour farming practices, the field is plowed across the slope of the land. Contour farming is an effective erosion-control measure on farmland with 2 to 8 percent slopes. It is less effective on steeper slopes. There is no upfront capital cost for this practice. Operational costs might be slightly higher than straight row-crop procedures. In the Otter Lake watershed, prairie soils are nearly level (0-2 percent).

Contour Stripcropping

Contour stripcropping is similar to contour farming, for which the farmer plows across the slope of the land. The difference is that strips of close-growing crops or meadow grasses are planted between strips of row crops, such as corn or soybeans. Contour stripcropping can be used more effectively on 8 to 15 percent slopes. Contour stripcropping is good to excellent for runoff control. Implementation (capital) costs average $24 per acre and $3 to $5 per acre per year for operation and maintenance (O & M).

Terraces

Terraces are used when conservation tillage, contour farming, or contour stripcropping do not achieve sufficient soil protection. Terraces are used in long slopes and slopes up to 12 percent. They are step platforms that reduce the slope by breaking it into lesser or near horizontal slopes. Terraces are fair for runoff protection and are more effective in reducing soil erosion than runoff volume. They have high initial costs, an average of $73 per acre. Maintenance costs are $16 per acre annually (USEPA, 1990).

Crop Rotation

Crop rotation is planned planting of crops, such as grass or legumes, that are alternated with corn in two- to four-year rotations. Surface runoff control is good when field sequences of crops are planted in some area of farmland. For example, plow-based crops are followed by pasture in grasses or legumes. Capital cost may be high if farm economy declines. Operational costs will be less of a problem in combination with a livestock operation that can use pasture and silage. Costs for O & M are moderate, but there is an increased labor requirement. Cost may be offset by lower nitrogen applications to the land when corn is planted after legumes, and there may be a reduction in pesticide application.

Grassed Waterways

Grassed waterways are broad and shallow drainage channels (natural or constructed) that are planted with erosion-resistant grasses. In some cases grassed waterways are combined with filter strips, which are strips of land between or on the edges of fields that are permanently planted with grasses.

The capital cost of grassed waterways is moderate, approximately $22 per acre. Average maintenance costs range from $1 to $14 per acre per year (USEPA, 1990). The effectiveness of soil loss control by this practice is good, with 60 to 80 percent reduction.

Retention Basins

Runoff retention (siltation) basins settle and filter out pollutants (mainly sediments and some nutrients) or hold water until treated. The retention basin itself provides no treatment. Retention facilities may include natural ponds, artificial basins, underground tunnels, and other holding structures.

Retention basins have fair-to-excellent effectiveness for sediment removal and runoff control, with 60 to 80 percent reduction in sediment load. The capital cost depends on the types and sizes of the basins, and range from $100 to $1,000 per acre; the O & M costs range from $10 to $125, depending on the site.

There is a silt retention basin above the entrance of the northeast tributary of Otter Lake. This basin was designed by the Natural Resource Conservation Service, U.S. Department of Agriculture, Carlinville, Illinois.

Construction of an in-lake sedimentation basin in the upper end of the lake also is an alternative method to reduce lake sedimentation by catching or retaining runoff water long enough to allow suspended solids to settle out before reaching the main body of the lake. An effective in-lake sedimentation basin would impound runoff water behind an earth- and rock-filled dam temporarily. The impounded water would be released gradually through a slotted drop-inlet structure with an overflow structure and an appropriate debris screen to prevent clogging. The cost of constructing this type of large structure would be high. In addition, Otter

Lake has a large storage capacity (15,000 acre-feet). Therefore, this alternative (in-lake sediment basin) is not considered an efficient option for reducing sediment delivery to the lake.

Summary

Each farming practice or land-treatment method given here, or any combination of practices, would provide erosion control, reduce farmland soil losses, and reduce input of sediments, nutrients, and agricultural chemicals (such as atrazine) to the lake. Regional soil specialists should be contacted for watershed management measures.

In 1995, the OLEPC developed a comprehensive plan to manage the lake and its watershed. A WQIP was carried out in 1995-1996. An estimated 1,920 acres (22.2 percent of the watershed) of land are highly erodible soil in the Otter Lake watershed. According to the Macoupin County SWCD (1995), the total sheet erosion rate is 27,587 tons per year in the watershed, of which 8,069 tons per year of eroded soils enter into Otter Lake. In addition, 5,500 tons per year of sediment from gully, ephemeral gully, and streambank erosion also enter the lake.

Previous watershed management programs coordinated by the U.S. Department of Agriculture NRCS in cooperation with the OLEPC have successfully treated approximately 50 percent of the targeted acreage. A treatment program is considered to be successful if 75 percent of the targeted acreage in a watershed is treated. The NRCS estimates that $250,000 will be necessary to complete the remediation level to 75 percent (I. Dozier, personal communication, October 22, 1998). The NRCS anticipates applying for funding for this additional treatment under the Environmental Quality Incentive Program (EQIP) in spring 1999. Watershed treatment does not need to be included in funding under the Illinois Clean Lakes Program.

Watershed management for soil stabilization should continue and be encouraged. Securing funding and detailed planning should be the responsibility of the OLEPC. The land-treatment measures may include sediment and erosion control structures, grass waterways, terraces, waterway diversion, streambank stabilization, and other BMPs.

Atrazine Education

Nonpoint pollution source control has been an on-going project in the Otter Lake watershed area. Through the efforts of Ciba-Geigy and the ADGPTV Water Commission, a voluntary atrazine monitoring program for both raw and treated waters has been carried out since June 1993. The WQIP sign-up and participation has been aggressively promoted since November 1995. In December 1995 a neighbor-to-neighbor network to help the WQIP plan implementation was established. In March 1996, a reminder was sent to watershed farms to use atrazine properly during the planting season. In April 1996, public education on conservation practices and pesticide use was conducted through the media.

Atrazine, one of the most popular herbicides used in Illinois, sometimes has been at levels exceeding the water quality standards for community surface water supplies (an example, Otter Lake). In August 1992, the manufacturer of atrazine made changes in the label. The new label calls for reduced application rates and the establishment of setback zones, areas around lakes, wells, and streams at which atrazine cannot be mixed, loaded, or applied.

The recommended application rates (in pounds of active ingredient per acre) and setback requirements are as (University of Illinois Cooperative Extension Service, 1993):

Total application rate for calendar year (pre-emergence and postemergence)	2.5 lb
Highly eroded land with at least 30 percent surface cover	2.0 lb
Highly eroded land with less than 30 percent surface cover	1.6 lb
Nonhighly eroded land, maximum single pre-emergence	2.0 lb
Mixing/loading setback requirements	50 feet
Application setback requirements	
Lakes and reservoirs	200 feet
Wells	50 feet
Perennial or intermittent streams	66 feet

More information about atrazine uses and watershed management (applying BMPs) can be obtained from the regional office of the University of Illinois Cooperative Extension Service; Soil Conservation Service, Agricultural Stabilization and Conservation Service; or Farmers Home Administration. The information and education campaign in the Otter Lake watershed should be continued and encouraged. Producers and other farmers should realize the economic benefits to their operation while protecting their natural resources.

Improve Lake Water Quality

A long-term solution to improving lake water quality in the north basin involves preventing as much pollutant (sediments, nitrogen, phosphorus, atrazine, etc.) entry as possible. One alternative is a short-term solution that involves sediment removal and nutrient inactivation. Another effective alternative is a combination of pollutant reduction and removal.

Because the agricultural erosion and storm runoff are the major sources of pollutants entering the lake, there should be a concentrated effort toward reducing agricultural chemical applications, increasing effective utilization, and preventing runoff through BMPs as stated previously. It is imperative that nutrients be maintained on the field through continued and increased conservation practices. The private land holders within the watershed could be encouraged to adopt no-till or conservation tillage practices, if they are not already using them. An educational program to promote conservation tillage in the watershed should be conducted by the Macoupin County SWCD in cooperation with the University of Illinois Cooperative Extension Service.

Removing nutrient-rich sediment from the lake bottom is a complement to nutrient prevention. Dredging is the most effective method for removing nutrient-rich sediment from the lake. It is discussed in detail in the following section (Shallow Lake Dredging).

Other potential alternatives for reducing nutrient inputs are nutrient diversion, dilution and flushing, and inactivation/precipitation. Diversion is routing the point source to other places. Dilution and dispersion (flushing) is accomplished by the replacement of nutrient-rich waters with nutrient-poor waters and washout of phytoplankton. These alternatives are impractical for Otter Lake.

In-lake nutrient inactivation techniques have been directed primarily toward phosphorus. The nutrient inactivation techniques that have received the most attention are: aluminum, iron, and calcium salts. Compounds of lanthanum, zirconium, tangsten, and titanium were found to be effective in removing phosphorus in laboratory studies, but their use in lakes has not yet been proven. Nutrient inactivation (or precipitation) can be effective only in lakes from which a significant input of nutrients has been eliminated. This technique is used only for algal control and not for control of rooted aquatic plants. Alum (aluminum sulfate) coagulation/precipitation takes a long period (one year) to be effective in controlling blue-green algae, improving lake transparency, and reducing lake phosphorus concentration. The precipitate can act as a barrier to prevent phosphorus release from the sediment. However, this alternative is not needed for Otter Lake.

Another alternative for improving lake water quality is aeration to destratify and increase DO in the lake water. Destratification techniques are discussed in another section.

Shallow Lake Dredging

Sediment removal in freshwater lakes is usually undertaken to increase lake water volume, improve sport fishery habitats, enhance overwinter fish survival, remove nutrient-rich sediments and/or hazardous materials, reduce the abundance of rooted aquatic plants, reduce the sediment's oxygen demand on the overlying water, reduce the potential for sediment resuspension, and control algae.

Advantages of sediment-removal techniques include the ability to selectively deepen parts of a lake basin, increase the lake volume, recover organically rich sediment for soil enrichment, and improve limnetic water quality. Disadvantages include high cost, possible phosphorus release from sediment, increased phytoplankton productivity, noise, lake drawdown, temporary reduction in benthic fish food organisms, and the potential for release of toxic materials to the overlying water and environmental degradation at the dredged material disposal site (Peterson, 1981). In addition, the nutrient content of the sediments may remain high at a considerable depth, thus making it impossible to reach a low nutrient level in sediment. Although satisfactory disposal of the spoils may be very expensive, high quality dredge material can be used for beneficial purposes and may offset the initial high cost of dredging. In nearly all cases, permits from the U.S. Army Corps of Engineers are required (USEPA, 1990).

Peterson's (1981) report on the restoration of Wisconsin Spring Ponds through dredging is one of the most thoroughly documented studies concerning the ecological effects of dredging small lakes. The purpose of the dredging was to deepen the ponds to improve fish production. Incidental to the deepening was the control of aquatic macrophytes. It is reported that, even though there was a temporary decrease in the benthic organisms soon after dredging, four to five years after lake restoration the average density and biomass of fishable-size fish were substantially greater than during the predredging period. During the dredging process, there will be an increase in turbidity in the immediate surrounding area and a possible decrease in the ambient DO concentrations. However these problems are short-lived and many of these problems can be minimized with proper planning.

Peterson (1981) also reports on the successful restoration of Lilly Lake (southeastern Wisconsin) by dredging. The main problems in the lake were severe shoaling, abundant aquatic plant growth, and winter fish kills. In addition to dredging the whole basin, ten percent of the 97-acre lake was dredged to a depth of approximately 6.0 m (20 feet). Dredging was completed in September 1979; and, as of 1981, water quality had remained good, macrophytes had virtually been eliminated, and local sponsors were generally pleased with the outcome.

The City of Springfield, successfully used hydraulic dredging to dredge Lake Springfield to meet multiple objectives: namely, to deepen the shallow end of the lake in order to increase sediment retention capacity, control emergent aquatic vegetation, and enhance aesthetic and recreational opportunities. This project is considered the largest inland lake dredging project completed in the early 1990s (Cochran & Wilkin, Inc., Springfield, Illinois, personal communication, 1994).

Sediment removal can be accomplished either by hydraulic dredging or by exposing lake sediments for removal by conventional earth-moving equipment. Pierce (1970) describes various types of hydraulic dredging equipment and provides guidance on the engineering aspects of dredge selection. Peterson (1981) describes various grab, bucket, and clam-shell dredges; hydraulic cutterhead dredges; and specialized dredges to minimize secondary water quality impacts. Sediment removal using earth-moving equipment after lake-level drawdown was successfully used in Crystal Lake, Urbana, Illinois, during 1990-1991.

The advantages and disadvantages of mechanical dredging or excavation and hydraulic dredging have been discussed by Berrini (1992). There are several methods of mechanical dredging or excavation presently available. The lake can either be dredged at normal pool with a dragline, or the water level can be lowered enough to allow low ground pressure excavation equipment into the dry lakebed. There are several advantages to dry lakebed excavation as compared to hydraulic or dragline dredging, such as the elimination of excessive turbidity or resuspended solids, and a smaller quantity of material to remove due to consolidation and compaction. However, many disadvantages and problems would be encountered. Although initial water level drawdown could be accomplished quickly with high capacity pumps, the length of time required for the sediment to dewater and consolidate enough to support excavation equipment would be a year or more.

Another method of mechanical dredging would be accomplished with a dragline while the lake water level is at normal pool. This is accomplished by extending excavating equipment from shore, or by mounting the equipment on a barge. This method is more practical for smaller lakes or when a large quantity of rocks or debris is anticipated. Removal of accumulated lake sediment is inefficient and can leave high percentages of material behind. Disposal of the sediment is also very inefficient and labor intensive since it must be handled several times. Once the sediment is removed from the lake, it must be placed on a barge or a truck and transported to the retention site. This repeated handling is generally not cost effective and can result in sediment losses during transfer. Equipment access for the removal and placement of dredged sediment would also have a negative impact on the lake shoreline. Therefore, mechanical dredging would not be considered as a feasible restoration method.

Hydraulic dredging involves a centrifugal pump mounted on a pontoon or hull that uses suction to pull the loose sediment off the bottom and pump it through a polyethylene pipeline to a sediment retention area. Generally, a cutterhead is added to the intake of the suction line in order to loosen the accumulated or native sediment for easy transport and discharge. A slurry of sediment and water, generally between 10 percent and 30 percent solids, can be pumped for distances as much as 5,000 feet or as much as 10,000 feet with the use of a booster pump (Berrini, 1992). The efficiently pumped sediment slurry must reach a suitably constructed earthern dike-walled containment area with adequate storage capacity. The sediment contaminant or retention area must be properly designed to allow sufficient retention time for the sediment particles to settle throughout the project and allow the clear decant or effluent water to flow through the outlet structure back to the lake.

One of the advantages of hydraulic dredging is the efficiency of sediment handling. The removal, transport, and deposition are performed in one operation, which minimizes expenses and potential sediment losses during transport. Another advantage is that the lake does not have to be drained, and most areas can remain open for public use. Most hydraulic dredges are considered portable and are easily moved from one site to another. They are extremely versatile and capable of covering large areas of the lake by maneuvering with their spud anchorages system and moving the discharge pipeline when necessary.

Restore Boat Launch Cove

Prior to stabilization of the boat launch cove area under the riprap program, it is recommended that the cove area be dredged to restore boat access and the general appearance of this small bay. According to the consulting engineers of the ADGPTV Water Commission, construction of an earthen sediment detention impoundment immediately east of the boat dock cove area is recommended to curtail future siltation and sedimentation on the area. The detention basin would have a surface area of approximately 1/3 acre, with an average depth of 5 feet. Initially, accumulated sediment would be removed periodically and applied to farm lands. Subsequent to dredging, the basin also will be used to store and dewater the dredged material from the boat ramp area prior to farmland applications.

It is recommended that a surface area of approximately 1 acre near the boat ramp dock area be dredged (hydraulic dredging) to restore the original water depth of the lake. Based on the opinion of the ADGPTV Water Commission's consulting engineers, an estimated depth of 2 feet of sediment would be removed by dredging. A total of 3,500 cubic yards of sediment will be removed.

The estimated total cost for dredging and a sediment detention pond is $112,550, which includes $46,250 for dredging, $46,300 for construction of a detention basin, $10,000 for engineering, and $10,000 for contingencies. The detailed cost analyses are presented in table 38 (provided by the ADGPTV Water Commission). In addition, the boat docks need to be replaced. The estimated cost for the replacement of the boat docks is $9,000. This would not be a cost-shareable item by the Illinois EPA under the Illinois Clean Lakes Program. The cost of dock replacement should be paid by the ADGPTV Water Commission.

North End of the Lake

Siltation at the north end of the lake causes an inconvenience for fishermen. Because Otter Lake has a large surface area, no action is planned for this area.

Methods available for in-lake treatment to control sedimentation in the northern (upstream) end of Otter Lake are limited and carry a potential for adverse impacts. Treatments considered are dredging and the construction of an in-lake sedimentation basin.

Dredging to remove existing sediment from the lake basin is a costly and potentially disruptive measure that is generally considered in only the most severe cases. As can be noted in table 36b of Part 1 of this study, significant sedimentation losses (greater than 50 percent of initial volume) are limited to the 10-acre area designated as lake segment 17 (figure 20) in the immediate upper end of the lake. Another 60 acres of the lake area, segments 15, 16, and 24, are moderately impacted (25 to 50 percent of initial volume) by sedimentation losses. The combined area of these segments is less than 10 percent of the total lake area and, with the exception of segment 17, all continue to maintain an average depth of over 3 feet at normal pool levels. Based on this analysis, dredging of the upper sections of the lake is not warranted at this time.

The intent of constructing an in-lake sedimentation basin (a dam) would be to confine the impacts of inflowing sediment by limiting the free flow of sediment-laden water into the lower reaches of the lake. By confining sedimentation impacts to a small area, future dredging programs would be of a more limited extent and presumably less expensive.

The extent of sedimentation impacts to Otter Lake is limited in extent under existing conditions. As can be seen from the previous discussion for potential dredging benefits, less than 10 percent of the lake area is moderately or severely impacted by sedimentation. Attempts to further restrict the circulation of sediment will be of little benefit and could cause additional disruption to fish habitat and recreational use of the lake.

Stabilize Eroded Shoreline Areas

Shoreline stabilization in Otter Lake has been an on-going process. In June 1993, 25 bald cypress trees were planted by Boy Scouts for shoreline erosion control for demonstration purposes. Riprap with crushed stones was installed in several places in December 1994. In the

Table 38. Cost Analyses for Dredging Cove Area and Sediment Detention Pond

Project	*Quantity*	*Unit price, $*	*Cost, $*	*Totals, $*
Dredging				
Mobilization	1	20,000	20,000	
Dredging	3,500 cu yd	7.5	26,250	
Subtotal				46,250
Sediment detention pond				
Clearing and grubbing	0.5 acres	2,500	1,250	
Embankment	2,750 cu yd	8	22,000	
Outlet structure	1	5,000	5,000	
Riprap	2,400 sq yd	7	16,800	
Seeding	0.5 acres	2,500	1,250	
Subtotal				46,300
Engineering				10,000
Contingencies				10,000
Total				112,550

Notes: Blank spaces - not applicable
cu yd - cubic yards
sq yd - square yards

summer of 1997, riprap also was installed on both sides of the Emerson Airline Road and at the southwest corner of the north portion of the lake through a grant from the Illinois EPA.

Shoreline erosion control techniques can be categorized into two groups: nonstructural (vegetative) and structural methods. Nonstructural methods include cypress plantings, willow plantings, hydroseeding, tree-cutting with grass seeding, and lower water levels. Structural methods include riprap, gabions, erosion mats, interlocking concrete blocks, railroad ties, used tires, plastic and natural geowebs, biologs (palm tree leaves), seawalls, bulkheads, and a combination of these methods. Some of the methods are discussed in detail in other reports (U.S. Army Corps of Engineers, 1981; City of Charleston, 1992; Hoag et al., 1993).

Tree Cutting

Trees that are on the verge of falling into the lake, if left to a natural course of events, will contribute substantial localized silt loading to the lake. The input of sediment to the lake would be slowed if trees on the edge of the cliffs were cut and removed,. The trees that should be tagged for cutting include: the crown diameter of its root-ball has been undercut by 30 percent or more, the tree's main trunk has an angle of 60 degrees or less from the horizontal level, and the damaged or diseased trees near the bank. The cost of tree cutting is estimated at $1,000 per year, with a total cost of $4,000 for four years.

Tree cutting can be carried out in the spring or fall. State wildlife officials should be informed before tree cutting for considerations of any potential destruction of riparian habitat and any endangered species of predatory birds.

Tree Planting

The planting of willows and/or cypresses is a biotechnical control and protects against shoreline erosion. Willow or cypress have the ability to root easily. Their fibrous root systems can hold the soil together, and the rest of the tree protects the bank by slowing wave action.

There are several methods of planting willows: willow staking, post driving, willow cuttings, live facsines, live booms, or combinations of more than one method. Planting willow tree post with roots will grow to a 6-foot root in diameter six months after planting. The mortality rate is 75 percent. One to 2 inches in diameter and 2 to 3 feet (or longer) in length would be an appropriate size. The cutting must be kept moist and shipped to the location to be treated. The cutting must be high enough above ground level to avoid shading from weeds and grass as well as to intersect wave action.

The planting distances for willow cuttings would be 3-4 feet apart, forming a diamond shape. Planting depth ranges from 12-18 inches. The mortality rate is expected to be 50 percent.

Jeffrey Pontnack, District 15 fisheries biologist of the IDNR Fisheries, recommended that around Otter Lake is an excellent project for planting bald cypress seedings. A tubex structure per tree is required to protect the shoreline. The cost of 300 tree shelters with a stake would cost approximately $700, without stakes (make the stakes) about $500. These young trees can be purchased through IDNR Division of Forest Resources in Hillsboro.

It is recommended that 300 cypress trees be planted each year during the four-year implementation period. The annual cost for cypress tree plantings is $1,000, including labor costs, or $4,000 total for the four years.

Interlocking Concrete Blocks

Interlocking concrete blocks revetment also are commonly used for erosion control, especially for high-flow current river banks; this method is very effective but costly. Interlocking concrete blocks are available in various shapes and weights, and many of the units are patented. The disadvantage of interlocking concrete blocks is that the interlocking feature between units must be maintained. After one block is lost, other units soon dislodge, and complete failure may result.

The cost of a pair of 1-foot a-jacks is $15.00, and it will cost $135.00 to cover 1 square yard. In comparison, the cost of rock is $7.00 per square yard. Therefore, the interlocking concrete block revetment is not recommended for Otter Lake shoreline erosion control.

Biolog

Coconut fiber fascines (coconut logs) are gaining in popularity for stream and river bank erosion control. It is an effective method and usually has a five-year life span. The cost of coconut logs is $160 for a 1-foot diameter, 20-feet long log. It costs $72 per square yard, which is about 10 times higher than the cost of rock. Therefore, this method for erosion protection is ruled out due to the high cost.

Bulkheads

A bulkhead (or a sea wall) is a structure that retains or prevents sliding of land or protects the land from wave damage. Bulkheads are used in areas with steep slopes. Various types of bulkheads for shoreline protection can be constructed by auto tire and timber post, treated timber, gabions, steel sheetpiling, steel or aluminum H-piles, or railroad ties.

Sheetpile bulkheads consist of interlocking or very tightly spaced sheets driven vertically into the ground. The sheets can be made of steel, aluminum, or timber. Sheetpiling structures either can be anchored or cantilevered. The advantages of sheetpile bulkheads are their long and maintenance-free life and uniform appearance. The disadvantages are the needs of special pile-driving equipment and trained operators for installment.

Steel H-piles and railroad ties with caps also can be used to form bulkheads. This metal uses vertical steel H-piles and railroad ties placed horizontally between the H-piles, and a steel channel is welded to the top.

The cost of materials and installation for bulkheads range from $50 to $100 per linear foot, depending on the location. Due to the high cost and poor accessibility to the lake, bulkheads for shoreline protection are not recommended for Otter Lake.

Post and Tires

Closely spaced vertical timber piling strung with used auto tires can be used to form a relatively inexpensive structure for shoreline erosion control. Tires are advantageous because they are durable and available (free or $1.00 a piece). Tie backs spur connecting the retard structure (tire posts) to the bank increase structural stability and induce sedimentation following overtopping. But the post-and-tire method allows too much wave energy between the tires. Cliff erosion may continue. Another problem is that the tires have to be replaced continually because the old tires disappear into the clay base (Hoag et al., 1993). In addition, tires look like pollution to the public. Thus, the post-and-tires method is not recommended.

Riprap

Riprap is the most commonly used method for lakeshore erosion control in Illinois. Riprap with rock or stone provides better weight or anchorage, permeability, and filtering characteristics and is more durable, erosion resistant, and flexible. The cost of riprap ranges from $25-$35 per linear foot (contractor's rate).

Approximately 18,400 linear feet of shoreline stabilization work (mainly riprap) has been installed at Otter Lake, but a significant amount of eroded shoreline is still in need of stabilization and continues to add sediment and nutrients to the lake. According to the 1998 Water Survey erosion survey (in this study), the length of untreated shoreline and treatment costs are listed in table 39.

On the basis of possible available funding, shoreline stabilization with riprap (without gabion) is chosen on all severely and moderately eroded areas for about 38,500 linear feet (25 percent) and of selected minimally eroded areas. The riprap would be placed along the shoreline 2 to 4 feet below and 2 feet above normal pool (spillway) elevation. The estimated cost of riprap stabilization using crushed stone is $7.32 per square yard. For the moderate and severe eroded areas, a 2-feet height of stones could be placed at the bottom of the bluff. The riprap would be installed in cooperation with the Department of Corrections prisoner-release program so labor would be free.

Constructions of riprap at severely eroded areas would be carried out in years 1 and 2. The costs for each year are estimated as $16,950 (2,316 feet of shoreline) and $20,650 (2,821 feet) for years 1 and 2, respectively. The total cost of riprap for severely eroded shoreline (5, 140 feet) would be $37,600. For the moderately eroded areas, shoreline stabilization will be completed in four years; the costs for each year are, respectively, $10,000 (1,367 feet), $100,000 (13,661 feet), $82,000 (11,202 feet), and $51,800 (7,077 feet). The total cost of riprap for moderately eroded shoreline (33,300 feet) would be $243,800. Due to limited funds, construction

Table 39. Estimated Cost of Riprap

Condition	*Length, ft*	*Area,* sq yd*	*Unit cost,** $/sq yd*	*Total Cost, $*
Minimally eroded (<3 feet)	121,600	67,500	7.32	494,100
Moderately eroded (3 to 8 feet)	33,300	33,300	7.32	243,800
Severely eroded (>8 feet)	5,140	5,140	7.32	37,600
Total	160,102			775,500

Notes: *Average width for minimally, moderately, and severely eroded areas are estimated as 5, 9, and 9 feet, respectively.

**Cost estimated by Mr. D. Ross, Manager of ADGPTV Water Commission: 7.32 $/sq yd (square yard), including rock, filter fiber, and barge operation (labor free from the Department of Corrections prison-release program).

will be carried out at a limited number of minimally eroded areas for each year (see Budget later in this report). Similarly for the minimal eroded shorelines, stabilization will be conducted in four years. The costs for each year are, respectively: $5,000 (1,230 feet), $27,350 (6,725 feet), $6,000 (1,475 feet), and $76,200 (18,738 feet). A total of approximately 28,168 linear feet of minimally eroded shoreline will be protected by riprap with a cost of $114,550. The total cost of shoreline stabilization by using riprap would be $395,950.

Upgrade Existing Destratifier near Station 4 (North Basin)

Augmentation of DO levels in a lake can be achieved by installation of destratifier (or aeration/circulation) devices. Since the late 1970s and early 1980s, the ISWS has demonstrated successful installations of destratifiers (Kothandaraman and co-workers, 1979, 1980, 1982). An aerator with a 1.5 hp motor was able to destratify Lake Eureka (227 acre-feet) completely and maintain DO levels throughout, including the near-bottom waters of the deep portion (18 feet) of the lake. Iron and manganese concentrations in the deep waters were reduced by 97 percent compared to the pre-aeration levels. Chlorine demand values were reduced more than half (Kothandaraman and Evans, 1982). An earlier study (Lin and Evans, 1981) had indicated that the odor episodes in the finished water were directly correlated with manganese levels and chlorine demand values. Also with the destratification, a dramatic shift of the algal species makeup was observed in the lake. Problem-causing blue-green algae was practically eliminated, and diatoms were the dominant algae during the summer months.

In Otter Lake, a destratifier (near station 4) was installed about 500 feet north of the intake. The intake is located on the north side of Emerson Airline Road, approximately centered in the lake, and within 15 feet off the shore. Figure 10 shows that summer stratification occurred and low DO concentrations were recorded at station 4, even with the operation of the aeration system. Increasing DO levels would reduce internal regeneration of phosphorus from the sediment into the lake water and increase the inhabitant areas for fish. The DO levels are expected to rise in the water column at station 4 during the summer period after the upgrade of the aeration motor.

The destratifier uses a 2-hp electric power unit operating a variable speed hydraulic motor with a 72-inch, six-blade, fixed-pitch propeller and mechanical gear reduction box. This unit should be replaced by a 5-hp aeration motor compatible with the gear reduction box and other electrical controls. The cost of the replacement motor is estimated at $3,000 and labor at $500, for a total cost of this conversion of $3,500. In comparison, a new system will cost $20,000-$60,000.

Install New Stratifier in the South Basin

The installation of a lake destratifier is intended to artificially circulate and mix lake water to replenish oxygen in the hypolimnion water and to eliminate stratification during the summer months. Advantages, disadvantages, and successful cases are discussed elsewhere (Kothandaraman and co-workers, 1979, 1980, 1982, 1983a and b; Raman and Twait, 1994; Raman et al., 1998).

Several types of destratification systems are available. The most commonly used is the mechanical type, typically consisting of a floating platform with a submerged motor-driven propeller or with a floating pump drawing bottom anoxic water to the surface. Another type of aeration system uses a compressed air system, such as that used in Charleston Side Channel Reservoir (City of Charleston, 1992) and Canton Lake (Crawford, Murphy & Tilly, 1995).

Aspir-Air Installation

The ISWS installed and monitored a Venturi-type aerator in Lake Catherine in Lake County. The aeration system consisted of a mounted submersible pump that drew anoxic water from near the lake bottom through a vertical induction pipe and discharged the water outward at the lake surface (Kothandaraman et al., 1979). An improved aerator, an Aspir-Air aeration system (Aspir-Air, Inc., Newberry Springs, California) was installed in Lake Evergreen and Lake Bloomington in 1996. Significant improvement in the physical, chemical, and biological characteristics of the three lakes were observed (Kothandaraman et al., 1979; Raman et al., 1998).

A destratification system developed by Aspir-Air is recommended based on the past experiences of the ISWS with a similar system in Lake Catherine in Lake County; the same system was used in Lake Evergreen and Lake Bloomington. The system consists of a two-stage submersible pump with a rated capacity of 1,200 gpm at 50 pounds per square inch (psi) driven by a 40-hp, three-phase, 460-V, 60-cycle Hitachi electric motor and the Aspir-Air destratification unit. Figure 23 shows the unit. The device operates on the Venturi principle. Discharge from the submersible pump is directed through a constriction created by the primary cone shown in figures 24a and b. The increased velocity created at the constriction causes a negative pressure to develop at the throat. Because of the negative pressure, air is drawn from the atmosphere through air hoses attached to the air-induction nipples and extending above the water surface. A PVC pipe directional nozzle is attached to the discharge end of the Aspir-Air unit. The assembly of the submersible pump and the Aspir-Air unit with the nozzle is mounted on a stainless steel skid with a variable pitch mounting system so that the angle of inclination of the assembly can be varied within limits. Figure 24c shows the completely assembled system, except for the air hoses, prior to installation.

A helicopter was used to install the aeration system in Lake Evergreen near the raw water intake structure (figure 24d). The system rested on the lake bottom, at a depth of about 34 feet, with the air hoses attached to a buoy anchored by a stainless steel cable. The system used in Lake Evergreen is quiet during operation. The only obstruction created on the lake surface is the buoy used to support the free ends of two air hoses. The system was installed in the lake on June 16, 1996. The City of Bloomington was able to procure the system completely installed, including all materials and installation costs, for a total of $55,000 based on an open-bid process. The city procured two systems, one for Lake Evergreen and another for Lake Bloomington, effecting some economy of scale. The price included a one-year warranty for all parts and labor.

An Aspir-Air destratification system is recommended for the south side (200-250 feet) of Emerson Airline Road at a location 25 feet deep (near deep channel, detail survey is required).

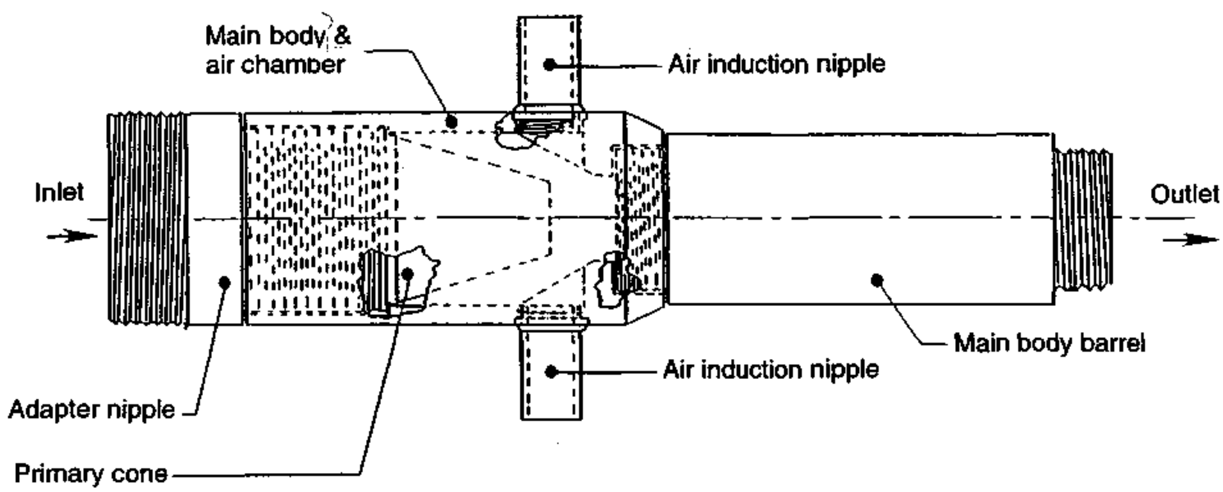
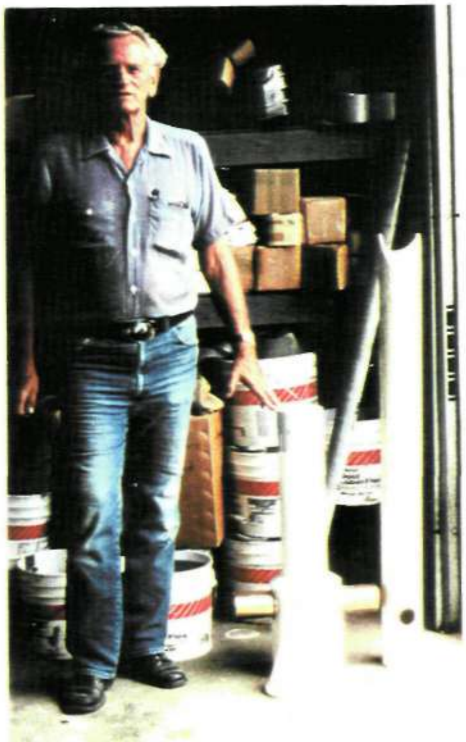
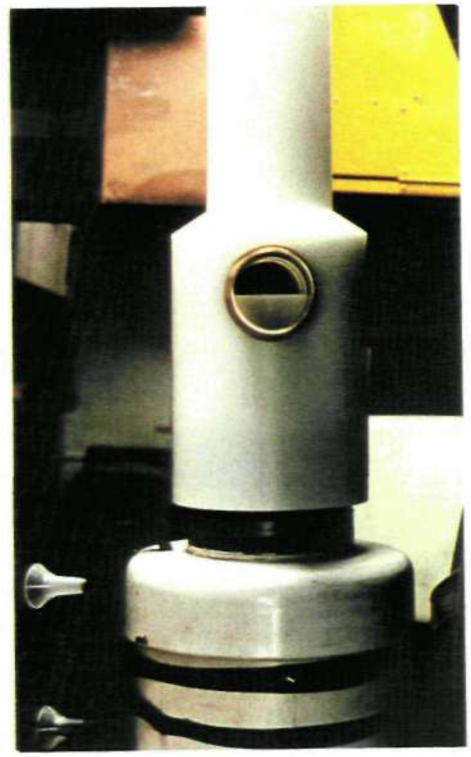


Figure 23. The Aspir-Air aeration unit



a. The main barrel, primary cone, and directional nozzle



b. The primary cone shows within the air chamber of the assembled unit

c. The completely assembled system, except air hoses, prior to installation

d. System installation in the lake using a helicopter

Figure 24. The Aspir-Air aeration system

The estimated cost of installing one destratifier (as recommended by the Aspir-Air system) in Otter Lake is approximately $60,000.

Relocate Intake

As stated in the Part 1 of this report, water quality monitored at station 2 (south of the Emerson Airline Road) was found to be better than that at station 4 (north of the road, 300 feet north of the existing intake of the water treatment plant). In addition, summer stratification in the south portion of the lake is expected to be eliminated after the installation of a destratifier. Therefore, it is recommended that the water supply intake be relocated to the south side of the road, i.e., across the road from the existing intake. However, the cost of relocation will not be assisted by the Illinois Clean Lakes Program.

The existing intake tower would be connected to the south basin of the lake by a conduit around the roadfill. Raw water would flow by gravity to the existing intake tower. The total length of the new conduit would be 250 feet, of which approximately 140 feet would be under the highway (alternatives 1 and 2), 5-10 feet under water to the intake. Approximately 100 feet of pipe would be extended to the south basin, which would be supported by three stainless steel H-piles. The pipe would be laid 10 feet (elevation 610.0 feet) below the normal lake surface elevation. Fourteen inches of ductile iron pipe would be chosen. A stainless steel screen would be connected at the inlet of the pipe. There are three alternatives for installing the pipe through or around the road to the existing intake: no-dig by pushing through the road and open-cutting at both slope sides, expensive; open-cut the road, inconvenient; and along the edges of the road, a suggested method. The cost analyses of these three methods are presented in table 40.

The proposed new intake point would be located opposite the existing intake tower, and 100 feet off the edge of the shore. The distance from the intake to the causeway opening under the Emerson Airline Road is 200 feet. The length through the road is 150 feet. Therefore, the total length of the 14-inch pipeline would be 650 feet. The portion of 100 feet extended into the lake would be supported by three H-piles (total length is about 90 feet) and would be installed 8-10 feet below the normal water level (elevation 620.0 feet). The main portion of the pipeline would be submerged at 8-10 feet below the surface and laid along on both sides of the road and along the bottom corner of the causeway. Supporting bars (3 feet lengths) with brackets would be installed to keep the pipe in place and would be installed at 10-feet intervals. The estimated cost is $35,700.

The consulting engineers for the ADGPTV Water Commission provided the cost estimations for three alternatives for drawing water from the south basin as shown in table 41.

BENEFITS EXPECTED FROM THE RESTORATION PROJECT

When implemented, the proposed lake restoration program will impart a wide range of water quality and aesthetic improvements to Otter Lake. Benefits expected will contribute directly and indirectly toward accomplishing the restoration objectives presented in the previous

Table 40. Cost Analyses of Three Methods for Relocation of the Intake

Method	*Cost*	*Total*
The no-dig pushing technique		
Pushing	$400/ft x 50 ft = $20,000	
Open cut at both side slopes	$20/cu yd x 180 cu yd = $3,600	
Riprap	$1,500	
Cofferdam, 10 ft diameter	$7,500	
Pumping	$2,500	
Construction cost		$35,100
14-inch ductile iron pipe	$26/ft x 250 ft = $6,500	
Stainless steel screen	$3,600	
Steel H-piles, 3	$100/ft x 90 ft = $9,000	
Support brackets, 3	$800 x 3 = $2,400	
Material cost		$21,500
Total cost		$56,600
All open-cut		
At both side slopes	$3,600	
At road $10/cu yd x 90 cu yd = $1,800		
Riprap	$1,500	
Blacktop	$10/sq ft x 270 sq ft = $2,700	
Cofferdam and pumping	$10,000	
Construction cost		$19,600
Material cost		$21,500
Total cost		$41,100
Submerged along the bank		
14-inch ductile iron pipe	$28/ft x 650 ft = $18,200	
Stainless steel screen	$3,600	
Steel H-piles, 3	$9,000	
Support brackets for H-piles and buoys	$2,400	
Support brackets with 3-ft bar for	$50 x 50= $2,500	
Total cost		$35,700

Table 41. Cost Estimates for Three Alternatives for Drawing Water from the South Basin

Plan	*Project*	*Cost*
Alternative 1	Install an open intake screen and transfer piping to existing intake tower	$383,563
Alternative 2	Install a new intake tower, 3 VT pumps, and transfer piping to existing raw water main	$506,335
Alternative 3	Install a new intake tower, 3 VT pumps, and transfer piping to existing water main at carbon feed building	$647,600

section and are that stabilizing about 69,000 feet of shoreline will reduce sediment loading and prevent further degradation and loss of valuable shoreline. The aesthetic appearance of the lake will be improved after riprap installation. On the basis of 100 percent effective shoreline stabilization, the positive impact of sediment and nutrient inputs to the lake would be reduced from 1,650 tons of sediment per year to 100 tons per year (6 percent of present levels). Nutrient load from the bank erosion also would be reduced to 6 percent of the current levels: total nitrogen from 2.48 to 0.15 tons per year and total phosphorus from 0.83 to 0.05 tons per year.

The on-going watershed management and nonpoint pollution source control are effective measures for reducing sediment and nutrient loading and turbidity entering the lake. These activities will improve the water quality of the upper end of the lake and will reduce atrazine input to the lake. Additional watershed treatment during or after the 1999 season will increase the treatment of targeted acreage from 50 percent to 75 percent in the Otter Lake watershed.

Upgrading the existing destratifier in the north basin and installation of a new destratifier in the south basin will eliminate the anoxic conditions in the hypolimnion, especially during the summer months. Subsequently, it will increase fish habitat; reduce regeneration of phosphorus, nitrogen, manganese, iron, and hydrogen sulfide from the lake bottom; improve raw water quality; and reduce water treatment costs.

Restoration of the boat launch area by dredging (1/3 acre of area with 3,500 cubic yards) and construction of a siltation basin will be beneficial for boating and curtail future sediment load to the lake. In addition, the replacement of the boat docks will increase lake usage, and the boat rental fee can be increased.

Tree cutting and cypress planting will help prevent further erosion of the shoreline and improve the aesthetic conditions of the lake.

If the raw water intake is shifted to the south basin, expected benefits are better raw water quality, possibly lower atrazine concentration (less legal concerns), and reduced cost of water treatment.

LAKE MONITORING SCHEDULE AND BUDGET FOR THE PHASE II PROJECT

Monitoring Program

In order to evaluate the response of Otter Lake to Phase II restoration activities, a monitoring program (one year) will be implemented when the restoration project is in place to document the changes in the lake's water quality. The proposed monitoring program is essentially the same as that conducted under the Phase I study. Samples will be collected by the ADGPTV Water Commission staff and analyzed by the Illinois EPA. The Phase II final report should be provided to the Illinois EPA. The following monitoring schedule will be used in evaluating the effectiveness of the Phase I management technique adopted for the lake.

The lake water will be monitored for DO, temperature, and Secchi disc readings at stations 1, 2, 3, and 4. Observations for DO and temperature will be made at 2-feet intervals commencing from the surface. Water samples for the monitoring program and other necessary field data will be collected by the ADGPTV Water Commission staff.

Water samples for chemical analyses will be taken at these deep stations from two different points: 1 foot below the water surface and 2 feet above the bottom. Analyses will be made for pH, alkalinity (phenolphthalein and total), conductivity, TSS, total and dissolved solids, VSS, turbidity, TP, DP, nitrate/nitrite-nitrogen, ammonia-nitrogen, TKN.

Integrated water samples (integrated to a depth of twice the Secchi disc depth) will be collected at each deep station for determining chlorophyll *a, b, c,* and pheophytin.

Physical and chemical water quality characteristics will be monitored at biweekly intervals from May through September and at monthly intervals from October through April.

Implementation Schedule

The proposed implementation schedule (table 42) is dependent on grant availability for the on-going programs in watershed soil erosion management and nonpoint pollution source control. Eroded shoreline areas can be stabilized immediately with financial assistance from the Illinois EPA.

Upgrading the existing destratifier, restoration of the boat launch area, tree planting, and tree cutting should be carried out in year 1 (1999). Installation of a new destratifier can take place during year 3 (2001). The intake can be relocated when the funds are available.

Budget

If the Phase II study is granted, a total of $300,000 will be available from the Illinois EPA for a six-year period. The ADGPTV Water Commission has to match $300,000, for a total fund of $600,000. The estimated costs for the essential proposed budget for the Phase II restoration and protection program are summarized in table 43.

Sources of Matching Funds

The ADGPTV Water Commission should provide up to $300,000 to use as matching funds for a $300,000 Illinois Clean Lakes Program grant for the restoration of Otter Lake.

Relationship to Other Pollution-Control Programs

The Otter Lake restoration program will be consistent with other pollution-control efforts. The Phase I study has been coordinated with other federal, state, and county agencies and will continue to be coordinated with these agencies through Phase II.

Table 42. Time-line Schedule for Proposed Otter Lake Restoration Projects

Project	1999 (year 1)												2000 (year 2)												2001 (year 3)											
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
Stabilization of eroded shoreline																																				
Severely eroded (5,140 feet)						X	X	X																												
Moderately eroded (33,000 feet)							X	X	X									X	X	X											X	X	X			
Minimally eroded (28,170 feet)									X												X	X										X	X	X		
Upgrading existing destratifier						X	X																													
Restoration of boat launch area						X	X																													
Tree cutting									xxX																											
Cypress planting				X	X												X	X													X	X				
Installation of a new destratifier																																X	X			
Phase II monitoring program																																				
Phase II quarterly report						X			X			X			X			X			X			X			X			X			X			X
Phase II final report																																				

Project	2002 (year 4)												2003 (year 5)												2004 (year 6)											
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
Stabilization of eroded shoreline																																				
Severely eroded (5,140 feet)																																				
Moderately eroded (33,000 feet)					X	X																														
Minimally eroded (28,170 feet)					X	X	X	X																												
Upgrading existing destratifier																																				
Restoration of boat launch area																																				
Tree cutting									X																											
Cypress planting				X	X																															
Installation of a new destratifier																																				
Phase II monitoring program													X	X	X	X	X	X	X	X	X	X	X	X												
Phase II quarterly report			X			X			X			X			X			X			X			X			X			X			X			
Phase II final report preparation																									X	X	X	X	X	X	X	X	X	X	X	X

Table 43. Proposed Budget for Phase II Restoration and Protection Activities

Project	*Estimated budget, $*						
	Year 1 (1999)	*Year 2 (2000)*	*Year 3 (2001)*	*Year 4 (2002)*	*Year 5 (2003)*	*Year 6 (2004)*	*Total*
Stabilization of eroded shoreline							
Severe (>8 feet), 5,139 linear feet	16,950	20,650					37,600
Moderate (3-8 feet), 33,342 linear feet	10,000	100,000	82,000	51,800			243,800
Minimal (<3 feet), 28,168 linear feet	5,000	27,350	6,000	76,200			114,550
Upgrade existing destratifier	3,500						3,500
Dredge and sediment detention pond at boat dock cove	112,550						112,550
Cut trees	1,000	1,000	1,000	1,000			4,000
Plant 300 cypress tree shelters with stakes	1,000	1,000	1,000	1,000			4,000
Install a new destratifier			60,000				60,000
Watershed management	0	0	0	0	0		0
Phase II monitoring program					2,000		2,000
Phase II final report						18,000	18,000
Total	150,000	150,000	150,000	130,000	2,000	18,000	600,000

Note: Blank spaces - no action needed

The primary objective of reducing pollutant (sediment, nutrients, atrazine, etc.) inflow to Otter Lake is consistent with Macoupin County SWCD and NRCS efforts to reduce agricultural soil erosion and thereby lengthen or perpetuate the useful life of the agricultural lands. The efforts of the ADGPTV Water Commission under the proposed implementation program should continue to be coordinated with the watershed land treatment programs of the NRCS.

The Safe Drinking Water Act (SDWA) presents tighter regulations on herbicides, pesticides, turbidity, and trihalomethanes. Improved control of agricultural runoff in this restoration program is consistent with SDWA objectives because this lake also is used for public water supply.

The stormwater runoff water quality from large construction sites is now regulated by the Illinois EPA through the NPDES (National Pollutant Discharge Elimination System) permit process. This program is consistent with the lake restoration program because it protects the lake from large, new erosion sources when development occurs within the watershed.

The restoration program is consistent with the IDNR initiatives to restore healthy fish populations to Illinois lakes. The IDNR has been actively involved in fisheries management at Otter Lake, including activities such as monitoring, surveying fish populations, fish stocking, and controlling algae and aquatic vegetation growth.

The staff of the ADGPTV Water Commission has been monitoring Otter Lake as part of the Illinois EPA's VLMP. Also, staff from the Illinois EPA has monitored Otter Lake as part of the EPA's Ambient Lake Monitoring Program. The Phase II restoration project is consistent with the EPA's Illinois' Nonpoint Source Management Program.

Public Participation Summary

Public notification was accomplished through the installation of signs at the boat launch ramp indicating that the Illinois EPA and the ADGPTV Water Commission were cooperating in conducting the Phase I Diagnostic Study of Otter Lake.

Other information was disseminated to the public through a series of newspaper articles *(Girard Gazette,* 4/17/96, 6/4/96; *Gillespie News,* 7/4/96; *Virden Recorder,* 9/18/97; *Divernon News,* 10/15/98, etc.) concerning monitoring activities at the lake, activities of the OLEPC, and shoreline management activities.

Operation and Maintenance Plan

If awarded a Phase II Illinois Clean Lakes Program grant, the ADGPTV Water Commission, as the owner of the lake, will be responsible for the operation and maintenance of all facilities located within Otter Lake Park and watershed, such as boat docks, dredging, shoreline stabilization, sediment detention sites, destratifiers, plant's intake, and watershed land treatment practices. In addition, fisheries management would be carried out in cooperation with the IDNR. The maintenance requirements will be written into the annual schedule of work prepared by the ADGPTV Water Commission and assigned to various employees as scheduled.

The ADGPTV Water Commission will be responsible for all costs associated with maintaining lake restoration facilities. Maintenance costs are expected to be less than $1,000 per year.

Necessary Permits

The removal of sediment would require a Section 404 dredge-and-fill permit from the U.S. Army Corps of Engineers; a Section 401 Water Quality Certification from the Illinois EPA for discharging the clarified effluent water back to the lake; and a construction and operating permit, also from the Illinois EPA. A dam construction and an operating permit from the Illinois Department of Transportation (IDOT) also will be required for the sediment basin. Construction of shoreline stabilization work may require a Section 404 Permit from the U.S. Army Corps of Engineers, which could be covered under the 404 Permit required for sediment removal. Both items can be considered under a single permit. In addition, approval must be granted from the Illinois Historic Preservation Agency prior to constructing the sediment retention site to ensure that no significant archaeological resources are present. Coordination and consultation with IDOT, the Illinois EPA, and the U.S. Fish and Wildlife Service also may be necessary. The permit application process will be initiated immediately upon approval of either the Phase I report or the implementation of Phase II restoration activities.

EVALUATION OF ENVIRONMENTAL IMPACTS

This section covers some of the environmental impacts of the proposed Phase II restoration project. The Clean Lakes Program requires that the following questions be addressed.

Will the project displace people?

The project will not displace people or places of business because all project-related activities occur in the lake area.

Will the project deface residential areas?

The project will have no adverse visual impacts on residential areas near the lake. In any case, the ripraping construction will be conducted on a barge not from the bank.

Will the project entail changes in land-use patterns or increases in development pressure?

No land-use pattern will be affected. There will be no increase in development pressure. Demand for further residential and campsite areas may intensify due to overall improvement as a result of the restoration project.

Will the project impact prime agricultural land or activities?

No agricultural land is affected by the project. Soil conservation measures applied in the watershed will help maintain soil fertility and erosion control on agricultural lands.

Will the project adversely affect park, public, or scenic land?

Almost all of the land around Otter Lake shoreline is publicly owned by the ADGPTV Water Commission. Lake restoration will provide long-term enhancement of the environmental, aesthetic, and recreational values in the general area.

Will there be adverse impacts to historical, architectural, archaeological, or cultural resources?

There are no known lands or structures of historical, architectural, archaeological, or cultural significance in the project area.

Will the project entail long-range increases in energy demand?

After the major components of the restoration scheme are implemented, there will be no activity requiring excessive energy use in the operation and maintenance of the lake system.

Are changes in ambient air quality or noise levels expected?

No significant long-term impact on air quality and noise levels is anticipated as a result of implementing the restoration project. Elevated noise levels are expected during work at the construction site or ripraping only.

Will there be any adverse effects due to chemical treatment?

No chemical treatment is included in the restoration project.

Does the management plan comply with Executive Order (E.O.) 11988 on floodplain management?

The restoration of Otter Lake does not involve any activities in floodplains and consequently does not infringe on E.O. 11988.

If the project involves physically modifying the lakeshore, its bed, or its watershed, will the project cause any short-term or long-term adverse impacts?

Dredging of Otter Lake is not a part of the proposed restoration. No long-term adverse impacts will result from project activities. Shoreline erosion-control practices involve installation of structural practices such as riprap. There may be short-term impacts as a result of such activities.

Are there any adverse effects on fish and wildlife, wetlands, or other wildlife habitat?

No significant adverse effects on fish and wildlife, wetlands, or other wildlife habitat will occur as a result of this project.

Will the project adversely impact threatened or endangered species?

No threatened or endangered plants or wildlife species will be affected by this project.

Have all the feasible alternatives been considered?

All the relevant and applicable management options were considered and discussed, and appropriate suggestions and recommendations have been made.

Are other mitigative measures required?

The pros and cons of various alternatives have been considered, and the need for no other mitigative measure should arise.

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Appendix. Ambient Lake Monitoring Data for Otter Lake

Abbreviations: NTU - nephelometric turbidity unit
$CaCO_3$ - calcium carbonate
blank spaces - no data

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	06/21/77	0		46		8.1	107		5	*2*	0.10		0.00	0.020		
RD-A06-F-1	05/22/79	1	22.0	18	330	7.8	90	0	15	3	0.02	0.7	1.70	0.080	0.040	
RD-A06-F-1	05/22/79	3														
RD-A06-F-1	05/22/79	42	38.0			6.7	40	0	23	4	0.04	1.0	1.40	0.130	0.060	
RD-A06-F-1	06/12/79	1	8.5	30		8.4	50	0	11	2	0.01	0.7	1.50	0.020	0.010	48.0
RD-A06-F-1	06/12/79	5			285											
RD-A06-F-1	06/12/79	46	27.0			6.6	40	0	10	2	0.06	0.6	1.30	0.070	0.040	
RD-A06-F-1	07/30/79	1	5.6	26	246	9.0	64	15	7	2	0.01	1.2	0.37	0.030	0.010	49.0
RD-A06-F-1	07/30/79	4			260											
RD-A06-F-1	07/30/79	47	44.0			6.2	87	0	39	5	0.73	1.6	0.30	0.120	0.020	
RD-A06-F-1	08/16/79	1	5.7	24	340	9.0	59	9	11	5	0.01	1.2	0.01	0.040	0.010	43.0
RD-A06-F-1	08/16/79	4			240											
RD-A06-F-1	08/16/79	41	19.0			6.9	90	0	21	8	0.62	1.3	0.48	0.070	0.040	
RD-A06-F-1	09/25/79	1	3.0	72	300	8.1	80	0	6	3	0.02	0.8	0.01	0.020	0.020	40.0
RD-A06-F-1	09/25/79	12			250											
RD-A06-F-1	09/25/79	38	9.0			6.9	120	0	10	2	0.92	1.4	0.03	0.040	0.020	
RD-A06-F-1	10/26/79	1	2.6	48	300	7.0	80	0	5		0.16	0.7	0.18	0.020	0.020	47.0
RD-A06-F-1	10/26/79	8			255											
RD-A06-F-1	10/26/79	45	4.4			7.1	80	0	9	3	0.19	0.7	0.21	0.040	0.010	
RD-A06-F-1	06/24/80	0			272	8.7										
RD-A06-F-1	06/24/80	1	1.5	76	130	8.7	100	12	12	2	0.10	0.6	0.30	0.010	0.010	43.0
RD-A06-F-1	06/24/80	3			216	8.7										
RD-A06-F-1	06/24/80	5			135	8.8										
RD-A06-F-1	06/24/80	7			139	8.7										
RD-A06-F-1	06/24/80	9			143	8.7										
RD-A06-F-1	06/24/80	11			173	8.7										
RD-A06-F-1	06/24/80	13			210	8.7										
RD-A06-F-1	06/24/80	15			248	8.5										
RD-A06-F-1	06/24/80	17			268	8.2										
RD-A06-F-1	06/24/80	19			277	7.7										

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	06/24/80	21			282	7.5										
RD-A06-F-1	06/24/80	23			281	7.6										
RD-A06-F-1	06/24/80	25			282	7.7										
RD-A06-F-1	06/24/80	27			281	7.7										
RD-A06-F-1	06/24/80	29			280	7.8										
RD-A06-F-1	06/24/80	31			281	7.7										
RD-A06-F-1	06/24/80	33			283	7.8										
RD-A06-F-1	06/24/80	35			286	7.8										
RD-A06-F-1	06/24/80	37			285	7.7										
RD-A06-F-1	06/24/80	39			286	7.8										
RD-A06-F-1	06/24/80	41	6.0		288	7.8	102	0	11	4	0.50	1.0	0.20	0.020	0.010	
RD-A06-F-1	09/02/80	1	5.0	30	285	8.4	90	0	6	2	0.01	1.0	0.01	0.040	0.002	43.0
RD-A06-F-1	09/02/80	5			312											
RD-A06-F-1	09/02/80	41	6.0			6.7	130	0	11	5	1.05	1.8	0.00	0.130	0.120	
RD-A06-F-1	05/24/82	1	2.1	54	355	8.4	94	38	2	1	0.02	0.6	1.62	0.010	0.007	41.0
RD-A06-F-1	05/24/82	9			132											
RD-A06-F-1	05/24/82	39	2.4			7.1	108	0	3	1	0.05	0.8	1.56	0.018	0.010	
RD-A06-F-1	08/09/82	1	3.2	42	285	8.3	90	20	4	3	0.10	0.8	13.00	0.025	0.015	42.0
RD-A06-F-1	08/09/82	7			290											
RD-A06-F-1	08/09/82	40	4.1			7.2	125	0	3	1	1.20	1.7	0.26	0.038	0.017	
RD-A06-F-1	05/17/84	1	11.0	24	302	7.7	85	0	3	0	0.03	0.6	2.90	0.045	0.020	51.5
RD-A06-F-1	05/17/84	4			298											
RD-A06-F-1	05/17/84	49	26.0			6.7	98	0	17	0	0.03	0.8	2.50	0.075	0.023	
RD-A06-F-1	08/17/84	1	1.5	78	308	8.6	80	20	4	2	0.04	0.3	0.05	0.001	0.001	51.0
RD-A06-F-1	08/17/84	13			277											
RD-A06-F-1	08/17/84	49	1.4			6.7	130	0	4	3	0.03	0.5	2.00	0.001	0.001	
RD-A06-F-1	04/18/89	1	3.6	48	361	7.9	130	0	4	2	0.11	0.9	0.38	0.012	0.001	46.0
RD-A06-F-1	04/18/89	8			337											
RD-A06-F-1	04/18/89	44	2.5			7.2	120	0	3	1	0.18	0.9	0.38	0.010	0.001	46.0
RD-A06-F-1	04/18/89	46			338											

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	06/07/89	1	0.8	94		8.4	120	10	1	1	0.10	0.6	0.20	0.013	0.001	46.5
RD-A06-F-1	06/07/89	16			343											
RD-A06-F-1	06/07/89	45	12.0			7.6	130	0	10	4	1.20	1.6	0.10	0.109	0.001	46.5
RD-A06-F-1	07/14/89	1	3.7	66	355	8.5	95	5	2	1	0.10	0.7	0.10	0.021	0.001	42.5
RD-A06-F-1	07/14/89	11			324											
RD-A06-F-1	07/14/89	41	12.0			6.9	125	0	4	2	1.60	2.1	0.10	0.144	0.126	42.5
RD-A06-F-1	08/17/89	1	4.6	36	368	8.4	100	5	6	3	0.09	1.0	0.10	0.006	0.001	47.0
RD-A06-F-1	08/17/89	6			313											
RD-A06-F-1	08/17/89	45	25.0			6.9	162	0	66	21	2.50	3.8	0.10	0.532	0.360	47.0
RD-A06-F-1	10/13/89	1	0.2	56	395	8.6	105	1	3	1	0.11	0.6	0.10	0.024	0.011	50.0
RD-A06-F-1	10/13/89	9			335											
RD-A06-F-1	10/13/89	48	8.2			6.9	170	0	32	10	2.90	3.6	0.10	0.330	0.280	50.0
RD-A06-F-1	04/25/91	1	1.5	36	406	9.1	95	10	5	2	0.01	1.0	2.40	0.161	0.106	45.0
RD-A06-F-1	04/25/91	6			317											
RD-A06-F-1	04/25/91	43	3.2			7.6	105	0	3	2	0.20	1.0	2.00	0.101	0.090	45.0
RD-A06-F-1	04/25/91	45			224											
RD-A06-F-1	06/10/91	1	2.3	54		8.4	100	10	1	1	0.02	0.6	2.30	0.023	0.013	46.0
RD-A06-F-1	06/10/91	9			329											
RD-A06-F-1	06/10/91	44	2.7			6.8	120	0	11	3	0.79	1.4	1.10	0.109	0.042	46.0
RD-A06-F-1	07/05/91	1	1.1	72	341	8.8	100	0	2	1	0.06	0.7	2.30	0.034	0.001	47.0
RD-A06-F-1	07/05/91	12			328											
RD-A06-F-1	07/05/91	45	4.7			7.4	120	0	10	2	1.30	2.1	0.39	0.101	0.023	47.0
RD-A06-F-1	08/14/91	1	5.2	20	356	9.0	80	0	5	4	0.01	1.3	0.90	0.021	0.012	46.0
RD-A06-F-1	08/14/91	4			287											
RD-A06-F-1	08/14/91	44	22.0			7.1	140	0	14	4	2.20	3.1	0.01	0.256	0.199	46.0
RD-A06-F-1	10/07/91	1	2.6	48	377	7.8	100	0	5	3	0.19	0.9	0.18	0.023	0.012	41.0
RD-A06-F-1	10/07/91	8			305											
RD-A06-F-1	10/07/91	39	20.0			6.9	150	0	30	8	2.70	3.4	0.01	0.196	0.148	41.0
RD-A06-F-1	04/21/94	1	2.2	18	373	7.9	100	0	28	6	0.03	1.1	1.97	0.145	0.038	40.0
RD-A06-F-1	04/21/94	3			353											

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	04/21/94	38	7.9			7.4	95	0	26	6	0.20	1.2	1.94	0.084	0.037	40.0
RD-A06-F-1	06/13/94	1	4.2	44	333	7.9	90	0	10	5	0.04	0.8	1.97	0.020	0.004	46.5
RD-A06-F-1	06/13/94	45	3.1		325	6.9	105	0	17	4	0.40	1.0	1.57	0.053	0.029	46.5
RD-A06-F-1	07/11/94	1	3.0	84	375	8.4	100	0	5	2	0.04	0.3	1.78	0.014	0.002	46.0
RD-A06-F-1	07/11/94	44	8.4		326	7.1	120	0	46	10	1.40	2.2	0.12	0.380	0.175	46.0
RD-A06-F-1	07/11/94	46			414											
RD-A06-F-1	08/02/94	1	3.9	72		8.5	110	5	4	2	0.01	0.7	1.42	0.013	0.001	51.0
RD-A06-F-1	08/02/94	12			325											
RD-A06-F-1	08/02/94	49	4.5			7.0	140	0	27	6	2.10	2.5	0.03	0.544	0.431	51.0
RD-A06-F-1	10/13/94	1	3.7	66	443	7.9	100	0	3	1	0.09	0.7	0.24	0.023	0.003	45.5
RD-A06-F-1	10/13/94	11			324											
RD-A06-F-1	10/13/94	44	17.0			6.9	155	0	17	5	2.00	2.5	0.02	0.204	0.153	45.5
RD-A06-F-1	04/11/96	1	3.9	64	403	7.7	125	0	6	2	0.07	0.8	0.35	0.018	0.006	46.0
RD-A06-F-1	04/11/96	11			327											
RD-A06-F-1	04/11/96	44	2.7			7.7	120	0	6	2	0.07	0.6	0.38	0.016	0.004	46.0
RD-A06-F-1	04/17/96	1	3.3	58	315	7.9	125		4	1	0.21	1.3	0.40	0.019	0.001	44.0
RD-A06-F-1	04/17/96	9			332											
RD-A06-F-1	04/17/96	22	5.8	58		7.9	118		10	3	0.01	1.2	0.40	0.026	0.002	42.0
RD-A06-F-1	04/17/96	42	5.6	58	332	7.8	117		7	3	0.01	1.2	0.38	0.025	0.004	44.0
RD-A06-F-1	05/09/96	1	6.6	42	333	7.8			8	2	0.41	1.1	0.43	0.029	0.013	49.0
RD-A06-F-1	05/09/96	7			325											
RD-A06-F-1	05/09/96	24	5.7	42		7.6			4	1	0.14	0.9	0.65	0.029	0.013	49.0
RD-A06-F-1	05/09/96	46	6.8	42	328	7.3			6	2	0.06	0.8	0.63	0.029	0.007	49.0
RD-A06-F-1	05/22/96	1	7.6	24	336	8.2			7	2	0.02	0.7	1.69	0.015	0.015	48.0
RD-A06-F-1	05/22/96	24	9.2	24	304	7.4			12	2	0.19	0.7	1.17	0.047	0.030	48.0
RD-A06-F-1	05/22/96	46	13.0	24	319	7.2			10	1	0.53	0.7	0.44	0.040	0.020	48.0
RD-A06-F-1	06/05/96	1	25.0	58	330	7.4	120	0	9	3	0.03	0.6	1.87	0.036	0.007	45.0
RD-A06-F-1	06/05/96	10			327											
RD-A06-F-1	06/05/96	43	28.0			7.1	130	0	12	3	0.23	0.6	0.77			45.0
RD-A06-F-1	06/17/96	1	3.3	38	329	8.5			21	6	0.01	0.5	1.84	0.025	0.006	47.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity Total (mg/L as $CaCO_3$)	Alkalinity Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids Total (mg/L)	Suspended solids Volatile (mg/L)	Nitrogen Ammonia (mg/L)	Nitrogen Total Kjehldahl (mg/L)	Nitrogen Nitrate/nitrite (mg/L)	Phosphorus Total (mg/L)	Phosphorus Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	06/17/96	6			299											
RD-A06-F-1	06/17/96	30	12.0	38		7.1			11	2	0.01	0.3	1.09	0.024	0.009	47.0
RD-A06-F-1	06/17/96	45	38.0	38	331	7.1			35	8	1.00	1.4	0.12	0.169	0.042	47.0
RD-A06-F-1	07/03/96	1	1.6	54	350	8.8	110	10	4	2	0.04	0.6	2.10	0.012	0.002	47.0
RD-A06-F-1	07/03/96	45	17.0		321	7.3	130	0	17	5	1.10	1.4	0.18	0.144	0.048	47.0
RD-A06-F-1	07/03/96	47			347											
RD-A06-F-1	07/15/96	1		53		8.5			4	2	0.01	0.9	1.78	0.020	0.005	47.0
RD-A06-F-1	07/15/96	9			296											
RD-A06-F-1	07/15/96	32		53		7.2			10	3	0.30	1.0	0.45	0.027	0.006	47.0
RD-A06-F-1	07/15/96	44		53	338	7.1			74	16	0.32	2.7	0.01	0.499	0.349	47.0
RD-A06-F-1	08/15/96	1	5.7	36	359	8.6	80	10	4	1	0.01	0.7	0.75	0.022	0.004	45.0
RD-A06-F-1	08/15/96	6			289											
RD-A06-F-1	08/15/96	43	28.0			7.0	150	0	40	12	1.40	1.7	0.01	0.270	0.227	45.0
RD-A06-F-1	08/19/96	1	8.1	31	362	8.8			10	5	0.01	0.7	0.62	0.023	0.003	46.0
RD-A06-F-1	08/19/96	5			274											
RD-A06-F-1	08/19/96	30	34.0	31		7.3			7	3	0.28	0.8	0.01	0.019	0.005	46.0
RD-A06-F-1	08/19/96	44	34.0	31	355	7.1			66	16	1.80	2.5	0.02	0.492	0.412	46.0
RD-A06-F-1	08/19/96	46			386											
RD-A06-F-1	09/09/96	30	20.0	48		7.7			26	16	0.27	1.0	0.06	0.090	0.018	48.0
RD-A06-F-1	09/09/96	1	21.0	48	352	8.2			36	12	0.34	1.2	0.06	0.123	0.025	48.0
RD-A06-F-1	09/09/96	46	19.0	48	257	7.0			44	18	0.08	1.3	0.01	0.112	0.018	48.0
RD-A06-F-1	09/24/96	1	2.8	42	385	8.3			6	5	0.05	1.4	0.08	0.023	0.003	52.0
RD-A06-F-1	09/24/96	34	5.7	42	275	7.1			12	6	1.10	1.4	0.02	0.073	0.041	52.0
RD-A06-F-1	09/24/96	44	6.1	42	357	7.0			46	14	2.50	2.2	0.03	0.463	0.404	52.0
RD-A06-F-1	10/02/96	1	5.3	5	379	8.3	110	0	5	2	0.07	0.6	0.06	0.020	0.004	47.0
RD-A06-F-1	10/02/96	9			305											
RD-A06-F-1	10/02/96	45	15.0			7.2	160	0	36	26	2.50	4.4	0.01	0.384	0.322	47.0
RD-A06-F-1	11/20/96	1	4.6	48	400	7.8	120		7	4	0.56	1.1	0.15	0.018	0.007	47.0
RD-A06-F-1	11/20/96	8			296											
RD-A06-F-1	11/20/96	23	5.1			7.7	115		6	3	0.64	1.0	0.15	0.024	0.007	47.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	11/20/96	45	4.3		*291*	7.7	119		8	5	0.58	1.0	0.14	0.023	0.002	47.0
RD-A06-F-1	01/23/97	1	2.5	117	297	8.0	95		2	1	0.12	0.5	0.22	0.005	0.002	47.0
RD-A06-F-1	01/23/97	19			210											
RD-A06-F-1	01/23/97	23	2.0	117		7.8	172		2	1	0.22	0.7	0.31	0.009	0.002	47.0
RD-A06-F-1	01/23/97	47			308											
RD-A06-F-1	01/23/97	45	3.1	117		7.7	180		4	1	0.22	0.7	0.31	0.008	0.002	47.0
RD-A06-F-1	02/11/97	1	3.5	88	309	8.0	125		10	2	0.12	0.3	9.10	0.079	0.065	41.0
RD-A06-F-1	02/11/97	15			269											
RD-A06-F-1	02/11/97	39	3.7	88		7.7	107		5	4	0.30	1.0	0.28	0.040	0.015	41.0
RD-A06-F-1	02/11/97	20	2.9	88	320	7.7	110		7	4	0.27	0.8	0.28	0.041	0.015	41.0
RD-A06-F-1	03/19/97	1	9.5	54	319	7.8	123		5	1	0.15	0.9	0.44	0.019	0.005	51.0
RD-A06-F-1	03/19/97	9			301											
RD-A06-F-1	03/19/97	27	8.3			7.8	119		9	4	0.16	0.8	0.49	0.023	0.060	51.0
RD-A06-F-1	03/19/97	49	7.9		301	7.8	122		11	1	0.17	0.8	0.53	0.024	0.004	51.0
RD-A06-F-1	04/18/97	1	9.5	66	301	7.9	105	0	5	4	0.09	0.7	0.73	0.017	0.003	51.0
RD-A06-F-1	04/18/97	11			320											
RD-A06-F-1	04/18/97	49	11.0			7.5	90	0	16	5	0.24	1.0	0.68	0.030	0.006	51.0
RD-A06-F-1	05/13/97	1	3.5	74	323	8.0			6	2	0.10	0.5	0.85	0.014	0.010	46.0
RD-A06-F-1	05/13/97	12			302											
RD-A06-F-1	05/13/97	24	2.7	74		8.0			8	2	0.08	0.6	0.85	0.015	0.006	46.0
RD-A06-F-1	05/13/97	44	3.9	74	303	7.4			11	3	0.33	0.8	0.65	0.024	0.011	46.0
RD-A06-F-1	06/06/97	1	6.1	90	309	7.9	104	0	6	2	0.08	0.8	0.82	0.016	0.006	46.0
RD-A06-F-1	06/06/97	15			335											
RD-A06-F-1	06/06/97	44	25.0			7.0	110	0	17	4	0.57	1.4	0.52	0.058	0.016	46.0
RD-A06-F-1	07/09/97	1	5.8	46	346	8.4	110	12	8	5	0.16	0.8	0.19	0.029	0.006	47.0
RD-A06-F-1	07/09/97	45	25.0		300	7.1	126	0	5	2	1.40	1.8	0.01	0.115	0.095	47.0
RD-A06-F-1	07/09/97	47			358											
RD-A06-F-1	08/08/97	1	1.1	40		8.2	114	8	8	4	0.21	0.4	0.01	0.027	0.004	49.0
RD-A06-F-1	08/08/97	47	7.1		308	7.0	160	0	38	12	2.70	2.9	0.01	0.268	0.225	49.0
RD-A06-F-1	10/03/97	1	6.7	48	364	7.9	100	0	5	2	0.30	0.5	0.01	0.017	0.005	46.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	10/03/97	44	7.8		323	7.0	100	0	6	3	0.30	0.3	0.01	0.020	0.006	46.0
RD-A06-F-2	06/21/77	0		44	390	7.6	106		6	4	0.00		0.00	0.020		
RD-A06-F-2	05/22/79	1	23.0	14	350	7.8	90	0	12	3	0.04	0.7	2.70	0.100	0.050	34.5
RD-A06-F-2	05/22/79	32	66.0			6.9	60	0	60	6	0.04	0.9	1.50	0.170	0.050	
RD-A06-F-2	06/12/79	1	6.4	24		8.5	40	40	9	1	0.02	0.9	1.60	0.040	0.010	30.0
RD-A06-F-2	06/12/79	4			275											
RD-A06-F-2	06/12/79	28	33.0			6.7	60	0	14	1	0.04	0.6	1.80	0.090	0.030	
RD-A06-F-2	07/30/79	1	9.0	24	287	9.1	60	14	10	3	0.01	1.4	0.21	0.030	0.010	30.5
RD-A06-F-2	07/30/79	4			260											
RD-A06-F-2	07/30/79	28	23.0			6.8	100	0	26	4	0.65	1.7	0.46	0.080	0.020	
RD-A06-F-2	08/16/79	1	5.3	24	350	8.6	64	0	7	4	0.01	1.3	0.03	0.040	0.010	30.0
RD-A06-F-2	08/16/79	4			240											
RD-A06-F-2	08/16/79	28	8.3			7.5	90	0	13	6	0.44	1.1	0.28	0.040	0.010	
RD-A06-F-2	09/25/79	1	3.3	60	300	8.0	90	0	6	3	0.01	0.7	0.03	0.030	0.010	30.0
RD-A06-F-2	09/25/79	10			250											
RD-A06-F-2	09/25/79	28	25.0			6.8	140	0	32	8	1.50	2.4	0.01	0.220	0.050	
RD-A06-F-2	10/26/79	1	4.4	33	320	7.3	75	0	9	2	0.21	0.8	0.32	0.030	0.010	32.5
RD-A06-F-2	10/26/79	5			257											
RD-A06-F-2	10/26/79	30	3.2			7.3	90	0	4		0.17	0.7	0.26	0.030	0.020	
RD-A06-F-2	06/24/80	0			258	8.7										
RD-A06-F-2	06/24/80	1	2.0	67	137	8.7	100	4	1	0	0.10	0.6	0.30	0.030		30.0
RD-A06-F-2	06/24/80	3			140	8.7										
RD-A06-F-2	06/24/80	5			149	8.7										
RD-A06-F-2	06/24/80	7			218	8.7										
RD-A06-F-2	06/24/80	9			287	8.6										
RD-A06-F-2	06/24/80	11			290	8.6										
RD-A06-F-2	06/24/80	13			290	8.6										
RD-A06-F-2	06/24/80	15			290	8.4										
RD-A06-F-2	06/24/80	17			293	8.2										
RD-A06-F-2	06/24/80	19			293	7.9										

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	06/24/80	21			295	7.7										
RD-A06-F-2	06/24/80	23			295	7.6										
RD-A06-F-2	06/24/80	25			292	7.7										
RD-A06-F-2	06/24/80	27			298	7.7										
RD-A06-F-2	06/24/80	28	11.0		315	7.8	107	0	18	5	0.50	1.0	0.10	0.070	0.010	
RD-A06-F-2	06/24/80	29			300	7.8										
RD-A06-F-2	06/24/80	30			300	7.8										
RD-A06-F-2	09/02/80	1	4.0	28	300	8.2	90	10	4	1	0.01	0.9	0.00	0.020	0.002	30.0
RD-A06-F-2	09/02/80	4			280											
RD-A06-F-2	09/02/80	28	18.0			6.8	130	0	19	3	1.20	2.0	0.00	0.250	0.200	
RD-A06-F-2	05/24/82	1	2.4	48	340	8.3	98	24	4	1	0.02	0.6	1.92	0.018	0.007	29.0
RD-A06-F-2	08/09/82	1	3.7	30	284	8.3	90	20	5	4	0.11	0.8	13.00	0.029	0.015	29.5
RD-A06-F-2	08/09/82	5			271											
RD-A06-F-2	05/17/84	1	25.0	16		7.4	88	0	1	0	0.03	0.6	3.40	0.078	0.045	35.5
RD-A06-F-2	05/17/84	2			288											
RD-A06-F-2	08/17/84	1	27.0	54		8.6	80	20	45	38	1.10	1.8	0.30	0.259	0.178	29.0
RD-A06-F-2	08/17/84	9			275											
RD-A06-F-2	04/18/89	1	3.5	38		8.2	120	0	5	2	0.13	0.8	0.42	0.016	0.001	28.0
RD-A06-F-2	04/18/89	6			336											
RD-A06-F-2	06/07/89	1	0.9	114		8.3	120	10	1	1	0.15	0.7	0.21	0.024	0.001	30.0
RD-A06-F-2	06/07/89	19			339											
RD-A06-F-2	07/14/89	1	2.9	54		8.5	105	5	4	2	0.14	0.3	0.10	0.021	0.001	30.5
RD-A06-F-2	07/14/89	9			324											
RD-A06-F-2	08/17/89	1	4.3	28		8.5	100	5	7	4	0.10	1.1	0.10	0.024	0.009	32.0
RD-A06-F-2	08/17/89	5			310											
RD-A06-F-2	10/13/89	1	1.3	66		8.1	110	0	3	1	0.17	0.6	0.10	0.031	0.010	29.0
RD-A06-F-2	10/13/89	11			331											
RD-A06-F-2	04/25/91	1	1.4	36		8.9	100	15	5	3	0.01	1.0	2.50	0.115	0.095	30.5
RD-A06-F-2	04/25/91	6			314											
RD-A06-F-2	06/10/91	1	0.1	54		8.3	100	10	4	2	0.04	0.6	2.60	0.018	0.006	30.0

							Alkalinity		Suspended solids		Nitrogen			Phosphorus		
Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Total (mg/L as $CaCO_3$)	Phenolph-thalein (mg/L as $CaCO_3$)	Total (mg/L)	Volatile (mg/L)	Ammonia (mg/L)	Total Kjehldahl (mg/L)	Nitrate/ nitrite (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	06/10/91	9			331											
RD-A06-F-2	07/05/91	1	2.0	60		8.7	100	10	3	1	0.04	0.8	2.20	0.019	0.006	30.0
RD-A06-F-2	07/05/91	10			334											
RD-A06-F-2	08/14/91	1	5.0	22		9.1	90	10	5	4	0.05	1.4	0.87	0.024	0.008	29.0
RD-A06-F-2	08/14/91	4			288											
RD-A06-F-2	10/07/91	1	3.3	40		8.0	90	0	6	4	0.20	0.8	0.17	0.039	0.013	29.0
RD-A06-F-2	10/07/91	7			305											
RD-A06-F-2	04/21/94	1	16.0	8		7.3	90	0	28	6	0.17	1.3	2.40	0.140	0.065	32.5
RD-A06-F-2	06/13/94	1	2.9	42	317	8.2	90	0	14	7	0.02	1.1	2.10	0.019	0.004	30.0
RD-A06-F-2	07/11/94	1	5.5	60	326	8.4	100	0	4	2	0.05	1.0	1.76	0.017	0.003	31.0
RD-A06-F-2	08/02/94	1	3.3	64	330	8.6	110	10	4	2	0.01	0.8	1.34	0.018	0.002	30.0
RD-A06-F-2	08/02/94	11			326											
RD-A06-F-2	10/13/94	1	2.9	66		7.7	100	0	2	1	0.15	0.8	0.22	0.028	0.002	30.5
RD-A06-F-2	10/13/94	11			332											
RD-A06-F-2	04/11/96	1	3.7	54		7.8	120	0	6	2	0.04	0.9	0.37	0.024	0.014	30.5
RD-A06-F-2	04/11/96	9			329											
RD-A06-F-2	04/17/96	1	5.9	24		8.3	113		22	6	0.01	1.4	1.16	0.063	0.015	25.0
RD-A06-F-2	04/17/96	4			350											
RD-A06-F-2	04/17/96	23	6.3	24		8.0	117		26	6	0.01	1.6	1.12	0.077	0.007	25.0
RD-A06-F-2	05/09/96	1	12.0	15	354	7.6			15	4	0.18	1.0	1.83	0.075	0.045	31.0
RD-A06-F-2	05/09/96	2			324											
RD-A06-F-2	05/09/96	29	9.8	15		7.4			21	4	0.24	1.2	1.75	0.106	0.048	31.0
RD-A06-F-2	05/22/96	1	18.0	24	328	8.0			12	3	0.07	0.7	1.92	0.064	0.027	31.0
RD-A06-F-2	05/22/96	29	12.0	24	304	7.3			12	2	0.32	0.6	0.88	0.049	0.026	31.0
RD-A06-F-2	06/05/96	1	31.0	36	326	7.6	110	0	12	2	0.01	0.5	2.50	0.048	0.008	31.0
RD-A06-F-2	06/05/96	6			320											
RD-A06-F-2	06/17/96	1	6.1	38		8.8			12	5	0.01	0.4	1.06	0.030	0.006	31.0
RD-A06-F-2	06/17/96	6			289											
RD-A06-F-2	06/17/96	29	24.0	38		7.2			21	4	0.10	0.5	1.06	0.068	0.034	31.0
RD-A06-F-2	07/03/96	1	4.1	48	338	8.8	110	10	9	6	0.04	0.5	2.20	0.015	0.002	30.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	07/03/96	8			317											
RD-A06-F-2	07/15/96	1		48		8.5			8	5	0.03	0.8	1.89	0.026	0.005	31.0
RD-A06-F-2	07/15/96	8			296											
RD-A06-F-2	07/15/96	29		48		7.1			36	6	0.28	0.9	0.79	0.060	0.007	31.0
RD-A06-F-2	08/15/96	1	7.9	36	334	8.8	100	10	13	6	0.01	0.8	0.70	0.023	0.003	31.0
RD-A06-F-2	08/15/96	6			292											
RD-A06-F-2	08/19/96	1	2.1	32		9.0			9	6	0.01	0.9	0.68	0.025	0.003	30.0
RD-A06-F-2	08/19/96	5			275											
RD-A06-F-2	08/19/96	28	8.3	32		7.3			20	8	0.52	1.1	0.01	0.096	0.044	30.0
RD-A06-F-2	08/19/96	30			366											
RD-A06-F-2	09/09/96	1	24.0	34		8.6			34	12	1.00	1.6	0.01	0.105	0.071	30.0
RD-A06-F-2	09/09/96	5			254											
RD-A06-F-2	09/09/96	28	2.3	34		7.2			10	7	0.18	1.1	0.08	0.035	0.006	30.0
RD-A06-F-2	09/24/96	1	3.0	39	356	8.2			10	7	0.01	0.9	0.06	0.034	0.007	30.0
RD-A06-F-2	09/24/96	28	6.4	39	277	7.1			18	6	1.00	1.8	0.02	0.062	0.020	30.0
RD-A06-F-2	10/02/96	1	5.5	4	362	8.5	100	0	6	2	0.07	0.8	0.06	0.031	0.004	29.0
RD-A06-F-2	10/02/96	8			304											
RD-A06-F-2	11/20/96	1	4.5	42		7.9	120		9	5	0.49	1.0	0.16	0.029	0.010	29.0
RD-A06-F-2	11/20/96	7			296											
RD-A06-F-2	11/20/96	27	4.2			7.7	119		9	5	0.48	1.0	0.16	0.036	0.009	29.0
RD-A06-F-2	01/23/97	1	2.7	117	296	8.2	128		1	1	0.19	0.6	0.30	0.010	0.002	29.0
RD-A06-F-2	01/23/97	19			210											
RD-A06-F-2	01/23/97	29														
RD-A06-F-2	01/23/97	27 '	2.2	117		7.7	162		2	1	0.20	0.6	0.33	0.013	0.005	29.0
RD-A06-F-2	02/11/97	1	3.6	85	309	8.0	85		30	6	0.26	1.3	3.20	0.326	0.254	30.0
RD-A06-F-2	02/11/97	14			308											
RD-A06-F-2	02/11/97	28	2.9	85		7.7	103		6	2	0.26	0.8	0.32	0.023	0.004	30.0
RD-A06-F-2	03/19/97	1	15.0	44	321	7.8			12	3	0.16	0.9	0.92	0.038	0.011	31.0
RD-A06-F-2	03/19/97	7			302											
RD-A06-F-2	03/19/97	29	8.7	44		7.8	121		15	4	0.21	0.9	0.89	0.041	0.011	31.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	04/18/97	1	12.0	60	302	7.8	110	0	8	3	0.10	0.7	0.81	0.019	0.004	31.0
RD-A06-F-2	04/18/97	10			321											
RD-A06-F-2	05/13/97	1	3.7	66		8.1			6	2	0.29	0.6	0.91	0.019	0.007	31.0
RD-A06-F-2	05/13/97	11			305											
RD-A06-F-2	05/13/97	29	4.2	66		7.5			11	2	0.23	0.7	0.77	0.018	0.006	31.0
RD-A06-F-2	06/06/97	1	4.4	90	308	8.0	100	0	6	4	0.10	1.7	0.82	0.017	0.006	31.0
RD-A06-F-2	06/06/97	15			338											
RD-A06-F-2	07/09/97	1	4.0	44		8.5	94	14	11	7	0.18	0.9	0.18	0.031	0.007	31.0
RD-A06-F-2	08/08/97	1	4.2	38	303	8.3	106	12	8	5	0.20	0.7	0.01	0.036	0.006	30.0
RD-A06-F-2	10/03/97	1	7.2	46	313	8.0	100	0	9	4	0.42	0.4	0.01	0.022	0.006	29.0
RD-A06-F-3	06/21/77	0		26	324	8.1	88		45	9	0.00		0.00	0.060		
RD-A06-F-3	05/22/79	1	78.0	6	280	7.4	40	0	39	7	0.04	1.0	3.60	0.220	0.100	9.0
RD-A06-F-3	06/12/79	1	31.0	12		7.6	50	0	11	1	0.07	0.8	2.70	0.110	0.060	16.0
RD-A06-F-3	06/12/79	2			300											
RD-A06-F-3	06/12/79	14	44.0			7.2	50	0	29	6	0.10	0.9	2.90	0.150	0.060	
RD-A06-F-3	07/30/79	1	14.0	18	300	9.1	65	18	18	8	0.01	1.7	0.01	0.100	0.020	10.0
RD-A06-F-3	07/30/79	3			250											
RD-A06-F-3	07/30/79	8	16.0			9.0	60	22	23	6	0.01	1.6	0.22	0.110	0.010	
RD-A06-F-3	08/16/79	1	9.4	24	260	7.6	70	0	19	12	0.23	1.4	0.01	0.120	0.010	10.0
RD-A06-F-3	08/16/79	4			250											
RD-A06-F-3	08/16/79	8	12.0			7.5	0	0	17	8	0.23	1.4	0.01	0.110	0.010	
RD-A06-F-3	09/25/79	1	8.1	24	250	8.3	80	10	15	8	0.01	1.0	0.01	0.090	0.010	10.0
RD-A06-F-3	09/25/79	4			270											
RD-A06-F-3	10/26/79	1	15.0	18		7.4	90	0	18	4	0.08	0.7	0.34	0.060	0.020	17.0
RD-A06-F-3	10/26/79	3			264											
RD-A06-F-3	10/26/79	15	15.0			7.6	90	0	20	2	0.07	0.8	0.30	0.060	0.010	
RD-A06-F-3	06/24/80	0			264	8.7										
RD-A06-F-3	06/24/80	1	5.0	36	134	9.0	98	6	16	2	0.10	0.8	0.20	0.070	0.010	
RD-A06-F-3	06/24/80	3			134	8.9										
RD-A06-F-3	06/24/80	5			141	8.5										

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved' (mg/L)	Total depth (ft)
RD-A06-F-3	06/24/80	6			150											
RD-A06-F-3	06/24/80	7				8.3										
RD-A06-F-3	06/24/80	9	8.0		298	8.0	102	0	23	*2*	0.20	1.2	0.20	0.080	0.010	
RD-A06-F-3	06/24/80	10			302	7.8										
RD-A06-F-3	09/02/80	1	8.0	18	309	8.2	90	5	11	4	0.08	1.3	0.01	0.080	0.005	15.0
RD-A06-F-3	09/02/80	3			265											
RD-A06-F-3	09/02/80	13	10.0			7.8	130	0	11	4	0.11	1.2	0.00	0.080	0.002	
RD-A06-F-3	05/24/82	1	3.5	30	265	8.3	96	25	6	2	0.01	0.7	2.86	0.028	0.003	13.0
RD-A06-F-3	05/24/82	5			157											
RD-A06-F-3	08/09/82	1	5.2	18		8.2	85	15	18	8	0.13	1.6	0.66	0.082	0.019	13.5
RD-A06-F-3	08/09/82	3			267											
RD-A06-F-3	05/17/84	1	53.0	6		7.2	85	0	4	2	0.03	1.0	4.40	0.133	0.077	18.0
RD-A06-F-3	08/17/84	1	2.0	30	274	8.7	80	20	5	4	0.03	0.4	1.90	0.020	0.010	15.0
RD-A06-F-3	08/17/84	5			259											
RD-A06-F-3	04/18/89	1	5.7	20		8.5	115	1	13	4	0.10	1.6	0.97	0.056	0.011	15.0
RD-A06-F-3	04/18/89	3			352											
RD-A06-F-3	04/18/89	15														
RD-A06-F-3	06/07/89	1	2.2	32		8.7			5	5	0.10	1.1	0.24	0.053	0.001	17.5
RD-A06-F-3	06/07/89	5			312											
RD-A06-F-3	07/14/89	1	7.3	26		8.4	100	5	10	5	0.18	0.9	0.10	0.047	0.005	15.5
RD-A06-F-3	07/14/89	4			317											
RD-A06-F-3	08/17/89	1	6.9	20		8.9	100	5	13	9	0.10	1.7	0.10	0.060	0.057	15.5
RD-A06-F-3	08/17/89	3			329											
RD-A06-F-3	10/12/89	6														
RD-A06-F-3	10/13/89	1	0.3	34		8.4	100	1	6	2	0.44	1.1	0.10	0.051	0.017	16.5
RD-A06-F-3	04/25/91	1	7.4	24	322	8.8	100	10	13	6	0.07	1.6	5.40	0.171	0.105	16.5
RD-A06-F-3	04/25/91	4			359											
RD-A06-F-3	04/25/91	17														
RD-A06-F-3	06/10/91	1	1.9	32		8.3	100	0	4	2	0.05	0.8	3.10	0.052	0.019	16.0
RD-A06-F-3	06/10/91	5			344											

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-3	07/05/91	1	4.3	32		8.8	90	10	7	4	0.04	1.2	1.80	0.067	0.016	16.0
RD-A06-F-3	07/05/91	5			319											
RD-A06-F-3	08/14/91	1	5.7	13		8.9	90	10	8	6	0.02	1.6	0.07	0.075	0.014	15.0
RD-A06-F-3	08/14/91	2			294											
RD-A06-F-3	10/07/91	1	7.5	20		7.9	100	0	17	5	0.28	1.0	0.05	0.091	0.017	15.0
RD-A06-F-3	10/07/91	3			304											
RD-A06-F-3	04/21/94	1		4		7.1	65	0			0.30	1.7	4.40	0.314	0.130	16.0
RD-A06-F-3	06/13/94	1	3.1	36	294	8.4	100	10	16	7	0.04	1.2	3.40	0.040	0.009	13.0
RD-A06-F-3	07/11/94	1	7.1	28	333	8.6	100	10	6	5	0.07	0.7	1.62	0.062	0.009	15.0
RD-A06-F-3	07/11/94	15			330											
RD-A06-F-3	08/02/94	1	2.9	24		8.6	110	10	19	10	0.02	1.4	0.59	0.118	0.014	16.0
RD-A06-F-3	08/02/94	4			317											
RD-A06-F-3	10/13/94	1	3.2	32		7.7	110	0	6	2	0.20	1.1	0.14	0.068	0.018	15.0
RD-A06-F-3	10/13/94	5			320											
RD-A06-F-3	04/11/96	1	3.3	24		8.4	115	10	20	7	0.01	1.3	1.58	0.070	0.009	15.0
RD-A06-F-3	04/11/96	4			346											
RD-A06-F-3	04/17/96	1	6.5	18		8.6	119		34	8	0.01	1.8	1.70	0.092	0.012	9.0
RD-A06-F-3	04/17/96	3			361											
RD-A06-F-3	05/09/96	1	400.0	3		6.9			140	24	0.11	5.0	4.20	0.741		10.0
RD-A06-F-3	05/22/96	1	22.0	10	179	7.6			34	6	0.26	0.9	4.60	0.158	0.098	9.5
RD-A06-F-3	06/05/96	1	39.0	10	292	7.2	110	0	44	10	0.01	0.6	6.40	0.138	0.071	9.0
RD-A06-F-3	06/05/96	2			342											
RD-A06-F-3	06/05/96	1	40.0	12		7.2	110	0	42	10	0.01	0.6	4.60	0.134	0.067	26.0
RD-A06-F-3	06/17/96	1	6.9	21	309	8.7			28	14	0.01	0.9	4.40	0.089	0.010	9.0
RD-A06-F-3	06/17/96	4			294											
RD-A06-F-3	07/03/96	1	14.0	20		8.8	110	10	25	9	0.06	0.9	2.90	0.077	0.004	8.0
RD-A06-F-3	07/03/96	3			319											
RD-A06-F-3	07/03/96	8														
RD-A06-F-3	07/15/96	1		18		8.7			30	14	0.02	1.0	1.74	0.110	0.012	9.0
RD-A06-F-3	07/15/96	3			281											

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-3	08/15/96	1	7.2	18		9.0	100	20	28	14	0.01	0.9	0.10	0.109	0.015	9.0
RD-A06-F-3	08/15/96	3			269											
RD-A06-F-3	08/15/96	1	8.2	30		8.7	110	10	10	6	0.01	0.8	0.50	0.067	0.008	26.0
RD-A06-F-3	08/19/96	1	5.1	17	292	9.6			30	20	0.01	1.8	0.06	0.243	0.043	9.0
RD-A06-F-3	08/19/96	3			266											
RD-A06-F-3	09/09/96	1	16.0	18		8.6			46	16	2.60	3.4	0.02	0.433	0.431	8.0
RD-A06-F-3	09/09/96	3			272											
RD-A06-F-3	09/24/96	1	5.2	16		8.6			26	11	0.01	0.1	0.01	0.127	0.034	8.0
RD-A06-F-3	10/02/96	1	11.0	1	279	8.9	100	10	18	13	0.01	1.4	0.02	0.112	0.018	8.0
RD-A06-F-3	10/02/96	3			306											
RD-A06-F-3	11/20/96	1	6.9	30		8.4	119		11	7	0.04	0.8	0.05	0.036	0.011	8.0
RD-A06-F-3	11/20/96	5			290											
RD-A06-F-3	01/23/97	1	12.0	6		8.0	122		74	16	0.08	1.3	1.56	0.488	0.289	8.0
RD-A06-F-3	01/23/97	8			281											
RD-A06-F-3	02/11/97	1	3.2	14		7.9	105		5	2	0.28	1.2	0.33	0.017	0.005	9.0
RD-A06-F-3	02/11/97	2			319											
RD-A06-F-3	03/19/97	1	9.0	15		7.6	105		36	8	0.19	1.3	5.93	0.141	0.079	9.0
RD-A06-F-3	03/19/97	3			356											
RD-A06-F-3	04/18/97	1	10.0	18		8.5	120	10	20	6	0.05	1.2	3.00	0.072	0.009	9.0
RD-A06-F-3	04/18/97	3			365											
RD-A06-F-3	05/13/97	1	4.0	24		8.8			18	10	0.07	1.0	1.77	0.063	0.016	9.0
RD-A06-F-3	05/13/97	4			327											
RD-A06-F-3	06/06/97	1	4.3	24		8.3	112	9	12	6	0.09	1.0	0.83	0.075	0.014	9.0
RD-A06-F-3	06/06/97	4			364											
RD-A06-F-3	07/09/97	1	5.2	18		8.4	92	9	26	12	0.15	1.6	0.01	0.092	0.016	8.0
RD-A06-F-3	07/09/97	8			309											
RD-A06-F-3	08/08/97	1	7.0	18		8.4	110	10	21	12	0.25	1.2	0.01	0.126	0.015	9.0
RD-A06-F-3	10/03/97	1	6.9	16	314	8.3	100	5	26	8	0.29	1.0	0.01	0.146	0.024	7.0
RD-A06-F-4	05/09/96	1	110.0	7	323	7.3			112	16	0.25	1.4	3.50	0.231	0.099	27.0
RD-A06-F-4	05/09/96	24	150.0	7	300	7.2			168	28	0.26	1.9	4.10	0.323	0.116	27.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-4	05/22/96	1	18.0	10	286	7.5			28	6	0.27	1.0	4.10	0.155	0.100	26.0
RD-A06-F-4	05/22/96	24	32.0	10	290	7.1			36	4	0.38	0.9	3.70	0.201	0.084	26.0
RD-A06-F-4	06/05/96	2			291											
RD-A06-F-4	06/17/96	1	9.6	24		8.7			22	12	0.06	0.7	3.60	0.048	0.008	26.0
RD-A06-F-4	06/17/96	24	20.0	24	294	7.1			12	4	0.01	0.6	4.90	0.093	0.057	26.0
RD-A06-F-4	06/17/96	4			313											
RD-A06-F-4	07/03/96	1	7.7	28		9.0	90	10	7	3	0.06	1.0	2.60	0.046	0.002	24.0
RD-A06-F-4	07/03/96	5			302											
RD-A06-F-4	07/07/96	1		26		8.6			9	6	0.05	1.0	2.00	0.059	0.010	25.0
RD-A06-F-4	07/15/96	4			291											
RD-A06-F-4	07/15/96	26		26		7.9			24	3	0.09	1.0	2.00	0.085	0.014	26.0
RD-A06-F-4	08/15/96	5			299											
RD-A06-F-4	08/19/96	1	5.3	29		8.5			10	2	0.01	0.9	0.47	0.081	0.010	26.0
RD-A06-F-4	08/19/96	4			280											
RD-A06-F-4	08/19/96	23	5.2	29		7.7			21	5	0.03	0.8	0.48	0.091	0.015	26.0
RD-A06-F-4	08/19/96	26			285											
RD-A06-F-4	09/09/96	1	15.0	28		7.7			9	2	0.64	1.1	0.01	0.025	0.006	25.0
RD-A06-F-4	09/09/96	5			278											
RD-A06-F-4	09/09/96	25	2.4	28		7.4			8	5	0.26	1.2	0.12	0.026	0.004	25.0
RD-A06-F-4	09/24/96	1	4.1	24	288	7.9			14	6	0.03	0.1	0.10	0.081	0.019	26.0
RD-A06-F-4	09/24/96	24	4.3	24	283	7.7			24	5	0.05	0.7	0.12	0.086	0.021	26.0
RD-A06-F-4	10/02/96	1	11.0	2	286	8.1	110	0	13	10	0.18	1.0	0.10	0.055	0.019	24.0
RD-A06-F-4	10/02/96	4			308											
RD-A06-F-4	11/20/96	1	7.2	30		7.9	119		14	11	0.29	0.9	0.19	0.037	0.009	24.0
RD-A06-F-4	11/20/96	5			296											
RD-A06-F-4	11/20/96	22	3.9			7.9	110		13	7	0.23	0.8	0.20	0.042	0.004	24.0
RD-A06-F-4	01/23/97	1	2.0	72	296	7.8	149		5	2	0.09	0.6	0.21	0.024	0.003	25.0
RD-A06-F-4	01/23/97	12			298											
RD-A06-F-4	01/23/97	25														
RD-A06-F-4	01/23/97	23	2.3	72		7.6	183		9	3	0.15	0.6	0.21	0.028	0.004	25.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity Total (mg/L as $CaCO_3$)	Alkalinity Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids Total (mg/L)	Suspended solids Volatile (mg/L)	Nitrogen Ammonia (mg/L)	Nitrogen Total Kjehldahl (mg/L)	Nitrogen Nitrate/ nitrite (mg/L)	Phosphorus Total (mg/L)	Phosphorus Dissolved (mg/L)	Total depth (ft)
RD-A06-F-4	02/11/97	1	3.5	64	315	7.9	102		3	1	0.28	1.0	0.39	0.015	0.005	26.0
RD-A06-F-4	02/11/97	12			311											
RD-A06-F-4	02/11/97	24	3.2	64		7.5	102		3	3	0.29	0.9	0.33	0.011	0.004	26.0
RD-A06-F-4	03/19/97	1	12.0	22	330	7.6	114		24	4	0.19	1.2	2.75	0.121	0.073	27.0
RD-A06-F-4	03/19/97	4			310											
RD-A06-F-4	03/19/97	25	12.0			7.6	116		22	6	0.19	1.1	2.76	0.117	0.073	27.0
RD-A06-F-4	04/18/97	1	8.7	26	312	8.4	115	10	19	4	0.05	0.9	2.80	0.056	0.010	25.0
RD-A06-F-4	04/18/97	4			352											
RD-A06-F-4	05/13/97	1	3.9	33		8.7			22	5	0.16	0.7	1.73	0.061	0.009	25.0
RD-A06-F-4	05/13/97	5			325											
RD-A06-F-4	05/13/97	23	3.7	33		8.2			22	9	0.12	1.0	1.58	0.046	0.015	25.0
RD-A06-F-4	06/06/97	1	4.2	28	330	8.2	100	8	13	5	0.10	1.3	0.86	0.077	0.016	25.0
RD-A06-F-4	06/06/97	5			356											
RD-A06-F-4	07/09/97	1	6.1	30		8.4	100	12	12	6	0.22	1.0	0.23	0.041	0.011	25.0
RD-A06-F-4	08/08/97	1	4.0	22	320	7.7	110	0	12	5	0.28	1.0	0.01	0.105	0.013	23.0
RD-A06-F-4	10/03/97	1	6.7	14	317	7.5	90	0	26	6	0.32	0.8	0.29	0.088	0.020	24.0
RD-A06-F-1	05/28/82	1		60												33.5
RD-A06-F-1	06/14/82	1		60												45.5
RD-A06-F-1	06/30/82	1		72												44.5
RD-A06-F-1	07/15/82	1		70												47.5
RD-A06-F-1	07/30/82	1		58												48.0
RD-A06-F-1	08/13/82	1		60												46.0
RD-A06-F-1	08/30/82	1		55												47.0
RD-A06-F-1	09/15/82	1		58												47.0
RD-A06-F-1	09/28/82	1		60												48.0
RD-A06-F-1	10/15/82	1		58												48.0
RD-A06-F-1	10/29/82	1		58												47.5
RD-A06-F-1	05/04/84	1		16												51.0
RD-A06-F-1	05/19/84	1		18												50.0
RD-A06-F-1	06/03/84	1		18												52.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	06/24/84	1		46												50.0
RD-A06-F-1	07/08/84	1		78												50.0
RD-A06-F-1	07/29/84	1		66												50.5
RD-A06-F-1	08/12/84	1		62												48.5
RD-A06-F-1	08/26/84	1		54												48.0
RD-A06-F-1	09/15/84	1		52												51.0
RD-A06-F-1	09/30/84	1		42												50.0
RD-A06-F-1	10/13/84	1		48												48.0
RD-A06-F-1	10/24/84	1		60												48.0
RD-A06-F-1	04/13/85	1		18												52.0
RD-A06-F-1	05/05/85	1		42												49.0
RD-A06-F-1	05/25/85	1		52												50.0
RD-A06-F-1	06/08/85	1		61												48.0
RD-A06-F-1	06/29/85	1		52												49.0
RD-A06-F-1	07/13/85	1		54												47.0
RD-A06-F-1	07/28/85	1		58												48.0
RD-A06-F-1	08/11/85	1		54												50.0
RD-A06-F-1	09/28/85	1		79												48.0
RD-A06-F-1	10/19/85	1		58												47.0
RD-A06-F-1	10/27/85	1		65												46.0
RD-A06-F-1	04/05/86	1		57												49.0
RD-A06-F-1	04/12/86	1		66												50.0
RD-A06-F-1	05/05/86	1		85												48.5
RD-A06-F-1	05/31/86	1		81												47.0
RD-A06-F-1	06/07/86	1		77												48.0
RD-A06-F-1	06/28/86	1		78												45.0
RD-A06-F-1	07/04/86	1		85												48.0
RD-A06-F-1	08/15/86	1		62												47.0
RD-A06-F-1	08/23/86	1		68												46.0
RD-A06-F-1	09/05/86	1		52												46.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (μmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	09/20/86	1		68												47.0
RD-A06-F-1	10/05/86	1		73												47.0
RD-A06-F-1	10/20/86	1		84												46.0
RD-A06-F-1	04/18/87	1		41												48.0
RD-A06-F-1	05/10/87	1		74												46.0
RD-A06-F-1	05/22/87	1		62												48.0
RD-A06-F-1	06/07/87	1		60												48.0
RD-A06-F-1	06/29/87	1		84												48.0
RD-A06-F-1	07/05/87	1		72												45.0
RD-A06-F-1	07/26/87	1		49												46.0
RD-A06-F-1	08/28/87	1		54												44.0
RD-A06-F-1	09/13/87	1		66												45.0
RD-A06-F-1	09/26/87	1		70												44.0
RD-A06-F-1	10/11/87	1		61												46.0
RD-A06-F-1	10/25/87	1		60												43.0
RD-A06-F-1	05/13/88	1		71												44.0
RD-A06-F-1	05/21/88	1		92												46.0
RD-A06-F-1	06/11/88	1		66												47.0
RD-A06-F-1	07/03/88	1		49												45.0
RD-A06-F-1	07/30/88	1		26												45.0
RD-A06-F-1	08/13/88	1		22												44.0
RD-A06-F-1	08/28/88	1		44												46.0
RD-A06-F-1	09/24/88	1		38												47.0
RD-A06-F-1	10/14/88	1		38												44.0
RD-A06-F-1	10/22/88	1		42												45.0
RD-A06-F-1	04/18/89	1		48												46.0
RD-A06-F-1	05/16/89	1		60												47.0
RD-A06-F-1	06/07/89	1		94												46.5
RD-A06-F-1	07/14/89	1		66												42.5
RD-A06-F-1	08/02/89	1		46												47.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-1	08/17/89	1		36												47.0
RD-A06-F-1	08/29/89	1		54												46.0
RD-A06-F-1	10/13/89	1		56												50.0
RD-A06-F-1	05/14/90	1		78												44.0
RD-A06-F-1	04/25/91	1		36												45.0
RD-A06-F-1	06/10/91	1		54												46.0
RD-A06-F-1	07/05/91	1		72												47.0
RD-A06-F-1	08/14/91	1		20												46.0
RD-A06-F-1	10/07/91	1		48												41.0
RD-A06-F-1	04/21/94	1		18												40.0
RD-A06-F-1	06/13/94	1		44												46.5
RD-A06-F-1	07/11/94	1		84												46.0
RD-A06-F-1	08/02/94	1		72												51.0
RD-A06-F-1	10/13/94	1		66												45.5
RD-A06-F-2	05/28/82	1		40												26.0
RD-A06-F-2	06/14/82	1		36												28.0
RD-A06-F-2	06/30/82	1		38												29.0
RD-A06-F-2	07/15/82	1		38												29.5
RD-A06-F-2	07/30/82	1		38												28.5
RD-A06-F-2	08/13/82	1		38												38.0
RD-A06-F-2	08/30/82	1		37												38.0
RD-A06-F-2	09/15/82	1		37												38.0
RD-A06-F-2	09/28/82	1		39												39.0
RD-A06-F-2	10/15/82	1		39												37.0
RD-A06-F-2	10/29/82	1		40												38.0
RD-A06-F-2	05/04/84	1		9												31.8
RD-A06-F-2	05/19/84	1		11												33.0
RD-A06-F-2	06/03/84	1		14												34.0
RD-A06-F-2	06/24/84	1		38												32.0
RD-A06-F-2	07/08/84	1		50												32.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	07/29/84	1		54												32.5
RD-A06-F-2	08/12/84	1		55												32.0
RD-A06-F-2	08/26/84	1		42												31.0
RD-A06-F-2	09/15/84	1		41												32.0
RD-A06-F-2	09/30/84	1		40												33.0
RD-A06-F-2	10/13/84	1		39												32.0
RD-A06-F-2	04/13/85	1		14												32.0
RD-A06-F-2	05/05/85	1		30												30.0
RD-A06-F-2	05/25/85	1		45												33.0
RD-A06-F-2	06/08/85	1		43												29.0
RD-A06-F-2	06/29/85	1		46												30.0
RD-A06-F-2	07/13/85	1		47												32.0
RD-A06-F-2	07/28/85	1		48												29.0
RD-A06-F-2	08/11/85	1		31												30.0
RD-A06-F-2	09/28/85	1		48												30.0
RD-A06-F-2	10/19/85	1		37												28.0
RD-A06-F-2	10/27/85	1		42												28.0
RD-A06-F-2	04/05/86	1		36												32.0
RD-A06-F-2	04/12/86	1		42												33.0
RD-A06-F-2	05/05/86	1		61												30.0
RD-A06-F-2	05/31/86	1		72												26.0
RD-A06-F-2	06/07/86	1		61												29.0
RD-A06-F-2	06/28/86	1		60												26.0
RD-A06-F-2	07/04/86	1		66												28.0
RD-A06-F-2	08/15/86	1		51												26.0
RD-A06-F-2	08/23/86	1		54												28.0
RD-A06-F-2	09/05/86	1		48												27.0
RD-A06-F-2	09/20/86	1		52												28.0
RD-A06-F-2	10/05/86	1		49												27.0
RD-A06-F-2	10/20/86	1		56												26.0

Station code	Sample date	Sample depth (ft)	Turbidity (MTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	04/18/87	1		34												27.0
RD-A06-F-2	05/10/87	1		56												26.0
RD-A06-F-2	05/22/87	1		48												29.0
RD-A06-F-2	06/07/87	1		46												30.0
RD-A06-F-2	06/29/87	1		68												28.0
RD-A06-F-2	07/05/87	1		58												28.0
RD-A06-F-2	07/26/87	1		34												26.0
RD-A06-F-2	08/28/87	1		33												27.0
RD-A06-F-2	09/13/87	1		38												28.0
RD-A06-F-2	09/26/87	1		54												26.0
RD-A06-F-2	10/11/87	1		47												27.0
RD-A06-F-2	10/25/87	1		42												27.0
RD-A06-F-2	05/13/88	1		44												26.0
RD-A06-F-2	05/21/88	1		69												27.0
RD-A06-F-2	06/11/88	1		45												26.0
RD-A06-F-2	07/03/88	1		35												27.0
RD-A06-F-2	07/30/88	1		24												26.0
RD-A06-F-2	08/13/88	1		14												25.0
RD-A06-F-2	08/28/88	1		36												26.0
RD-A06-F-2	09/24/88	1		32												26.0
RD-A06-F-2	10/14/88	1		32												24.0
RD-A06-F-2	10/22/88	1		34												25.0
RD-A06-F-2	04/18/89	1		38												28.0
RD-A06-F-2	05/16/89	1		42												30.5
RD-A06-F-2	06/07/89	1		114												30.0
RD-A06-F-2	07/14/89	1		54												30.5
RD-A06-F-2	08/02/89	1		42												40.0
RD-A06-F-2	08/17/89	1		32												30.0
RD-A06-F-2	08/29/89	1		42												30.0
RD-A06-F-2	10/13/89	1		66												29.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-2	05/14/90	1		72												32.0
RD-A06-F-2	04/25/91	1		36												30.5
RD-A06-F-2	06/10/91	1		54												30.0
RD-A06-F-2	07/05/91	1		60												30.0
RD-A06-F-2	08/14/91	1		22												29.0
RD-A06-F-2	10/07/91	1		40												29.0
RD-A06-F-2	04/21/94	1		8												32.5
RD-A06-F-2	06/13/94	1		42												30.0
RD-A06-F-2	07/11/94	1		60												31.0
RD-A06-F-2	08/02/94	1		64												30.0
RD-A06-F-2	10/13/94	1		66												30.5
RD-A06-F-3	05/28/82	1		36												21.0
RD-A06-F-3	06/14/82	1		28												23.5
RD-A06-F-3	06/30/82	1		38												22.5
RD-A06-F-3	07/15/82	1		38												27.0
RD-A06-F-3	07/30/82	1		36												27.0
RD-A06-F-3	08/13/82	1		37												34.0
RD-A06-F-3	08/30/82	1		35												34.0
RD-A06-F-3	09/15/82	1		36												34.0
RD-A06-F-3	09/28/82	1		37												37.0
RD-A06-F-3	10/15/82	1		37												37.0
RD-A06-F-3	10/29/82	1		39												34.0
RD-A06-F-3	05/04/84	1		3												18.5
RD-A06-F-3	05/19/84	1		4												17.0
RD-A06-F-3	06/03/84	1		6												20.0
RD-A06-F-3	06/24/84	1		24												19.0
RD-A06-F-3	07/08/84	1		30												20.0
RD-A06-F-3	07/29/84	1		36												19.0
RD-A06-F-3	08/12/84	1		29												18.0
RD-A06-F-3	08/26/84	1		24												18.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi transparency (in.)	Conductivity (μmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolphthalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-3	09/15/84	1		20												18.0
RD-A06-F-3	09/30/84	1		40												20.0
RD-A06-F-3	10/13/84	1		27												21.0
RD-A06-F-3	04/13/85	1		6												20.0
RD-A06-F-3	05/05/85	1		24												18.0
RD-A06-F-3	05/25/85	1		25												20.0
RD-A06-F-3	06/08/85	1		30												19.0
RD-A06-F-3	06/29/85	1		32												21.0
RD-A06-F-3	07/13/85	1		23												20.0
RD-A06-F-3	07/28/85	1		23												18.0
RD-A06-F-3	08/11/85	1		18												19.0
RD-A06-F-3	09/28/85	1		31												18.5
RD-A06-F-3	10/19/85	1		23												18.0
RD-A06-F-3	10/27/85	1		24												17.0
RD-A06-F-3	04/05/86	1		16												21.0
RD-A06-F-3	04/12/86	1		18												21.0
RD-A06-F-3	05/05/86	1		26												19.0
RD-A06-F-3	05/31/86	1		41												17.0
RD-A06-F-3	06/07/86	1		36												19.0
RD-A06-F-3	06/28/86	1		26												17.0
RD-A06-F-3	07/04/86	1		22												16.0
RD-A06-F-3	08/15/86	1		23												16.0
RD-A06-F-3	08/23/86	1		26												17.0
RD-A06-F-3	09/05/86	1		24												15.0
RD-A06-F-3	09/20/86	1		26												18.0
RD-A06-F-3	10/05/86	1		18												17.0
RD-A06-F-3	10/20/86	1		24												16.0
RD-A06-F-3	04/18/87	1		18												17.0
RD-A06-F-3	05/10/87	1		26												15.0
RD-A06-F-3	05/22/87	1		19												18.5

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi transparency (in.)	Conductivity (µmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolphthalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjeldahl (mg/L)	Nitrogen: Nitrate/nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-3	06/07/87	1		28												18.0
RD-A06-F-3	06/29/87	1		24												16.0
RD-A06-F-3	07/05/87	1		18												17.0
RD-A06-F-3	07/26/87	1		16												16.0
RD-A06-F-3	08/28/87	1		14												16.0
RD-A06-F-3	09/13/87	1		22												15.0
RD-A06-F-3	09/26/87	1		24												14.0
RD-A06-F-3	10/11/87	1		22												15.0
RD-A06-F-3	10/25/87	1		24												16.0
RD-A06-F-3	05/13/88	1		23												15.0
RD-A06-F-3	05/21/88	1		26												16.5
RD-A06-F-3	06/11/88	1		24												16.0
RD-A06-F-3	07/03/88	1		18												15.5
RD-A06-F-3	07/30/88	1		12												14.5
RD-A06-F-3	08/13/88	1		10												13.5
RD-A06-F-3	08/28/88	1		15												15.0
RD-A06-F-3	09/24/88	1		16												14.0
RD-A06-F-3	10/14/88	1		16												13.5
RD-A06-F-3	10/22/88	1		18												13.5
RD-A06-F-3	04/18/89	1		20												15.0
RD-A06-F-3	05/16/89	1		24												15.0
RD-A06-F-3	06/07/89	1		32												17.5
RD-A06-F-3	07/14/89	1		26												15.5
RD-A06-F-3	08/02/89	1		22												12.0
RD-A06-F-3	08/17/89	1		20												15.5
RD-A06-F-3	08/29/89	1		24												11.5
RD-A06-F-3	10/13/89	1		34												16.5
RD-A06-F-3	05/14/90	1		21												13.0
RD-A06-F-3	04/25/91	1		24												16.5
RD-A06-F-3	06/10/91	1		32												16.0

Station code	Sample date	Sample depth (ft)	Turbidity (NTU)	Secchi trans-parency (in.)	Conduc-tivity (μmho/cm)	pH	Alkalinity: Total (mg/L as $CaCO_3$)	Alkalinity: Phenolph-thalein (mg/L as $CaCO_3$)	Suspended solids: Total (mg/L)	Suspended solids: Volatile (mg/L)	Nitrogen: Ammonia (mg/L)	Nitrogen: Total Kjehldahl (mg/L)	Nitrogen: Nitrate/ nitrite (mg/L)	Phosphorus: Total (mg/L)	Phosphorus: Dissolved (mg/L)	Total depth (ft)
RD-A06-F-3	07/05/91	1		32												16.0
RD-A06-F-3	08/14/91	1		13												15.0
RD-A06-F-3	10/07/91	1		20												15.0
RD-A06-F-3	04/21/94	1		4												16.0
RD-A06-F-3	06/13/94	1		36												13.0
RD-A06-F-3	07/11/94	1		28												15.0
RD-A06-F-3	08/02/94	1		24												16.0
RD-A06-F-3	10/13/94	1		32												15.0

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