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In cooperation with the Village of Cherry Valley

Hydrology, Water Quality, and Nutrient Loads to the Bauman Park Lake, Cherry Valley, Winnebago County, Illinois, May 1996–April 1997

Water-Resources Investigations Report 98–4087

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

CONTENTS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
acre	0.4047	hectare
square foot (ft^2)	0.09290	square meter
Volume		
gallon (gal)	3.785	cubic decimeter
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
Flow rate		
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
inch per day (in/d)	2.54	centimeter per year
Mass		
pound, avoirdupois (lb)	0.4536	kilogram
Density		
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day
Application rate		
inch per acre (in/acre)	0.0627	meter per hectare
pounds per acre (lb/acre)	1.1208	kilogram per hectare
pound per day (lb/d)	0.4536	kilogram per day
pounds per acre per day [(lb/acre)/d]	1.1208	kilogram per hectare
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

*__Transmissivity:__ The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

The following abbreviations are used in this report:

mg/m^3	milligrams per cubic meter
mg/kg	milligrams per kilograms
g/L	grams per liter
mol/L	moles per liter
ml	milliliter
L	liter

Hydrology, Water Quality and Nutrient Loads to the Bauman Park Lake, Cherry Valley, Winnebago County, Illinois, May 1996–April 1997

By Robert T. Kay *and* Aaron Trugestaad

ABSTRACT

The Bauman Park Lake occupies a former sand and gravel quarry in the Village of Cherry Valley, Illinois. The lake is eutrophic, and nuisance growths of algae and aquatic macrophytes are supported by nutrients (nitrogen and phosphorus) that are derived primarily from ground-water inflow, the main source of water for the lake. The lake has an average depth of about 18 feet, a maximum depth of about 28 feet, and a volume of 466 acre-feet at a stage of about 717 feet above sea level. The lake also is subject to thermal stratification, and although most of the lake is well oxidized, nearly anoxic conditions were present at the lake bottom during part of the summer of 1996.

About 734 pounds of phosphorus and 4,575 pounds of nitrogen compounds were added to the Bauman Park Lake from May 1996 through April 1997. Phosphorus compounds were derived primarily from inflow from ground water (68.7 percent), sediments derived from shoreline erosion (15.6 percent), internal regeneration (11.7 percent), waterfowl excrement (1.6 percent), direct precipitation and overland runoff (1.2 percent), and particulate matter deposited from the atmosphere (1.2 percent). Nitrogen compounds were derived from inflow from ground water (62.1 percent), internal regeneration (19.6 percent), direct precipitation and overland runoff (10.1 percent), particulate matter deposited from the atmosphere (3.5 percent), sediments derived from shoreline erosion (4.4 percent), and waterfowl excrement (0.3 percent). About 13 pounds of phosphorus and 318 pounds of nitrogen compounds flow out of the lake to ground water. About 28 pounds of nitrogen is removed by denitrification.

Algae and aquatic macrophytes utilize nitrate, nitrite, ammonia, and dissolved phosphorus. The availability of dissolved phosphorus in the lake water controls algal growth. Uptake of the nutrients, by aquatic macrophytes and algae, temporarily removes nutrients from the water column but not from the lake basin. Because the amount of nutrients entering the lake greatly exceeds the amount leaving, the nutrients are concentrated in the sediments at the lake bottom, where they can be used by the rooted aquatic macrophytes and released to the water column when the proper geochemical conditions are present.

INTRODUCTION

Aquatic macrophytes (plants visible to the unaided eye), including coontail, elodea, and milfoil, were observed near the bottom of the Bauman Park Lake on May 30, 1996, and were described as having become abundant by June 11, 1996 (Allan Pulley, Illinois Department of Conservation, written commun., 1996). No large algae blooms were observed on the lake during the summer of 1996, but large amounts of algae were observed in the water column in October 1996. Personnel from the Village of Cherry Valley have reported frequent algal blooms on the lake during previous summers. The proliferation of aquatic macrophytes and algae detract from the aesthetic quality of the lake and can cause changes in water chemistry that have the potential to harm the fishery.

The concentrations of nitrogen and phosphorus compounds in the lake water and bottom sediments of a lake affect the amount of plant life in the lake. These nutrients are necessary to plant metabolism, and their concentrations in water, along with the availability of light, typically are the factors that limit the growth of algae. Determining the most effective method for limiting algal growth requires identification and quantification of the sources of nitrogen and phosphorus in Bauman Park Lake.

Erosion is occurring along most of the lakeshore, detracting from the aesthetic appeal of the lake. In some areas, erosion has the potential to undercut the banks of the lake, the structural support for the amphitheater, and parts of the exercise path (fig. 1). Some trees, originally planted at what was thought to be a safe distance from the lakeshore, have been relocated to prevent undercutting by erosion.

The U.S. Geological Survey (USGS), in cooperation with the Village of Cherry Valley, conducted a study of the hydrology and water quality in and around Bauman Park Lake (fig. 1) to provide the data that will form the basis for future lake-management strategies developed to improve the quality of the lake's environment. The investigation, conducted from May 1996 through April 1997, was a part of the Illinois Environmental Protection Agency's (IEPA) Clean Lakes 2000 initiative, which provides funding for investigation and remediation of lakes in Illinois.

Background

The Bauman Park Lake is located in the Village of Cherry Valley in southeastern Winnebago County, Illinois (fig. 1). The lake area is bounded by Bauman Park to the north and west, a corn field to the south, and a fallow field to the east. The lake lies north of an unnamed stream, and a short distance east of the Kishwaukee River.

The lake occupies a former sand and gravel quarry. Quarrying began in 1980 and ended in 1991. The lake originated from ground water infilling the excavated quarry. At the time of the USGS investigation, the lake was about 5 years old.

Construction of park facilities, including a boat ramp, observation hills, exercise path, amphitheater, and rest rooms, was completed in 1991. An estimated 200,000 people use the lake and the surrounding park every year for fishing, picnics, and exercising (William Hutchison, Village of Cherry Valley, written commun., 1996). The lake is not used for swimming or boating and is not a source of water supply. The lake does not receive wastewater discharge.

There are no known septic tanks, fertilizer storage facilities, or compost piles in the vicinity of the lake. However, sludge drying beds once were located next to a former wastewater-treatment plant in this area. The sludge drying beds were near the current site of the rest rooms (fig. 1). The sludge dewatered into a drainage system that went to a wastewater treatment plant. The sludge drying beds were excavated in 1990. A stormwater sewer is present in the western part of the lake area near the Kishwaukee River (fig. 1).

The Village of Cherry Valley stocked the lake with 500 channel catfish in 1995 and again in 1996. Prior to 1995, local sportsmen are thought to have stocked the lake with panfish, bass, and walleye. The Village plans to stock the lake in accordance with the recommendations of the Illinois Department of Conservation.

Purpose and Scope

This report details the results of an investigation designed to determine the nutrient sources contributing to the growth of algae and aquatic macrophytes in the Bauman Park Lake and to quantify the amount of erosion from the shoreline into the lake. In addition to a description of the hydrogeology of the area, the results of aquifer testing, water-level measurements, water-quality sampling, measurement of shoreline erosion, sediment sampling, and waterfowl counts in the vicinity of the lake are presented. The report identifies the direction of ground-water flow; the amount of water entering and leaving the lake; the concentration of nitrogen and phosphorus compounds in the lake and surrounding ground water; and the amount of nutrient loading to the lake from ground-water inflow, atmos-pheric deposition, shoreline erosion, waterfowl excrement, and internal regeneration. The nutrient limiting algal growth and the trophic state of the lake also are determined in this report. Study results are based on data collected May 1, 1996–April 30, 1997, with the exception of the erosion data, which were collected from January 23, 1997, through January 23, 1998.

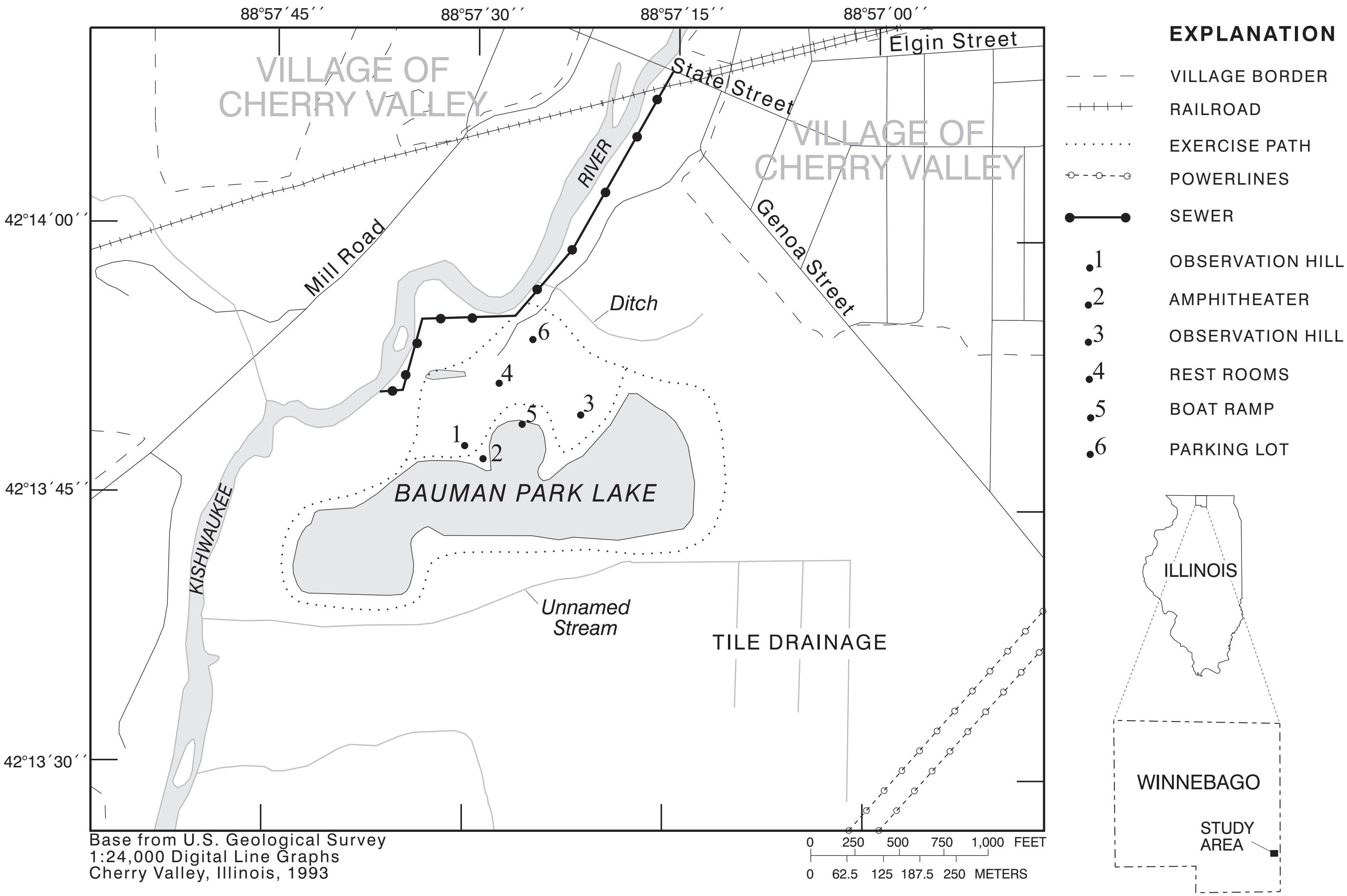

Figure **1.** Location of the Bauman Park Lake, Cherry Valley, Winnebago County, Ill.

Study Methods

Ten ground-water-monitoring wells and four surface-water-gages were installed by the USGS to characterize the interaction between surface-water flow and ground-water flow in the area (table 1, fig. 2). Four ground-water-monitoring wells were installed north of the lake by a consulting firm in April 1997 for an unrelated investigation (B. Gallagher, Hanson Engineers, Inc., written commun., 1997). Data from these wells also were used in this investigation. Surface- and ground-water-level data were combined with the results of hydraulic testing and water-quality sampling to quantify the amount of nutrients added to the lake by inflow from ground water, the amount of nutrients removed from the lake by outflow to ground water, and the factors that affect the growth of algae and aquatic macrophytes in the lake. Shoreline erosion markers were installed and sediment samples were collected at four transects at the lakeshore (fig. 2) to measure the amount of sediment eroding from the shoreline into the lake and the concentration of nutrients in the sediments. Climate data were obtained from published sources to determine the amount of precipitation and evaporation at the lake. These data were combined with information on the site soils to determine the amount of nutrients derived from atmospheric deposition and overland runoff. Waterfowl counts were performed to determine the amount of nutrients in the lake derived from fecal matter. Finally, data obtained from literature reviews were combined with measurements of dissolved oxygen in the lake to determine the amount of nutrients released to the water column from the lake bottom sediments.

Acknowledgments

The authors thank Mr. Bill Hutchison, formerly of the Village of Cherry Valley, and Mr. Joe Caveny, Director of Public Works for the Village of Cherry Valley, for their roles in obtaining much of the background information on the lake. Mr. Jeff Mittzelfeld, Mr. Steve Kolsto, and Mr. Jack Adams of the Illinois Environmental Protection Agency are thanked for the assistance they provided during the investigation.

PHYSICAL SETTING OF BAUMAN PARK LAKE

Bauman Park Lake has no surface inlet or outlet. Most of the water entering the lake is from ground-water flow. Smaller amounts of water enter the lake directly from precipitation and overland runoff of

Table 1. Well and surface-water gage data, Bauman Park Lake, Cherry Valley, Ill.

Ground-water-monitoring well name	Latitude/longitude	Depth of open interval[1] (feet below land surface)	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)
1	42°13′51″/88°57′26″	5–15	725	723.89
2	42°13′54″/88°57′28″	5–15	724	723.38
3	42°13′46″/88°57′40″	5–15	720	719.67
4	42°13′39″/88°57′36″	10–20	727	726.25
5	42°13′43″/88°57′16″	5–15	723	721.96
6	42°13′48″/88°57′10″	5–15	720	719.77
7	42°13′48″/88°57′11″	5–15	723	722.52
8	42°13′52″/88°57′29″	5–15	726	725.42
9	42°13′48″/88°57′41″	5–15	719	718.35
10	42°13′49″/88°57′43″	5–15	719	718.09

Surface-water gage name	Latitude/longitude	Surface-water body monitored
BPL	42°13′48″/88°57′26″	Bauman Park Lake
KR	42°14′10″/88°57′16″	Kishwaukee River
CE	42°57′15″/88°57′15″	Unnamed stream
CW	42°13′38″/88°57′39″	Unnamed stream

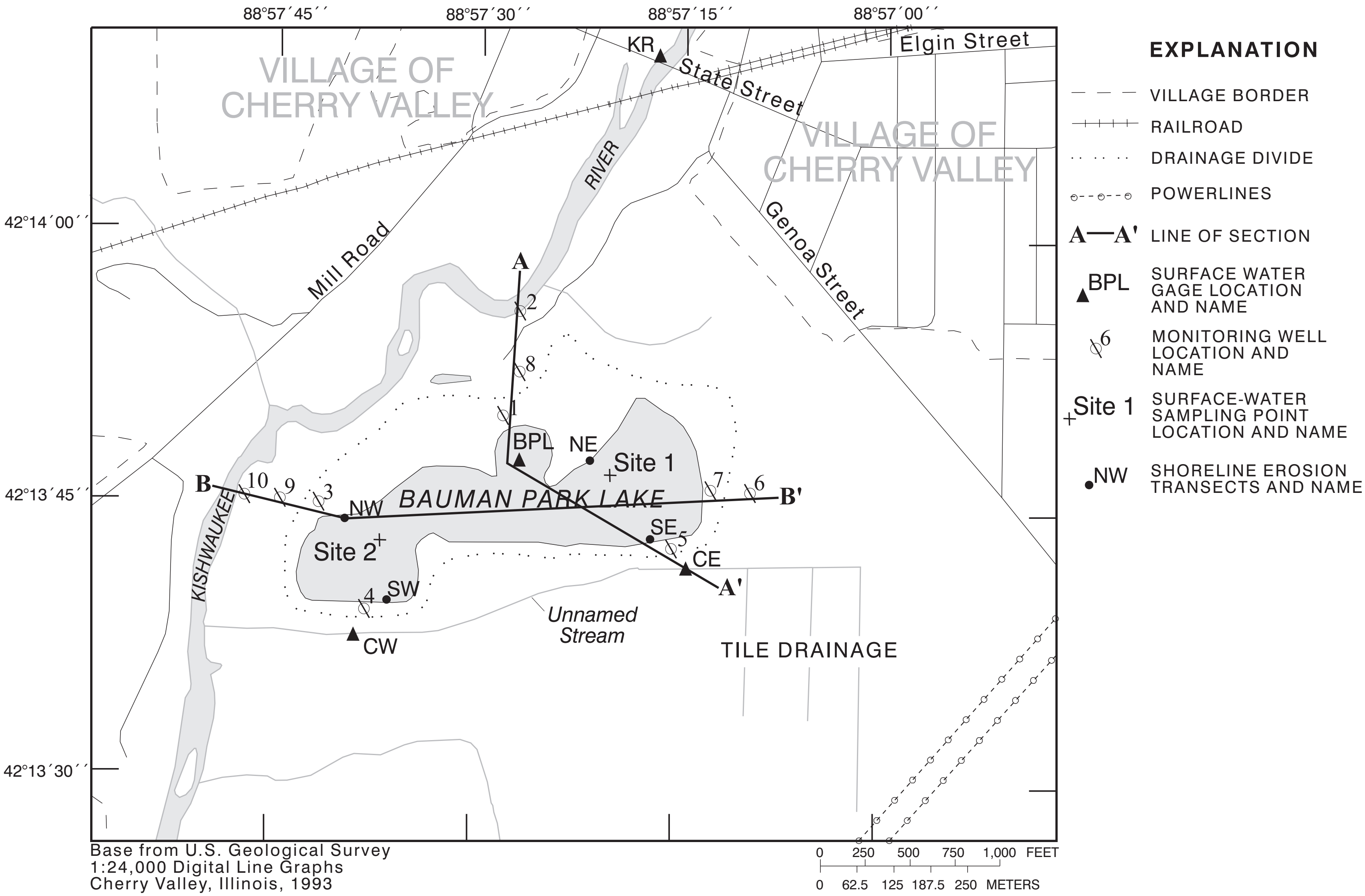

Figure **2.** Location of surface-water gages, surface-water sampling points, ground-water monitoring wells, and lines of section, in the vicinity of the Bauman Park Lake, Cherry Valley, Ill.

precipitation. In addition to evaporation, water leaves the lake by flowing out to ground water.

Watershed Characteristics

The maximum area within which water at the land surface will flow toward the lake (the watershed) is defined by a drainage divide (fig. 2) associated with a topographic ridge near the exercise path to the east and south, a berm to the west, and topographic highs north of the lake. The altitude of the land surface along most of the drainage divide is between about 724 and 728 ft above sea level (fig. 3). The location of the drainage divide was determined in the lake area, plotted on the 1993 USGS 1:24,000 quadrangle map of the area, and entered into a digital polygon coverage. The area of the watershed inside the drainage divide, including the lake, was calculated at approximately 54 acres using ARC/INFO software.

Approximately 75 percent of the original surface soil within the lake's watershed is Selma Loam (U.S. Department of Agriculture, 1982). The Selma Loam is present in the central part of the watershed and a small area in the northwestern part of the watershed. The Millington Silt Loam constitutes about 20 percent of the original surface soil in the watershed. The Millington Silt Loam is in the western part of the watershed and a small area in the southern part of the watershed. The Hononegah Loamy Coarse Sand is present in the eastern part of the watershed. Undrained Selma Loam and Millington Silt are characterized by low infiltration and high runoff rates. The Hononegah Loamy Coarse Sand is characterized by high infiltration and low runoff rates. Silt, sand, and clay fill are present beneath the observation hills, the berm, and the exercise path (fig. 1). The fill is likely to have moderate to high infiltration rates. An approximately 300-ft^2 paved parking lot is present north of the boat ramp (fig. 1). It is assumed that construction activities at the park have not appreciably affected the distribution and characteristics of the original surface soils. The small area of the watershed, in comparison to the surface area of the lake, indicates that small to moderate amounts of water derived from overland runoff will enter the lake.

Grass is the primary plant cover within the drainage basin. Since 1992, about 1,600 trees and bushes have been planted in the park. About one-half of the trees were planted within the limits of the watershed.

Lake Basin and Shoreline Characteristics

A bathymetric survey of the lake was done on March 21, 1997, by USGS personnel. The altitude of the lake surface was about 717 ft above sea level on that date, 1 ft above the normal stage of the lake during the period of investigation. The bathymetric survey involved making approximately 90 transects of the lake with a spacing of about 15 ft between transects. Readings of horizontal location and depth to the bottom of the lake were collected at approximately 3-ft intervals along each transect. A differentially corrected global positioning system, which is typically accurate to within 3 ft, was used to measure horizontal location. A digital fathometer, accurate to within 1 in. under the conditions present at the time of the survey, was used to measure the depth to the lake bottom. Horizontal location and depth measurements were contoured by means of a contouring package in ARC/INFO (lattice contour) to produce a bathymetric map (fig. 4).

Bathymetric data show the lake has steep sides and a flat bottom (figs. 3, 4). The bathymetric map indicates the average depth of the lake was about 18 ft during the survey, and the maximum depth was about 28 ft. These values indicate that the average and maximum depths of the lake at its normal stage would be about 17 and 27 ft, respectively. A ridge, at a depth from 5 to 10 ft, crosses the lake bottom south of the boat ramp. This ridge separates the deep, circular basin near the boat ramp from the rest of the lake. The steepest parts of the lake basin are in the southern and southeastern parts of the lake.

The boundaries of the lake, which were identified on the 1993 USGS 1:24,000 quadrangle map of the area, were entered into a digital polygon coverage, and a lake-surface area of 27.4 acres was calculated using the ARC/INFO software. If the area of the watershed is approximately 54 acres, the ratio of the watershed area to the surface area of the lake is approximately 2:1. At a typical average depth of about 17 ft, the volume of the lake at this stage is about 466 acre-feet (1.5×10^8 gal).

The lake has about 6,700 ft of shoreline. Nearly all of the shoreline has some erosion. Erosion is caused primarily by fluctuations in the lake stage, but overland runoff of precipitation to the lake also causes minor erosion (Thomas Graceffa and Associates, Inc., 1995). Depending on the slope of the shoreline, erosion extends from 5 to 25 ft from the shore onto dry land. Erosion is considered to be severe if the lake bank, trees, or manmade structures are in danger of being undercut. Severe erosion occurs along the southern part

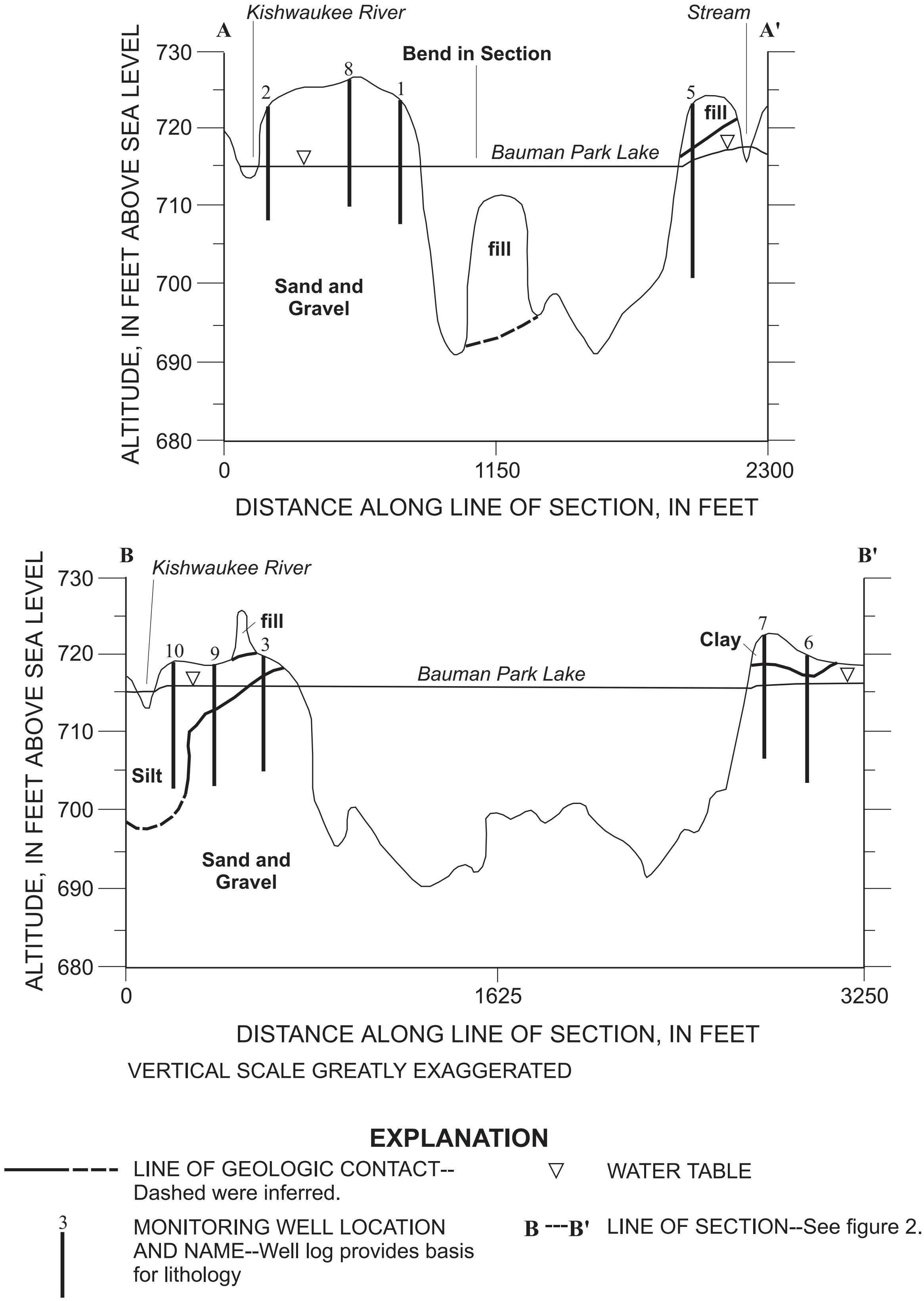

Figure **3.** Geologic sections A-A’ and B-B’, Bauman Park Lake, Cherry Valley, Ill.

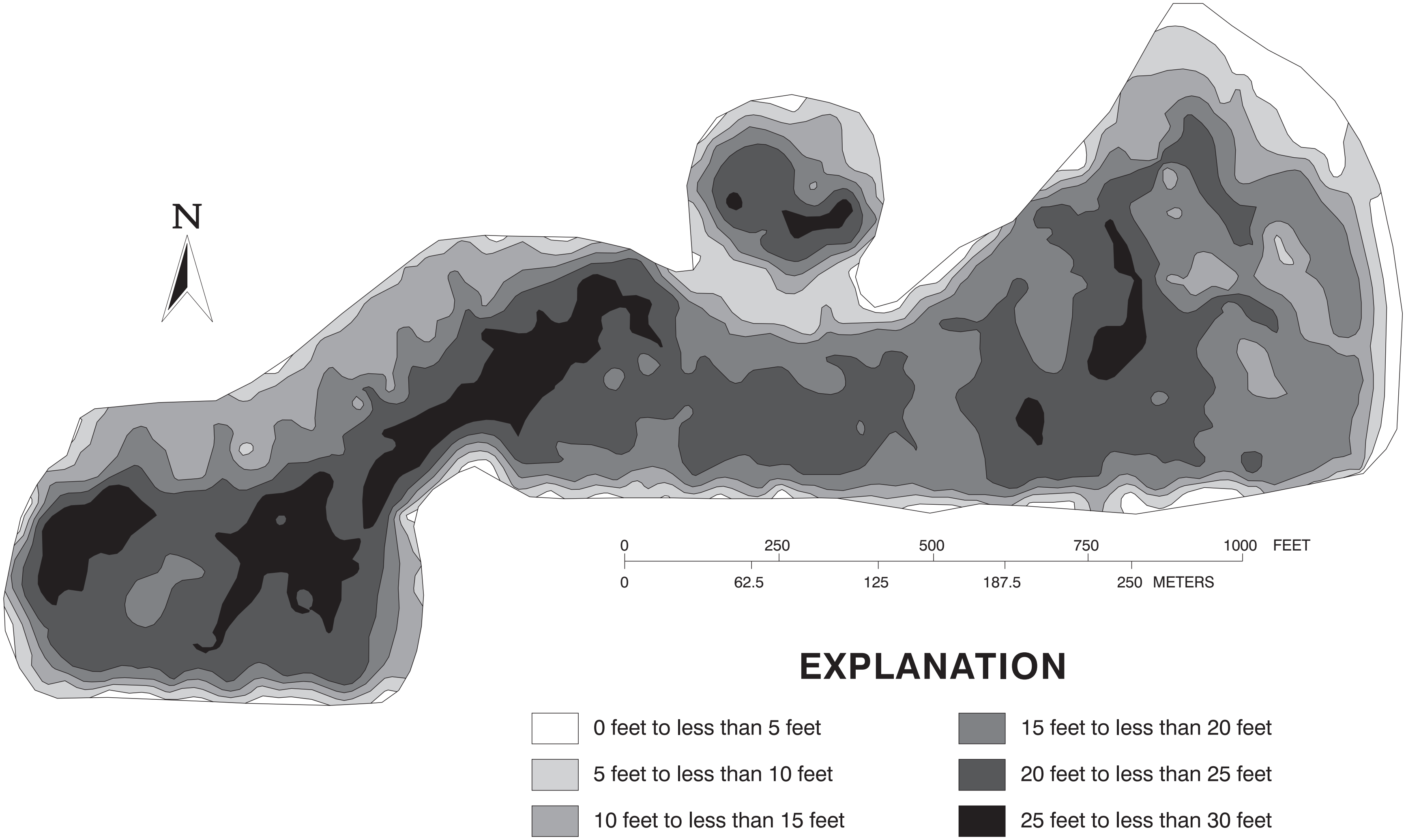

Figure **4.** Bathymetry of the Bauman Park Lake, Cherry Valley, Ill., March 21, 1997.

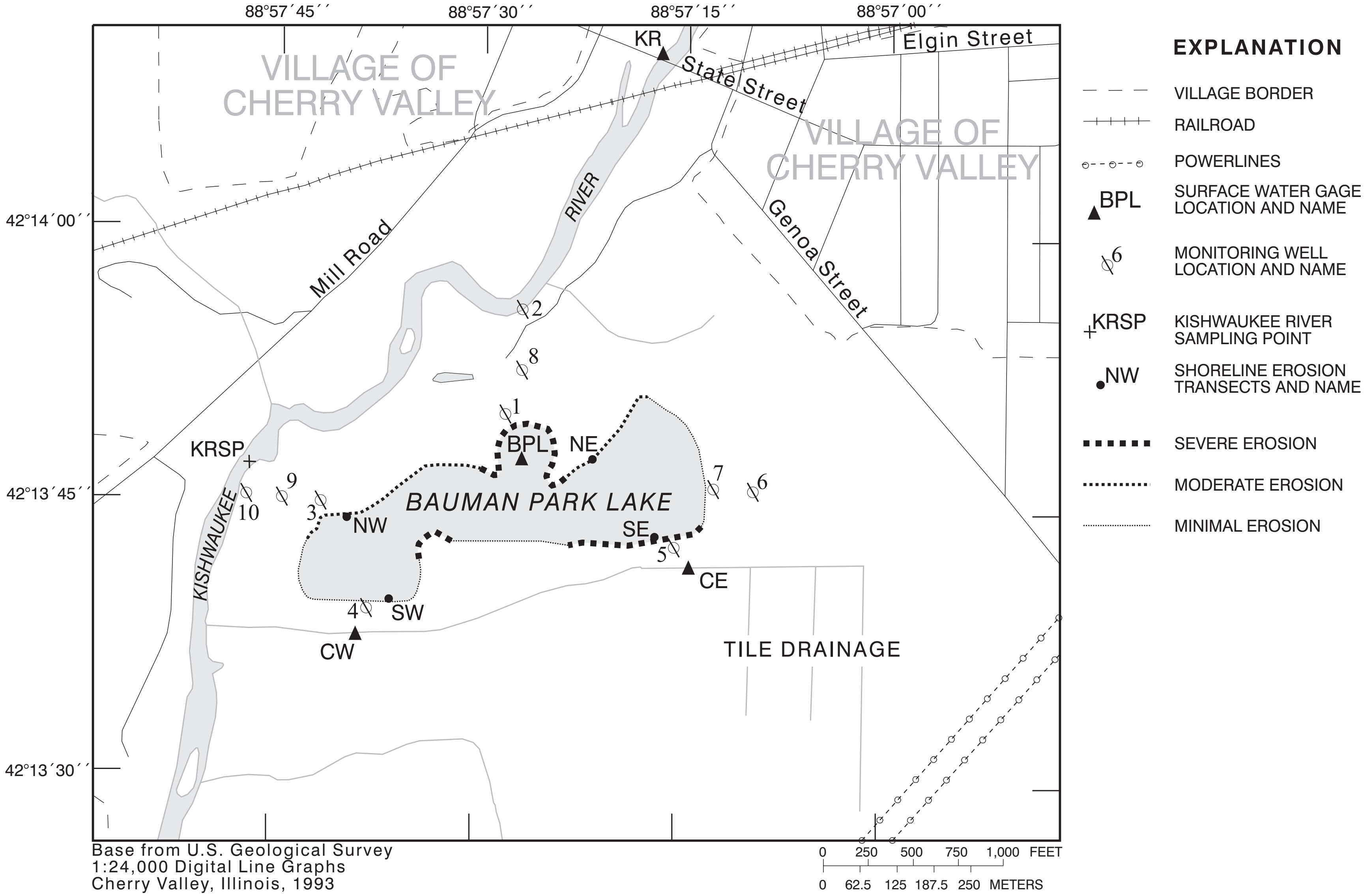

Figure **5.** Shoreline erosion at the Bauman Park Lake, Cherry Valley, Ill.

of the lake near well 5 and near the bend in the lakeshore (fig. 5). The bank is nearly vertical along much of the southern shoreline. Erosion is considered to be moderate if scouring of the sediments at the lakeshore has resulted in the removal of more than 5 ft of the vegetative cover, but there is no indication that the banks are being undercut. Moderate erosion is occurring along the northern and northwestern parts of the lakeshore. Erosion is considered minimal if there is no substantial removal of the vegetative cover. Erosion is minimal along most of the eastern and much of the southern shore of the lake.

The slope (change in distance divided by change in altitude) of the land surface in the watershed was calculated from the drainage divide near wells 4, 5, 7, 8, and 9 to the lake (fig. 3). The altitude of the land surface at these wells is given in table 1. The calculations assume a typical lake elevation of 716 ft above sea level and a uniform variation in the land surface. The distance between the wells and the shore of the lake were measured from figure 2. The slope of the land surface was calculated to be 40.0 ft/ft north of the lake near well 8, 17.9 ft/ft along the east side of the lake near well 7, 11.4 ft/ft along the west side of the lake near well 3, and about 4.4 ft/ft along the southern part of the lake near wells 4 and 5.

The slope of the land surface, in the zone of active shoreline erosion, was determined from measurements of the elevation of sediment at markers (metal posts inserted into the sediment that identify the location where measurements are to be taken) installed along the NE, SE, NW, and SW shoreline erosion transects (fig. 2) on January 23, 1997. The slope of the land surface in the zone of shoreline erosion was about 4.2 ft/ft at the NE, NW, and SW erosion transects (table 2). The land surface in the zone of shoreline erosion near the SE erosion transect was nearly vertical but had a slope of 5.2 ft/ft where the markers were located.

HYDROLOGY

The hydrologic components of the study area include precipitation, evaporation, and the interaction between ground water and the surface-water bodies, particularly the Bauman Park Lake. Each of these components affects the lake and the amount of nutrient the lake receives and discharges.

Precipitation and Evaporation

The amount of precipitation at the National Oceanic and Atmospheric Administration station at the Rockford Airport, 5 mi west of the lake, was measured daily from May 1, 1996, through April 30, 1997 (Tammy Creech, Midwestern Climate Center, written commun., 1997) (fig. 6). It is assumed that the data from this station was representative of conditions at the lake.

The total precipitation at the Rockford Airport was 44.44 in., during the period of the investigation (table 3). This total is 6.87 in. greater than the normal annual precipitation measured at this station. Monthly precipitation totals were more than 5 in. above normal in May and July 1996, and more than 2 in. below normal in September and November 1996. Monthly precipitation totals were within 2 in. of normal for the remainder of the period of investigation.

Overland runoff to the lake during storm periods was calculated using the methods outlined by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), formerly known as the U.S. Soil Conservation Service (1986, p. 2:1-2:16), and assuming overland flow to the lake from the paved areas of the watershed are negligible. Approximately 95 percent of the basin has a hydrologic soil group of D, and 5 percent has a group of A (U.S. Department of Agriculture, 1982; U.S. Soil Conservation Service, 1986). Cover type for the entire basin is considered good (more than 75 percent grass), yielding a composite runoff curve number of 78. By means of the rainfall-runoff correlation reported by NRCS (U.S. Soil Conservation Service, 1986, fig. 2.1), direct runoff was determined for each storm and totaled monthly. The rainfall-runoff correlation indicates that precipitation must exceed 0.9 in. for runoff to occur. A total of 8.09 in/acre of runoff was calculated during the investigation. Assuming the area of runoff is 26.6 acres (area of watershed basin minus the area of the lake), a volume of 5.84×10^6 gal of water was added to the lake from overland runoff from May 1, 1996, through April 30, 1997 (table 3).

The amount of monthly evaporation from the lake during the investigation was calculated using the technique of Hammon (1961) (table 3). The total evaporation during the period of investigation was calculated to be 24.66 in., which is slightly more than one-half the precipitation. Evaporation ranged from 0.13 in. in January 1997 to 4.73 in. in June 1996. Total evaporation during the 1-year period of this investigation was

Table 2 . Land-surface measurements at markers along shoreline erosion transects, Bauman Park Lake, Cherry Valley, Ill.

[na, measurement not available]

	Altitude of land surface (feet above sea level)													
	NE shoreline erosion transect				NW shoreline erosion transect			SE shoreline erosion transect				SW shoreline erosion transect		
	Marker 1	Marker 2	Marker 3	Marker 4	Marker 1	Marker 2	Marker 3	Marker 1	Marker 2	Marker 3	Marker 4	Marker 1	Marker 2	Marker 3
	January 23, 1997													
	718.21	716.90	716.15	na	718.75	717.65	716.20	na	716.20	715.45	715.25	na	716.29	na
	March 27, 1997													
	718.23	716.75	716.08	715.25	718.73	717.69	716.13	na	na	na	na	na	na	na
	May 20, 1997													
	718.45	717.13	715.57	na	718.42	717.29	715.62	716.11	715.70	715.48	na	716.62	715.81	715.46
	July 1, 1997													
	718.49	717.12	715.61	na	718.43	717.31	715.66	716.07	715.72	715.48	na	716.61	715.87	715.47
	November 4, 1997													
	718.48	716.99	715.51	na	718.44	717.30	715.72	716.09	715.69	715.29	na	716.59	715.78	715.30

	Distance between markers (feet)			
	NE shoreline erosion transect	NW shoreline erosion transect	SE shoreline erosion transect	SW shoreline erosion transect
Marker 1-Marker 2	6.2	5.7	1.9	2.4
Marker 2-Marker 3	7.3	5.7	2.3	2.7
Slope from marker 1 to marker 3 on November 14, 1997	4.5	4.2	5.2	4.0

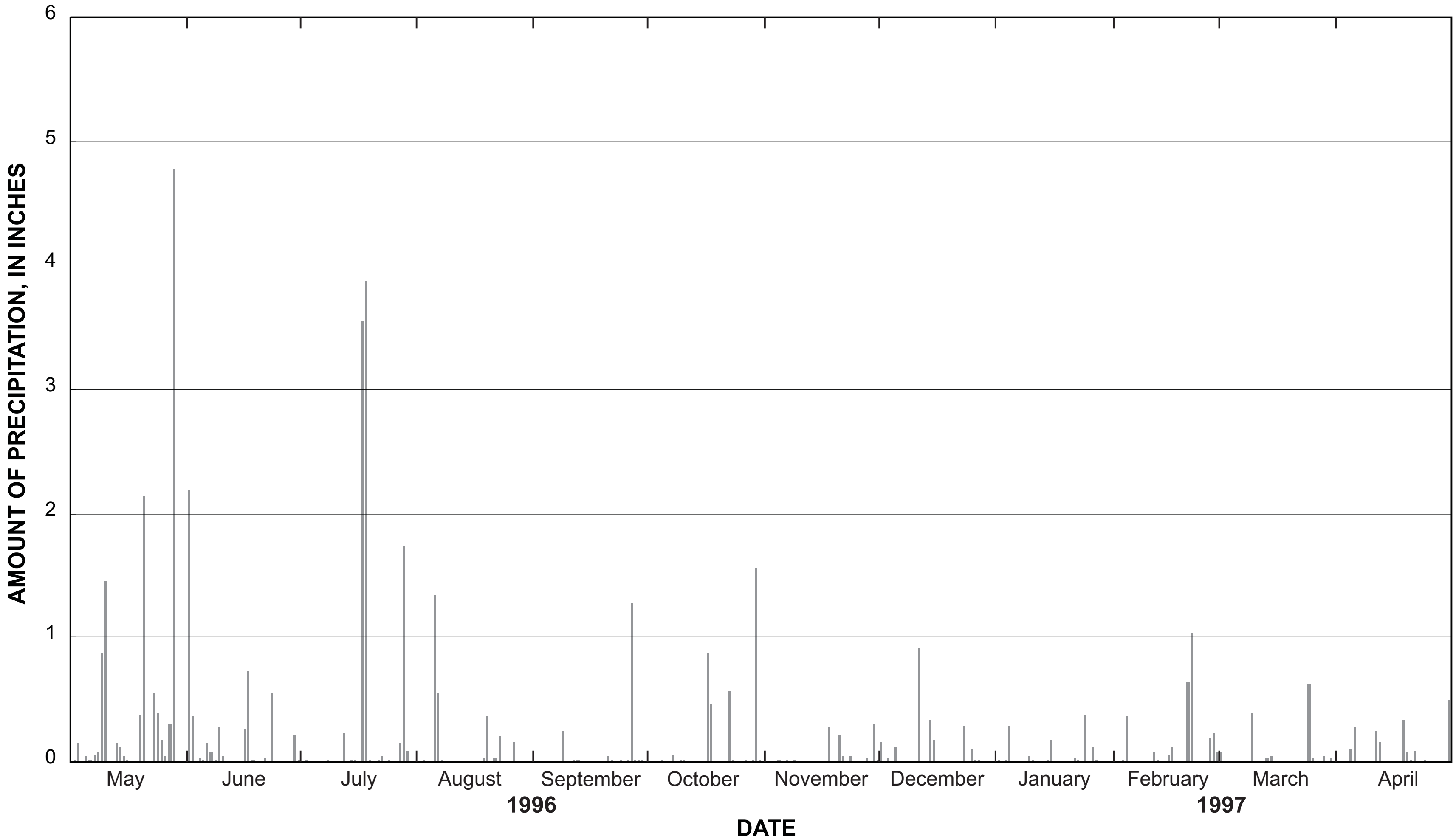

Figure 6. Precipitation at the Rockford Airport, May 1, 1996–April 30, 1997.

Table 3. Monthly summary of precipitation, overland runoff from precipitation, and evaporation data in the vicinity of the Bauman Park Lake, Cherry Valley, Ill., May 1, 1996–April 30, 1997

[+, precipitation or evaporation greater than mean or precipitation exceeds evaporation; –, precipitation or evaporation less than mean or evaporation exceeds precipitation]

Month	Precipitation measured at Rockford Airport (inches)	Deviation from mean amount of precipitation measured at Rockford, 1961–90 (inches)	Overland runoff from precipitation (inches)	Calculated amount of evaporation at Bauman Park Lake (inches)	Average monthly lake evaporation measured at Rockford, [1]1911–62 (inches)	Deviation from mean amount of evaporation measured at Rockford, 1911–62 (inches)	Difference, amount of precipitation and evaporation (inches)
			1996				
May	11.75	+8.09	3.60	2.85	4.03	−1.18	+8.90
June	4.95	+.43	.60	4.73	4.37	+.36	+.22
July	9.72	+5.60	3.35	4.61	5.09	−.48	+5.11
August	2.70	−1.45	.12	4.38	4.05	+.33	−1.68
September	1.62	−2.18	.11	2.56	2.95	−.39	−.94
October	3.56	+.68	.21	1.41	2.15	−.74	+2.15
November	.96	−2.47	.00	.61	.89	−.28	+.35
December	2.14	+.09	.05	.34	.34	+.00	+1.80
			1997				
January	1.13	−.15	.00	.13	.31	−.18	+1.00
February	2.83	+1.69	.05	.53	.57	−.04	+2.30
March	1.28	−1.18	.00	.99	1.75	−.76	+.29
April	1.80	−1.85	.00	1.52	2.90	−1.38	+.28
Total	44.44	+7.30	8.09	24.66	29.40	−4.74	19.78

4.74 in. less than the average annual evaporation for this area from 1911 to 1962, which was calculated by Roberts and Stall (1967) by means of the energy budget method. The amount of precipitation was 14.23 in. greater than the amount of evaporation from May through July 1996; 2.62 in. less than the amount of evaporation during August and September 1996; and 8.17 in. greater than the amount of evaporation from October 1996 through April 1997.

The amount of precipitation during the period of investigation exceeded the normal amount, and the amount of evaporation was less than normal. The deviation from the normal amount of precipitation and evaporation indicates that climatic conditions during the period of investigation were not representative of normal conditions. It is possible that hydrologic, chemical, and biologic conditions in the Bauman Park Lake during the period of investigation are atypical. These atypical conditions need to be considered when evaluating conditions at the lake.

Surface Water

The three surface-water bodies in this study area are the Kishwaukee River, the Bauman Park Lake, and the unnamed stream south of the lake (hereafter referred to as the stream). The drainage ditch north of the lake was dry during the study period, except during floods, and had no effect on the hydrology in the study area.

Surface-water levels were measured by means of a wire-weight gage on the Kishwaukee River at State Street (gage KR in fig. 2), a staff gage on the lake near the boat ramp (gage BPL), and two staff gages on the stream (gages CE and CW). Measurements were collected almost daily from May 6 through December 23, 1996, and several times weekly during most of the period from December 23, 1996, through April 30, 1997. Surface-water-level measurements were made by personnel from the Village of Cherry Valley. All gages were incremented to 0.01 ft. Surface-water-level measurements from these gages should be accurate to within 0.02 ft in calm water, if read correctly. Waves on the lake would result in larger measurement errors.

The stage of the Kishwaukee River measured at the KR gage (fig. 2) during the investigation ranged from 715.10 to 723.95 ft above sea level (fig. 7). The high stages measured in May through early August 1996 reflect primarily overland runoff and stormwater discharge to the river associated with specific precipitation periods in the area and further upstream in the basin (compare figs. 6 and 7). The high stage measured in late February 1997 reflects primarily overland runoff of water from widespread snowmelt in the Kishwaukee River Basin.

The stage of the Kishwaukee River also was measured near wells 2 and 10 on August 29 and October 15, 1996, and on January 23, February 19, March 27, and May 20, 1997. The river stage measured near well 2 on these dates was 0.82 to 1.57 ft lower than the river stage measured at the KR gage and 0.93 to 1.71 ft higher than the river stage measured near well 10. The distance along the river from the KR gage to well 2 is approximately 1,580 ft (fig. 2), indicating a gradient from 5.19×10^{-4} to 9.9×10^{-4} ft/ft along this reach of the Kishwaukee River. The river distance between wells 2 and 10 is approximately 2,320 ft, indicating a gradient from 4.0×10^{-4} to 7.4×10^{-4} ft/ft along this reach on these dates.

During the investigation, the stage of the Bauman Park Lake, measured at the BPL gage (fig. 2), ranged from 714.95 to more than 717.80 ft above sea level with a mean value of about 716 ft above sea level (fig. 7). The lake was covered with ice continuously from January 6 to March 8, 1997.

Before January 6, 1997, the stage of the lake rose following periods of precipitation and gradually declined until the next substantial precipitation period. During this time, the trends in the lake stage generally were a subdued reflection of the trends in the stage of the Kishwaukee River. Beginning on about February 28, 1997, the stage of the Bauman Park Lake rose gradually until mid-March, then began a gradual decline that continued until the end of the investigation. This is contrary to the trends in the stage of the Kishwaukee River, which crested on February 21, 1997, and declined through the end of April 1997. The difference in the trends in the stage of the lake and the Kishwaukee River in late February and early March 1997 indicates that ice in the ground in mid-to-late February minimized recharge of the snowmelt to ground water and enhanced overland flow to the Kishwaukee River. This resulted in a high river stage and a minimal increase in ground-water levels and lake stage. The thawing of ice in early March 1997 resulted in recharge to ground water and an increase in ground-water levels and lake stage.

The stage of the Bauman Park Lake typically was lower than the stage of the Kishwaukee River measured at the KR gage during and shortly after times of high river stage. The lake stage typically was higher than the river stage when the river stage began to return to more normal levels (fig. 7). The difference in the stage of the lake and the river indicates that ground-water flow in this area typically is toward the river.

The stream south of the lake receives water by tile drainage from farm fields south of the stream (fig. 1). The stream discharges to the Kishwaukee River during normal hydraulic conditions. The stage of the stream at the CE gage ranged from 715.70 to more than 719.53 ft above sea level during the investigation (fig. 7). The stage of the stream at the CW gage ranged from 714.57 to more than 717.79 ft above sea level during the investigation (fig. 7).

The stage of the stream at the CE gage did not vary substantially during the investigation except for peaks associated with backwater from the Kishwaukee River on May 22, 1996, the large rainfall (4.77 in.) on May 28, 1996, and the snowmelt in late February 1997. Backwater from the Kishwaukee River probably contributed to the high stream stage at the gage on May 29, 1996, and in February 1997. The stream stage returned to normal from peak values within 2 days.

The stage of the stream at the CW gage showed peaks of short duration associated with the rain in late May and early June 1996 and the runoff in late February 1997. Again, backwater from the Kishwaukee River was the probable cause of the high stream stage at the gage on May 22, 1996, and was probably a contributing factor in the high stream stage at the gage measured on May 29, 1996, and in late February 1997. The stream stage at the CW gage gradually rose during August 1996, showed minimal variation from late August through early October 1996, then rapidly declined in early October. A subdued reflection of these trends also is observed at the CE gage at this time. These trends are attributed to a beaver dam on the stream about 30 ft west of the CW gage. This dam was first observed on August 14, 1996, and destroyed on October 7, 1996.

The stream stage at the CE gage exceeded the stage at the CW gage by less than 0.10 ft during

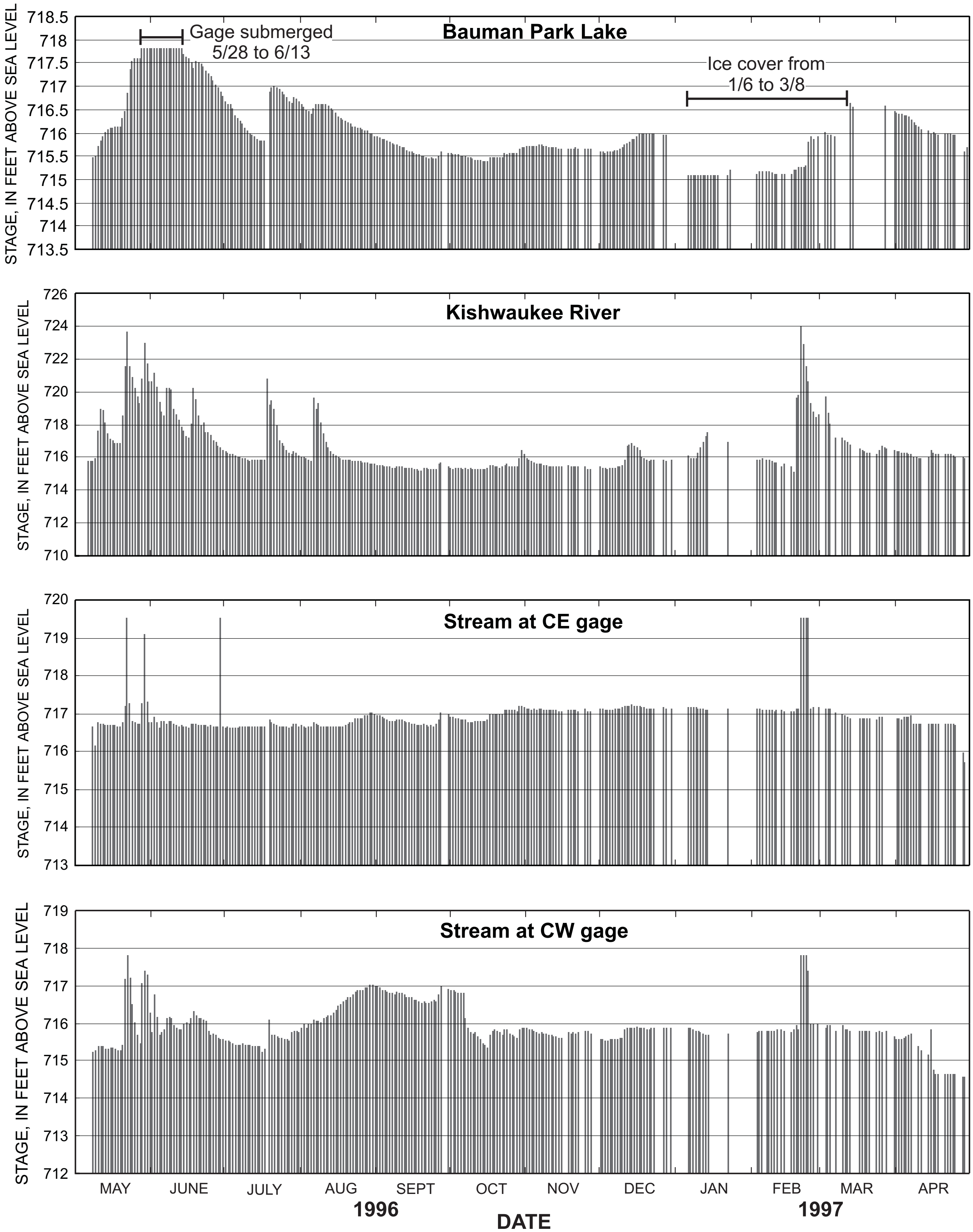

Figure 7. Stage of the Kishwaukee River, the Bauman Park Lake, and at the stream at the CE and CW gages, Cherry Valley, Ill., May 1, 1996–April 30, 1997.

periods of high water associated with precipitation events in late May and early June 1996, and periods of high water associated with the beaver dam in August through early October 1996. The stream stage at the CE gage typically exceeded the stage at the CW gage by more than 1 ft during the rest of the investigation. The difference in the stream stage typically present between the CE and CW gages can be attributed to a debris pile about 30 ft west of the CE gage that has caused the water to pool in the eastern part of the stream.

The stage of the stream at the CE gage was lower than the stage of the Bauman Park Lake from May 23 to July 1 and from July 19 to July 27, 1996. These time periods correspond to high lake stages associated with large amounts of rainfall. The stage of the stream at the CE gage was greater than the stage of the Bauman Park Lake during the rest of the investigation, indicating the potential for flow from the stream toward the lake near the CE gage during most of the investigation.

The stage of the stream at the CW gage is higher than the stage of the lake during most of the period from August 16 to November 27, 1996, and from January 6 to March 2, 1997. During these periods, the difference in the stages indicates the potential for ground-water flow from the stream toward the lake near the CW gage (approximately one-half the period of investigation) and the potential for ground-water flow from the lake toward the stream during the remaining times.

Ground Water

In the vicinity of the lake, ground water flows through unconsolidated sand and gravel deposits of the Mackinaw Member of the Henry Formation (Berg and others, 1984) (fig. 3). These deposits are approximately 100 ft thick in this area and were deposited in a tributary to the Troy Bedrock Valley. The Troy Bedrock Valley is about 3 mi east of the lake. Silty sand and clay deposits of the Cahokia Alluvium are near the Kishwaukee River. Where saturated, the deposits of the Mackinaw Member and the Cahokia Alluvium constitute what is hereafter referred to as the sand and gravel aquifer. The stratigraphic nomenclature used in this report is that of the Illinois State Geological Survey (Willman and Frye, 1970, p. 45) and does not necessarily follow the usage of the USGS.

Characterization of ground water was accomplished by the installation of 10 monitoring wells in the study area by the USGS (table 1, fig. 2). Lithologic logs, obtained during the drilling, confirm that the geologic deposits in most of the area are sand and gravel characteristic of the Mackinaw Member. A silty deposit, presumed to be Cahokia Alluvium, is present at well 10. The wells were drilled by means of hollow-stem augers with an 8-in. outside diameter. The wells were constructed so the well screen intercepted the water table. Wells 1–3 and 5–10 are approximately 15 ft deep (table 1). The boring for well 4 is 20-ft deep. The protective well casing surrounding the wells are flush with the land surface. The well screens and riser pipe are 2-in. diameter polyvinylchloride. The screens have a slot size of 0.10 in. Drill cuttings and clean gravel were used as backfill to a depth about 2 ft above the well screen. Bentonite chips were placed over the backfill and gravel, and hydrated to form a low-permeability barrier above the well screen. Finally, 1–2 ft of concrete was poured to the land surface to secure the protective casing. The wells were developed by purging a minimum of 10 times the volume of
water in the well with a bailer. Well development was completed within 2 weeks of drilling.

Slug tests were done by USGS personnel in each of the wells drilled for this study to determine the horizontal hydraulic conductivity of the sand and gravel aquifer (table 4). Slug tests consisted of removing a bailer filled with water from the well; then measuring the water-level rise over time with a pressure transducer capable of reading changes in water level of less than 0.01 ft.

Slug-test data for wells 1–7 exhibited an oscillatory water-level response and were analyzed by means of the oscillatory response technique developed by van der Kamp (1976). This technique was developed for analysis of slug-test data from highly permeable aquifers where the effects of the inertia of water in the well dominate the aquifer response (underdamped response). A fully penetrating well in a confined aquifer is assumed for data analysis with application of this technique. The aquifer storage coefficient was assumed to be 0.001 when aquifer transmissivity was calculated. This storage coefficient is probably representative of conditions where the entire well screen is below the water table (wells 3–7) but is too high for a sand and gravel aquifer where the water table intercepts the well screen (wells 1 and 2). The technique became mathematically unstable and transmissivity could not be calculated when larger storage coefficients were

Table 4. Horizontal hydraulic conductivities calculated from slug-test data in the vicinity of the Bauman Park Lake, Cherry Valley, Ill.

[ft/d, feet per day; NT, no test done; NA, not applicable]

Ground-water-monitoring well name	Storage coefficient (dimension-less)	First test (ft/d)	Second test (ft/d)	Average horizontal hydraulic conductiv-ity value (ft/d)
1	0.001	9.9×10^{1}	1.3×10^{2}	1.2×10^{2}
2	.001	1.5×10^{2}	2.1×10^{2}	1.8×10^{2}
3	.001	1.1×10^{2}	1.1×10^{2}	1.1×10^{2}
4	.001	1.6×10^{2}	1.2×10^{2}	1.4×10^{2}
5	.001	1.3×10^{2}	NT	NA
6	.001	1.1×10^{2}	1.1×10^{2}	1.1×10^{2}
7	.001	2.2×10^{2}	2.0×10^{2}	2.1×10^{2}
8	NA	2.8×10^{2}	1.2×10^{2}	2.0×10^{2}
9	NA	7.9×10^{2}	1.1×10^{2}	4.5×10^{2}
10	NA	2.4×10^{-1}	2.5×10^{-1}	2.5×10^{-1}
Mean of all values = 79 ft/d				

used in the calculations, so that values from wells 1 and 2 should be considered the best available estimates. The thickness of the aquifer was assumed to equal the saturated thickness of the well screen when horizontal hydraulic conductivity was calculated from the transmissivity value.

Slug-test data for wells 8–10 displayed a continual decline in water levels with time and were analyzed using the technique of Bouwer and Rice (1976). This technique was developed for use in aquifers under unconfined conditions with wells that fully or partially penetrate the aquifer.

The following conditions are assumed in the application of the van der Kamp, and the Bouwer and Rice techniques:

1. The water-level change in the vicinity of the well is negligible,
2. Flow above the water table can be ignored,
3. Head losses as the water enters the well are negligible,
4. The hydraulic unit is homogeneous and isotropic.

These conditions are met or approximated at this site.

The following assumptions were made when analyzing the slug-test data:

1. The radius of the casing is equal to the radius of the inner casing if the water-level altitude measured before the start of the test was above the top of the screened interval of the well. If this was not the case, the radius of the casing was computed applying the technique described by Bouwer and Rice (1976, p. 424);
2. The length of the well through which water enters the aquifer is equal to the length of the screened interval of the well if the water-level altitude measured before the start of the test was above the top of the well screen. If this was not the case, the value is equal to the distance from the bottom of the well screen to the water level measured before the start of the test; and
3. The borehole radius is equal to the nominal outside diameter of the auger (8 in.) used to drill the well.

These assumptions greatly simplify the analysis of the slug-test data and should not result in a substantial error in the calculated horizontal hydraulic conductivities.

Calculated horizontal hydraulic conductivities of the sand and gravel aquifer at a well ranged from 2.5×10^{-1} to 7.9×10^{2} ft/d (table 4). Well 10 is the only well where a horizontal hydraulic conductivity less than 9.9×10^{1} ft/d was calculated. Well 10 is located within 30 ft of the river and probably is open to the Cahokia Alluvium. Horizontal hydraulic conductivity values at this well probably are not representative of the aquifer in the vicinity of the Bauman Park Lake. The geometric mean of the horizontal hydraulic conductivities for all wells was calculated at 7.8×10^{1} ft/d. The geometric mean of the horizontal hydraulic conductivity for all wells, except well 10 was calculated at 1.6×10^{2} ft/d.

Approximately every week from May 11 through October 28, 1996, and between March 27 and April 29, 1997, water levels were measured in each of the wells. Ground-water levels were measured infrequently from October 28, 1996, through March 27, 1997. Ground-water levels typically were measured by personnel from the Village of Cherry Valley. Water levels also were measured on May 20, 1997. Water-level data collected on May 20, 1997, included data from selected ground-water-monitoring wells drilled in April 1997 for a separate investigation and is the most complete data set available for this report. Ground-water levels were measured by means of a steel or electric tape graduated in increments of 0.01 ft.

Surface- and ground-water-level measurements were used to construct maps showing the altitude and configuration of the water table on each of the dates of measurement. Ground water flows perpendicular to the water-table contours. Four distinct water-table configurations were observed during the period of investigation.

The water-table configuration depicted in figure 8 is typical of conditions during most of the investigation (May 18, July 10, August 17, November 13, December 14, and December 28, 1996, and March 27, April 5, April 11, April 17, and April 29, 1997). Although these data were collected on May 20, 1997, after the end of the investigation, these data were used because they are the most complete set of water levels available for the study area. Ground-water flow generally was from east to west, toward the Kishwaukee River. Under these conditions, ground water had the potential to flow into the lake along most of the southern and eastern parts of the lake. Lake water had the potential to flow out to ground water along the northern, western, and southwestern parts of the lake under these conditions. Under these conditions, water from the stream had the potential to flow out to ground water near the CE gage, and ground water had the potential to flow into the stream near the CW gage. This water-table configuration appears to reflect the hydraulic effects of the lake superimposed on the regional pattern of ground-water flow toward the river (Berg and others, 1984, fig. 16a).

The water-table configuration depicted in figure 9 is typical of conditions during periods of flooding in the Kishwaukee River and the stream (May 29 and July 20, 1996, and February 19, 1997). The overall direction of ground-water flow was from north to south, toward the lake. Under these conditions, water from the Kishwaukee River had the potential to flow into ground water along the entire reach of the river. It appears that flow from the river into ground water is considerably greater north of the lake near wells 2 and 8 than west of the river near wells 9 and 10, indicating that the low-permeability deposit near well 10 is present along much of the riverbank west of the lake, restricting the amount of flow between ground water and the river. Under these conditions, ground water had the potential to flow into most of the northern and eastern parts of the lake. During these periods, lake water had the potential to flow out to ground water along the southern part of the lake, unless the stream stage was high enough to create the potential for flow from the stream to ground water and for ground-water flow into the southern part of the lake. This water-table configuration probably is present for only a few days during and after flooding.

The water-table configuration depicted in figure 10 is a transitional configuration following periods of high precipitation and flooding as the lake stage decreased to more typical levels (May 25, June 12, June 15, June 25, and July 1, 1996). The overall direction of ground-water flow was from east to west, away from the lake. Under these conditions, ground water had the potential to flow into the eastern part of the lake, whereas lake water had the potential to flow out to ground water along the northern, southern, and western parts of the lake. This water-table configuration indicates that water in the lake drains into the ground water.

The water-table configuration depicted in figure 11 is typical of conditions during and shortly after the period when the beaver dam was present near the CW gage and flow out of the stream into ground water was enhanced (August 17–October 28, 1997). The overall direction of ground-water flow was from south to north, toward the river. Ground water flowed into the southern and eastern parts of the lake, under these conditions. At this time, lake water flowed out to ground water along the northern and western parts of the lake, .

Horizontal hydraulic gradients were calculated along the southeastern part of the lake (typically between the CE gage and the lake), the eastern part of the lake (typically between well 6 and the lake), the northern part of the lake (typically between the lake and well 2), the western part of the lake (typically between the lake and well 9), and the southwestern part of the lake (typically between the lake and the CW gage)
during 32 of the 33 measurement periods (app. 1). Gradients were not calculated for the data collected

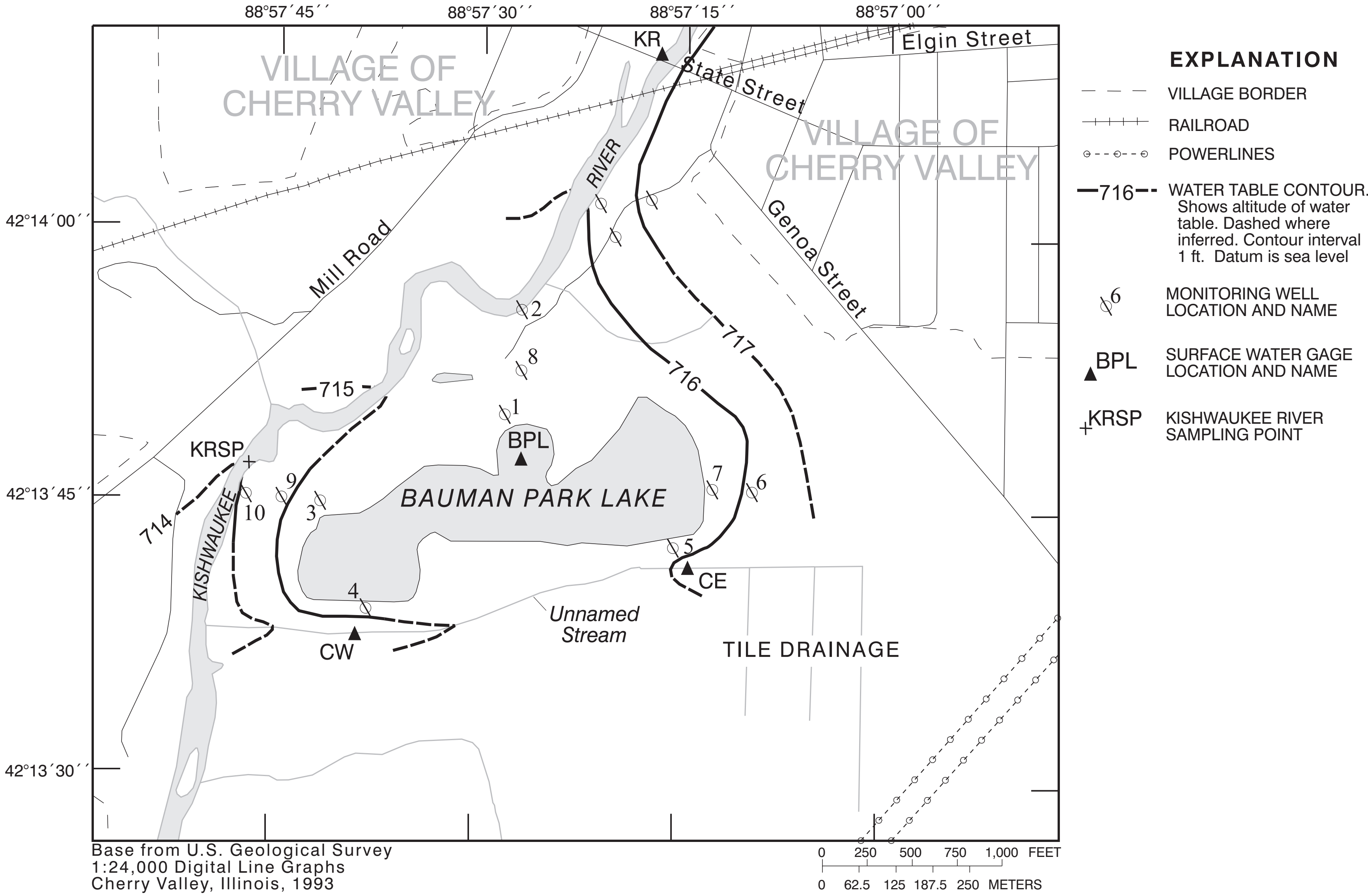

Figure 8. Water-table configuration in the vicinity of the Bauman Park Lake, Cherry Valley, Ill., May 20, 1997.

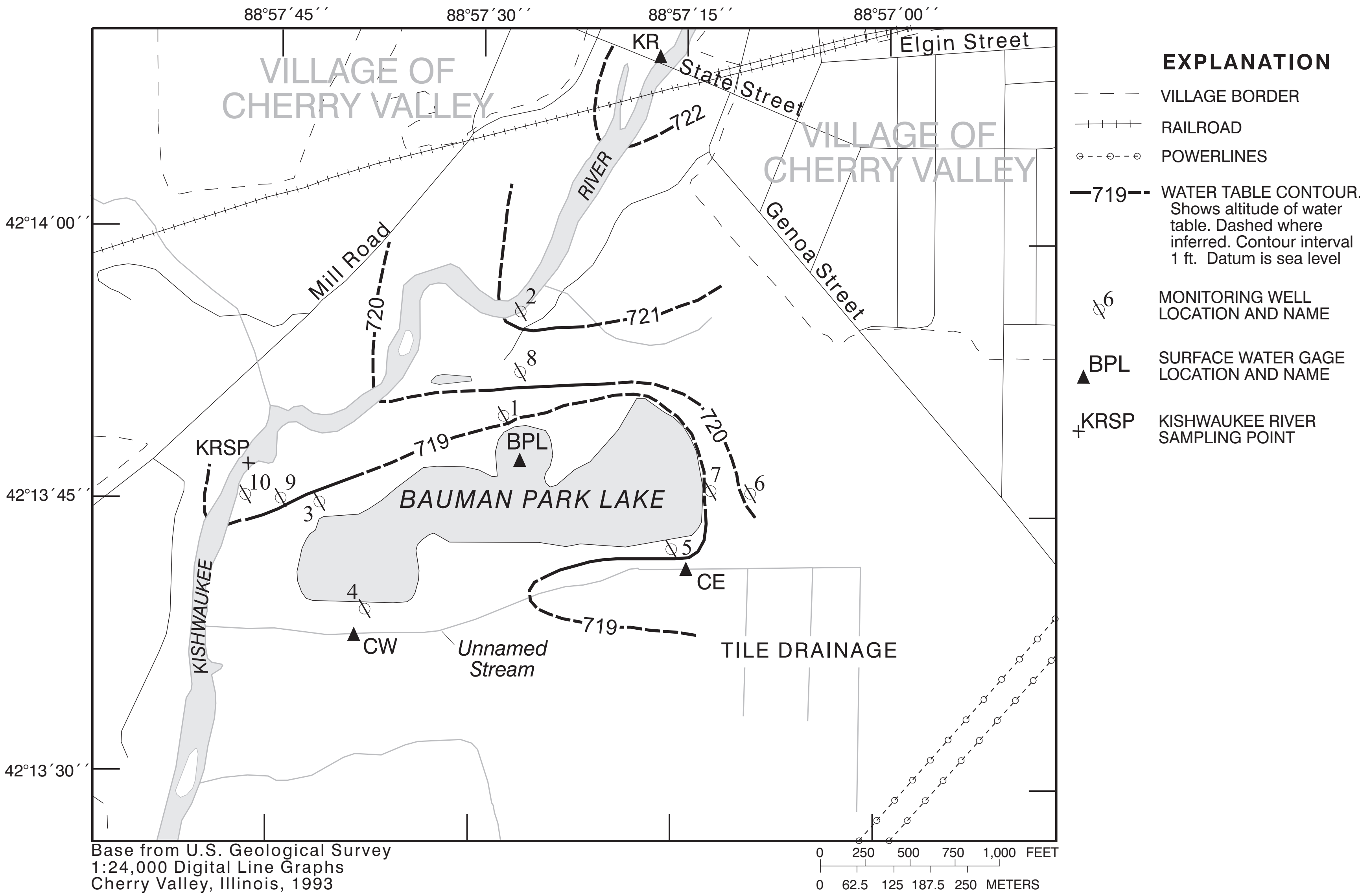

Figure 9. Water-table configuration in the vicinity of the Bauman Park Lake, Cherry Valley, Ill., May 29, 1996.

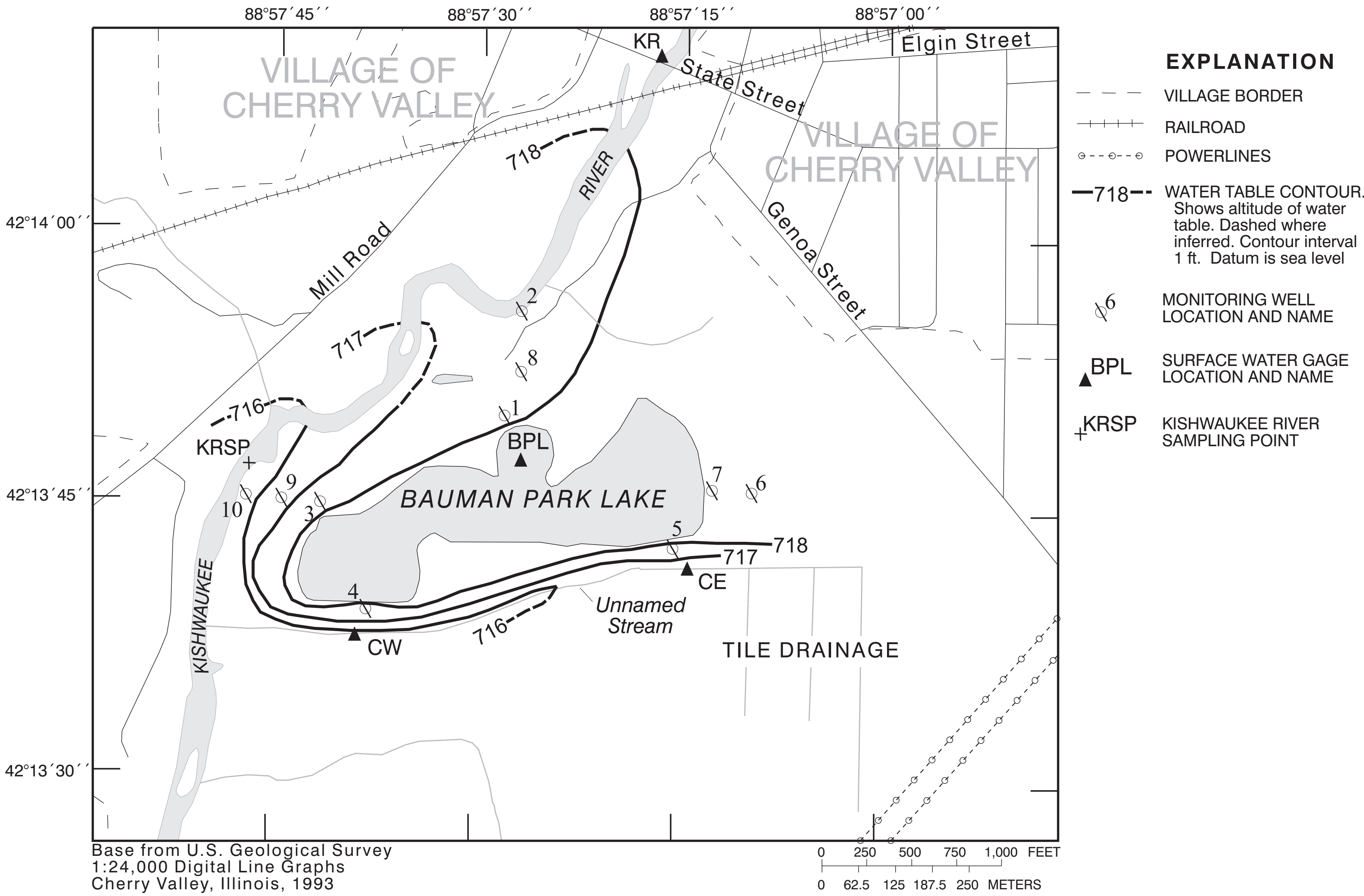

Figure 10. Water-table configuration in the vicinity of the Bauman Park Lake, Cherry Valley, Ill., June 12, 1996.

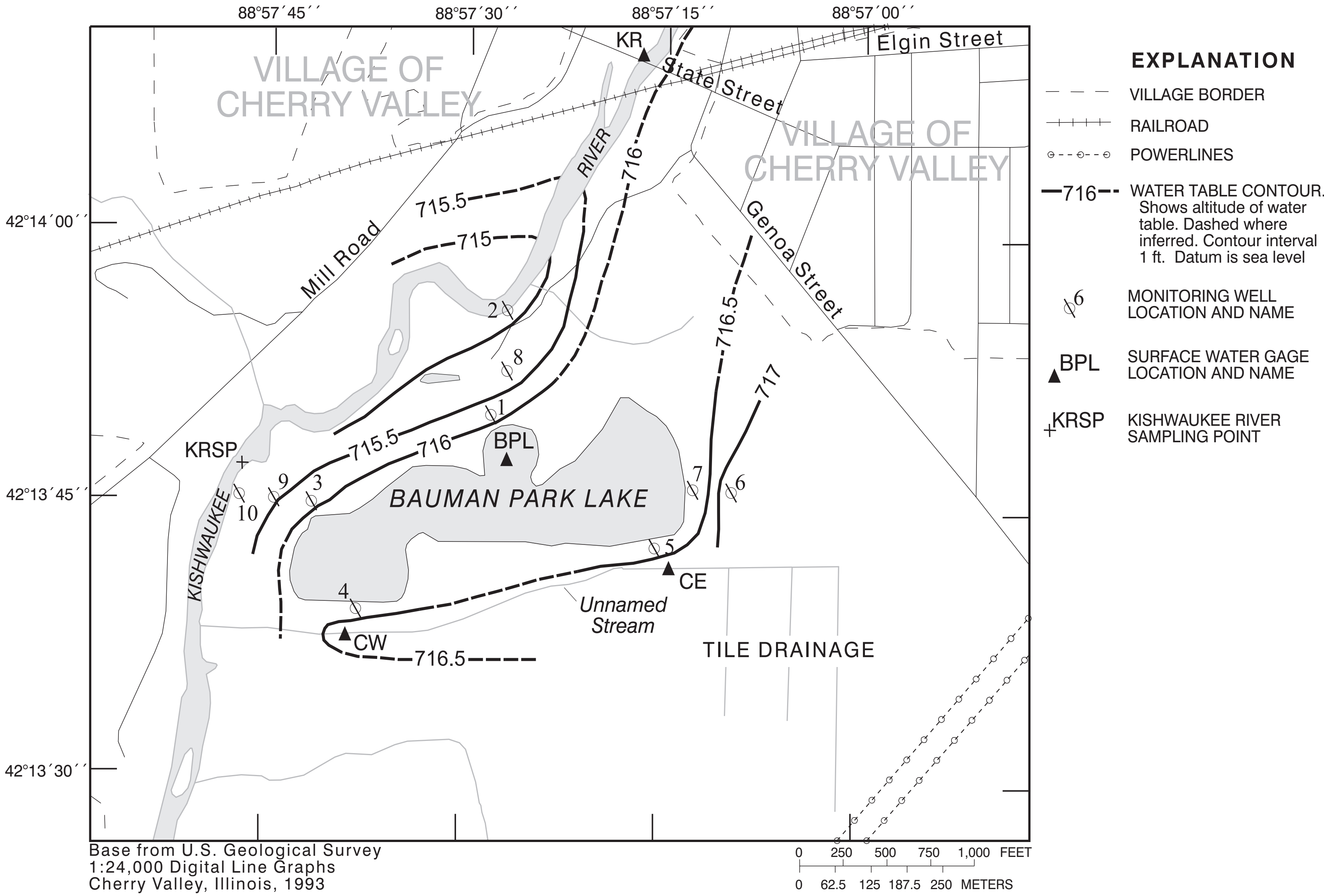

Figure 11. Water-table configuration in the vicinity of the Bauman Park Lake, Cherry Valley, Ill., August 24, 1996.

on May 29, 1996, because wells 6, 9, and 10 were submerged by surface water. A complete set of measurements was collected on June 2, 1996. Horizontal hydraulic gradients are calculated by dividing the change in the altitude of the water table (dh) along two points parallel to the direction of ground-water flow by the horizontal distance between those points (dl). The direction of flow is from the first point of water-level measurement (h1) to the second point (h2).

During the measurement periods, the specific discharge (Q) into or out of the lake was calculated at the southeastern, eastern, northern, western, and southwestern parts of the lake, by solving

$$Q = KAI, \quad (1)$$

where,

K is the horizontal hydraulic conductivity, in feet per day and is equal to the mean of the values obtained from the slug tests (78 ft/d);

A is the cross-sectional area of flow between the aquifer and the lake and is equal to the length of the lakeshore along which water is being recharged or discharged multiplied by the average depth of the lake. The average depth of the lake was calculated by taking the lake stage at the time of the measurements and assuming the average depth of the lake is 18 ft at a stage of 717 ft above sea level; and

I is the horizontal hydraulic gradient, in ft/ft.

The volume (V) of water flowing from ground water into the lake or flowing out of the lake to ground water was calculated for each of the measurement periods by multiplying the specific discharge by the time period (t) that the specific discharge is assumed to represent (app. 1). This calculation assumes horizontal flow to and from the lake through the nearly vertical sides of the quarry walls (fig. 4). Inflow or outflow through the bottom of the lake is assumed to be minimal. Volume of flow from May 1 through May 10, 1996, was assumed to be proportionate to the flow for the remainder of the month. From May 11, 1996, through February 19, 1997, volume was calculated by multiplying the specific discharge on any given date by the amount of time until the next measurement date. A value for time of 7 days was assumed when calculating the volume of flow during February 19–26, 1997. From February 27 to April 30, 1997, the volume of flow was calculated by multiplying the specific discharge on the measurement date by the amount of time from the previous measurement date.

The total volume of flow from ground water into the lake was calculated to be 9.1×10^6 ft^3 (6.8×10^7 gal) during the period of measurement (table 5). The total volume of flow out of the lake into

Table 5. Water inputs at the Bauman Park Lake, Cherry Valley, Ill., May 1996–April 1997

Month	Volume of precipitation added to lake (gallons)	Volume of overland runoff to lake (gallons)	Volume of evaporation removed from lake (gallons)	Volume of inflow to lake from ground water (gallons)	Volume of outflow to ground water from lake (gallons)	Total volume of water added to lake (gallons)	Total volume of water removed from lake (gallons)
1996							
May	8,752,772	2,600,123	2,143,536	14,491,379	8,700,843	25,923,571	10,844,379
June	3,684,203	433,354	3,520,460	6,716,943	15,743,981	10,847,716	19,264,441
July	7,234,434	2,419,559	3,431,146	1,832,425	8,817,739	11,560,208	12,248,885
August	2,009,565	86,671	3,259,961	3,498,050	6,977,391	5,596,929	10,237,352
September	1,205,739	79,448	1,905,365	9,290,925	4,056,959	10,578,535	5,962,324
October	2,649,053	151,674	1,049,440	8,102,822	4,191,351	10,908,175	5,240,790
November	714,512	0	454,013	6,082,048	2,323,087	6,796,560	2,777,100
December	1,589,789	36,113	253,056	6,716,743	5,525,700	2,818,046	5,778,756
1997							
January	839,552	0	96,757	3,052,438	6,189,761	3,891,989	6,286,518
February	2,106,024	36,113	394,470	1,891,658	3,980,334	4,034,896	4,374,804
March	982,454	0	714,512	4,366,990	4,920,295	5,349,444	5,634,806
April	1,339,710	0	1,161,082	2,418,653	9,642,746	3,758,363	10,803,828
Total	33,107,807	5,843,055	18,383,798	68,461,074	81,070,187	102,064,432	99,453,984

ground water was calculated at 1.1×10^7 ft^3 (8.1×10^7 gal).

Lake Stage and Storage

Because the sides and shoreline of the lake have a high slope, any realistic change in lake stage will not appreciably affect the surface area (27.4 acres) of the lake. Therefore, every 1 ft of change in the stage of the lake will result in a change of about 27.4 acre-ft (8.93×10^6 gal) in the volume of water stored in the lake.

Sediment is deposited into the lake from shoreline erosion. In addition, the quarry walls that constitute the sides of the lake may be too steep below the lake surface to be mechanically stable and eventually could slump into the lake. Over a period of time, erosion of shoreline sediments and slumping of sediments from the sides of the lake will make the lake shallower and wider. This will eventually result in a substantial change in the storage capacity of the lake and alter the stage-storage relation.

Determining the volume of sediment added to the lake from slumping of the sides is beyond the scope of this investigation. To quantify the volume of sediment added to the lake from erosion at the shoreline, changes in the altitude of the land surface in the zone of shoreline erosion were measured at a series of markers installed at the NE, NW, SE, and SW shoreline erosion transects (fig. 2) from January 23 to March 27, 1997 (table 2). The metal stakes that marked the measurement points along the shoreline erosion transects were vandalized sometime after March 27, 1997, and new stakes were installed in the vicinity of the original stakes on May 20, 1997. Changes in the altitude of the land surface at the locations of the new stakes were measured on May 20, July 1, and November 14, 1997. It is assumed that conditions during the measurement period are representative of conditions from May 1996 through April 1997.

The altitude of the land surface measured between markers 1 and 2, and markers 2 and 3 during a measurement period was divided into geometric shapes (triangles, rectangles) so that the area between adjacent markers and the land surface along the shoreline erosion transects could be approximated. Differences in the these areas were compared between successive measurements to calculate the area of eroded sediment. A uniform decrease in the land surface between adjacent markers was assumed for the calculations. The area of erosion along a line of transect was multiplied by the length of the lakeshore, over which conditions at the transect are assumed to be representative, to determine the volume of sediment entering the lake from erosion.

Erosion conditions at the NE shoreline erosion transect are assumed to be representative of conditions from the boat ramp to the southeast part of the lake, a distance of about 1,900 ft. Erosion at the NW transect is assumed to be representative of conditions from the boat ramp to the northwest edge of the lake, a distance of about 1,800 ft. Erosion at the SE transect is assumed to be representative of conditions in the area of near vertical slopes along the southeastern part of the lake, a distance of about 1,000 ft. Erosion at the SW transect is assumed to be representative of conditions along most of the western and southern part of the lake except near the SW transect, a distance of about 2,000 ft.

Comparison of the altitude of the land surface at the markers along the transects on January 23 and March 27, 1997, indicated no discernible changes at the NW, SW, and SE shoreline erosion transects. Sediment covering an area of about 1.05 ft^2 had been eroded at the NE transect from January 23 through March 27, 1997. Comparison of the altitude of the land surface at the markers along the shoreline erosion transects on May 20 and July 1, 1997, indicated no discernible changes at any of the transects. Comparison of the altitude of the land surface at the markers along the transects on July 1 and November 14, 1997, indicated sediment with an area of about 0.68 ft^2, 0.16 ft^2, 0.22 ft^2, and 0.46 ft^2 had been eroded at the NE, NW, SE, and SW shoreline erosion transects, respectively. A volume of about 1,995 ft^3 of sediment had eroded into the lake from January 23 through March 27, 1997, at the NE transect. About 1,292 ft^3, 288 ft^3, 220 ft^3, and 920 ft^3 of sediment had eroded from the shoreline into the lake between May 20 and November 14, 1997, at the NE, NW, SE, and SW transects, respectively. The total amount of erosion from January 23 to November 14, 1997, was 4,714 ft^3. If this load was spread evenly over the entire lake bottom, it would equate to a thickness of about 2.7×10^{-2} in. There is minimal change in the storage capacity of the lake because of erosion from shoreline sediments.

Hydrologic Budget

A general equation describing the water budget of a lake consists of several components that are summarized as

$$DS = P - E + SI + SR - SO + GI - GO + WW - DW \quad , \qquad (2)$$

where,

DS is the change in volume of lake storage,
P is precipitation on the lake surface,
E is evaporation off the lake surface,
SI is streamflow into the lake,
SR is surface runoff into the lake,
SO is surface outflow through the lake outlet,
GI is ground-water inflow to the lake,
GO is ground-water outflow from the lake,
WW is wastewater discharge to the lake, and
DW is water removed from the lake for drinking or industrial use.

The streamflow, wastewater discharge, removal for drinking water, and surface outflow components of the water budget are absent at the Bauman Park Lake. Therefore, the equation for determining the water budget of Bauman Park Lake is

$$DS = P - E + GI - GO + SR . \qquad (3)$$

The change in lake storage volume was determined using a stage-storage relation derived from the bathymetric map of the lake (1 ft of change in lake stage is equal to about 8.93×10^6 gal of water in storage).

The volume of water added to or removed from the lake by each of the components of the lake budget (precipitation, evaporation, overland runoff, inflow from ground water to the lake, and outflow from the lake to ground water) were compiled monthly for the period of investigation (table 5). The volume of water entering the lake during the period of investigation was approximately equal to the volume of water leaving the lake. A total of about 1.02×10^8 gal of water was calculated to have entered the lake, mainly from ground-water inflow (about 66 percent) and precipitation (about 32 percent), during the 1-year period of investigation. A total of about 9.95×10^7 gal of water was calculated to have been removed from the lake by flowing to ground water (82 percent) and evaporation (18 percent) during the 1-year period of investigation. If about 9.95×10^7 gal of water is removed from this lake every year, and the lake has a volume of about 1.5×10^8 gal, then the residence time of water in the Bauman Park Lake is about 1.5 years.

If the difference in the amount of water added to and removed from the Bauman Park Lake over the period of the investigation (2,432,249 gal) (table 5) is divided by the volume of water required to change lake stage by 1 ft (8.93×10^6 gal), it is calculated that the lake stage should have increased 0.29 ft over the period of investigation. The stage of the Bauman Park Lake measured at the BPL gage at the beginning of the investigation was 0.19 ft higher than the measured stage at the end of the investigation. The difference in the measured and calculated change in lake stage is less than 1 percent of the volume of water in the lake. The small variation between the measured and calculated changes in lake stage indicates that the calculated volumes of flow into and out of the lake are a good approximation of the actual volumes of flow.

Differences between the measured and calculated lake stage and volumes of flow into the lake can be related to uncertainty in the (1) accuracy of the specific components of the water budget associated with variations in rainfall between the measuring station and the lake, (2) effect of snowmelt on the volume of water added to the lake, (3) calculation of the amount of evaporation off the lake, (4) horizontal hydraulic conductivity of the aquifer, (5) effects of construction activities at the park on precipitation runoff, (6) area of lakeshore through which ground water is flowing, (7) uncertainty in the lake level prior to gage installation and during periods of gage submergence and ice cover, and (8) frequency of stage and ground-water measurements. When combined, the individual uncertainties can cause some variation in the calculated water budget (Winter, 1981). There also is a lag between the time water is added to and removed from the lake. This lag affect can impact the agreement between the calculated and measured water balance. Uncertainties in the water budget can be minimized by obtaining realistic estimates of each of the components of the water budget (assuming no residual component) (Winter, 1981).

WATER QUALITY

Water-quality samples were collected from the Kishwaukee River, monitoring wells, and the lake as part of this investigation. Profiles of temperature and dissolved oxygen at depth and algae samples in the lake also were collected. Samples from ground-water monitoring wells and the Kishwaukee River were collected by USGS personnel. Water-quality and algae samples from the lake, and temperature and dissolved oxygen profiles of the lake were collected by personnel from the IEPA and the Village of Cherry Valley. All samples were collected and analyzed by means of standard procedures outlined by the Illinois Environmental Protection Agency (1987a, 1987b).

Samples from the Kishwaukee River and the monitoring wells were analyzed for total and dissolved phosphorus, nitrate and nitrite as nitrogen, total Kjelhdahl nitrogen (TKN), ammonia nitrogen, volatile suspended solids (VSS), total suspended solids (TSS), and turbidity by the IEPA laboratory in Champaign, Ill. The concentration of turbidity, VSS, and TSS in all samples was from one to three orders of magnitude greater during the first sampling event than during subsequent sampling events. The reason for this discrepancy is unclear. Visual observation of the samples from the monitoring wells and the Kishwaukee River, however, indicates that high concentrations of turbidity, VSS, and TSS should have been detected in samples during each of the sampling events. The results of the analysis for turbidity, VSS, and TSS in all of the samples from the river and monitoring wells are considered unreliable and are not discussed in this report.

Samples were collected from the Bauman Park Lake at sites 1 and 2 (fig. 2). Samples collected at the surface at sites 1 and 2 (sites 1S and 2S) and at the bottom of the lake at site 1 (site 1D) were analyzed for nitrate and nitrite as nitrogen, ammonia nitrogen, TKN, dissolved phosphorus, total phosphorus, TSS, VSS, turbidity, total alkalinity, and phenolphthalein alkalinity by the IEPA laboratory in Champaign, Ill. The conductivity, pH, and Secchi depth of the lake were measured in the field. These are the standard IEPA analytes for an investigation of lake-water quality. Samples collected at sites 1I and 2I were analyzed for concentrations of chlorophyll *a*, *b*, and *c*; pheophytin; and numbers of algae. Chlorophyll *a* concentrations were corrected to account for interferences caused by the presence of pheophytin, a breakdown product of chlorophyll *a*. Chlorophyll and algae samples are integrated samples collected from the surface to a depth of 2 ft above the lake bottom. This interval samples the photic zone of the lake. No water-quality data were collected from the Bauman Park Lake prior to this investigation. When the mean concentration of the analyte was calculated, a concentration of one-half the reported detection limit was assumed for all analytes present at concentrations below the detection limit.

All samples analyzed for total dissolved phosphorus and total dissolved solids (TDS) were poured into a clean stainless-steel bowl and pumped through a 0.45 micron filter into 1-liter, plastic sample bottles. All other samples were poured, unfiltered, into 0.150-liter plastic bottles. Sample bottles were obtained from the IEPA with a sufficient amount of preservative already added, if appropriate. Once the samples were collected, they were placed in a cooler filled with ice and transported to the IEPA offices in Rockford, Ill. within 8 hours of collection for next-day shipment to the IEPA laboratory in Champaign, Ill.

Kishwaukee River

Water samples were collected from the Kishwaukee River at the KRSP sampling point (fig. 2) on June 25, 1996, November 13, 1996, February 19, 1997, and April 29, 1997. The sample from the river was collected by submerging a clean, stainless-steel bowl into the river and transferring the water into the sample bottle. The sample was collected at the riverbank near well 10, which is where the effects of water flowing into the river from ground water would be greatest. Tertiary treated sewage is discharged to the river from a number of municipalities upstream from the sampling point.

Nitrogen usually is present in the form of organic nitrogen and inorganic forms such as ammonia, nitrate, and nitrite. Ammonia, a byproduct of the breakdown of plant and animal matter, is converted to nitrate in aerobic water. In anoxic water, nitrate is converted to ammonia. Therefore, nitrate tends to be the predominant form of nitrogen in aerobic water, whereas ammonia is the predominant form of nitrogen in anaerobic water. Denitrification, the biochemical reduction of nitrate to nitrite and then to gaseous nitrogen, is a potentially important nitrogen sink in lakes (Keeney, 1973) and is affected by the oxygen supply, pH, temperature, and the type of bacteria present in the lake.

Concentrations of nitrate and nitrite as nitrogen in samples from the Kishwaukee River ranged from 1.24 mg/L on February 19, 1997, to 5.9 mg/L on June 25, 1996. The mean concentration for all samples was 2.57 mg/L. Concentrations of ammonia nitrogen ranged from 0.14 mg/L on April 29, 1997, to 1.3 mg/L on February 19, 1997. The mean concentration of ammonia nitrogen for all samples was 0.31 mg/L.

The concentration of TKN is a measure of the chemically reduced nitrogen present as ammonia and organic nitrogen. Organic nitrogen typically is present as algae, humic acids, and plant matter. Concentrations of TKN in samples from the Kishwaukee River ranged from 0.63 mg/L on April 29, 1997, to 2.70 mg/L on November 13, 1996. The mean concentration for all samples was 1.56 mg/L. Ammonia concentrations are substantially lower than TKN concentrations, indicating most of the TKN in the river is present as organic nitrogen.

Total phosphorus refers to both particulate and dissolved forms of phosphorus in the water column. Most phosphorus in lakes and rivers is bound to particulate matter (sediment, plant material). The concentration of total phosphorus in samples from the Kishwaukee River was 0.292 mg/L on June 25, 1997, 0.10 mg/L on November 13, 1996, 1.08 mg/L on February 19, 1997, and 0.044 mg/L on April 29, 1997. The mean concentration of total phosphorus for all samples was 0.19 mg/L.

Dissolved phosphorus is that part of the total phosphorus dissolved in water that is considered to be less than 0.45 microns in size. Samples from the Kishwaukee River on February 19 and April 29, 1997, were not analyzed for dissolved phosphorus concentrations. The concentration of dissolved phosphorus in samples from the Kishwaukee River was 0.095 and 0.063 mg/L on June 25 and November 13, 1996, respectively. Dissolved phosphorus concentrations on these dates are approximately one-half the concentration of total phosphorus on these dates.

Ground Water

Samples were collected from monitoring wells 1, 2, 3, 4, 5, 6, 8, 9, and 10 on June 25, 1996, November 13, 1996, February 19, 1997, and April 29, 1997. Ground-water samples were poured from a clean, teflon bailer after a minimum of three times the volume of water in the well was purged to ensure a representative sample (Schuller and others, 1981).

Concentrations of nitrate and nitrite as nitrogen in ground water ranged from below the detection limit of 0.01 mg/L to 11.2 mg/L in well 8 on June 25, 1996. The mean concentration was 0.03 mg/L for all 36 samples (table 6). Mean concentrations of nitrate and nitrite as nitrogen were an order of magnitude greater in wells 9 and 10 than in the other sampled wells. The elevated nitrate concentrations detected in samples from wells 9 and 10 may be attributed to mixing of ground water with river water during high-water periods on the Kishwaukee River in late May through early June 1996 and late February 1997. During these periods, wells 6, 9, and 10 were observed to have been submerged. Nitrate concentrations in the Kishwaukee River typically were an order of magnitude higher than in ground water.

Concentrations of nitrate and nitrite as nitrogen in shallow ground water less than about 2.0 mg/L can be attributed to natural sources, primarily precipitation (Mueller and Helsel, 1996). Some of the nitrate in the precipitation would have been used by plants and bacteria before reaching the water table. This indicates that, with the exception of the samples from well 8 on June 25, 1996, there are no substantial anthropogenic sources of nitrogen in the area. Nitrogen in the sample from well 8 may have been derived from runoff from the parking lot.

Concentrations of ammonia nitrogen in ground water ranged from 0.03 mg/L in well 9 on April 29, 1997, to 2.8 mg/L in well 10 on June 25, 1996. The mean concentration for all of the samples was 0.32 mg/L. The mean concentration of ammonia nitrogen in the samples was somewhat higher in wells 1, 4, and 5 than in samples from the other wells (table 6).

Concentrations of TKN ranged from 0.17 mg/L in samples from well 10 on November 11, 1996, to 69 mg/L in samples from well 8 on June 25, 1996. The mean concentration of TKN in ground water was 2.56 mg/L for all samples. The mean concentration of TKN was higher in wells 4 and 5 than in the other wells (table 6). TKN concentrations generally increase with increasing concentrations of ammonia but are more than an order of magnitude greater than ammonia concentrations. This indicates that most of the nitrogen in ground water is bound to particulate organic matter.

Samples collected on February 19 and April 29, 1997, were not analyzed for concentrations of dissolved phosphorus by the laboratory. Concentrations of dissolved phosphorus in ground water on June 25 and November 13, 1996, ranged from 0.006 mg/L in well 3 on June 25, 1996, to 0.049 mg/L in well 5 on June 25, 1996. The mean concentration was 0.02 mg/L for all samples and was somewhat higher in well 5 than in the other wells (table 6).

Table 6. Mean concentration of nutrients in ground water in the vicinity of the Bauman Park Lake, Cherry Valley, Ill.

[mg/L, milligrams per liter; na, not applicable]

Analyte	Mean concentration in all samples[3]	Mean concentration of samples by date[1] — Date of sample collection: June 25, 1996	November 13, 1996	February 19, 1997	April 29, 1997	Mean concentration of samples from well[2] — Ground-water-monitoring well name: Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 9	Well 10
Ammonia, total (mg/L)	0.3195	0.6376	0.3626	0.2696	0.1672	0.4023	0.1688	0.285	0.4509	0.5297	0.2106	0.2341	0.267
Nitrate and nitrite, total (mg/L)	.0349	.1017	.0387	.0122	.0311	.023	.0296	.0093	.0299	.0234	.0111	.250	.313
Nitrogen, total kjeldahl (mg/L)	2.560	10.356	1.5335	1.8637	1.4512	2.1771	1.3165	3.792	5.7141	6.6826	1.6699	1.5027	.708
Phosphorus, dissolved (mg/L)	.022	.0182	.0266	na	na	.030	.0232	.0143	.0261	.0485	.0257	.0172	.0154
Phosphorus, total (mg/L)	.7079	1.4847	.624	.6954	.476	.3979	.6019	1.3404	1.2587	.8388	.2795	.9185	.5016

[1]Nine samples used for mean calculation.
[2]Four samples used for mean calculation.
[3]Thirty-six samples used for mean calculation.

Dissolved phosphorus in shallow ground water at concentrations of less than 0.05 mg/L can be attributed to natural sources (Matthess, 1982, p. 268). Consequently, because the concentration of dissolved phosphorus did not exceed 0.05 mg/L in any sample, there is no indication of substantial anthropogenic sources of phosphorus in this area.

Concentrations of total phosphorus in ground water ranged from 0.127 mg/L in well 10 on February 19, 1997, to 2.476 mg/L in well 4 on June 25, 1996. The mean concentration was 0.71 mg/L for all samples (table 6). Concentrations of dissolved phosphorus were substantially lower than the concentrations of total phosphorus, indicating that most of the phosphorus in the ground water was present on particulate or organic matter.

Except for dissolved phosphorus, mean concentrations of all nutrients in ground water were substantially higher on June 25, 1996, than during the other sampling periods (table 6). The explanation for this trend is not readily apparent, but may be related to the high turbidity of the samples collected in June 1996. Turbidity is affected by the amount of particulate matter in the sample, which also can affect the concentration of TKN and total phosphorus in the sample. Water quality and turbidity also may have been affected by flooding of the Kishwaukee River in late May and early June 1996.

Nutrient concentrations in the eastern part of the study area, hydraulically upgradient from the lake, were not substantially different than the concentrations in the western part of the study area. However, concentrations of nitrate and nitrite as nitrogen, and total phosphorus in ground water generally increased to the west from well 3 to well 10. The concentration of TKN and ammonia in ground water typically decreased overall from well 3 to well 10. The trends in TKN, nitrate and nitrite as nitrogen, and total phosphorous concentrations indicate that flow from the lake to ground water has some effect on nutrient concentrations in ground water, but the effect is not substantial enough to affect the characteristics of the ground water downgradient from the lake.

Lake Water

Water-quality and algae samples were collected from the Bauman Park Lake on April 30, June 11, July 23, August 23, September 30, and October 7, 1996, at sites 1 and 2 (fig. 2). Samples also were collected at site 2 on July 31, 1996. Temperature and dissolved oxygen profiles were measured at sites 1 and 2 on April 30, May 30, June 11, July 23, July 31, August 23, September 30, and October 7, 1996. Temperature and dissolved oxygen profiles also were measured at site 1 on May 15, 1996.

Secchi depth is the depth at which the black and white Secchi disk (diameter 8 in.) is no longer visible and is a measure of the clarity of the lake water. During the period of measurement, Secchi readings in the Bauman Park Lake ranged from 96 to 216 in. The mean Secchi reading was 137 in. at site 1S and 127 in. at site 2S (table 7). The photic zone, or the zone of the lake with sufficient sunlight penetration to allow photosynthesis by algae and aquatic macrophytes, is considered to be 2-5 times the Secchi reading (Illinois Environmental Protection Agency, 1978). If the maximum depth of the lake is about 28 ft (336 in.), most or all of the lake should have been within the photic zone during the period of measurement. The fact that aquatic macrophytes, which require sunlight for growth, dominate the aquatic community of the lake supports this interpretation.

TSS concentrations constitute all organic and inorganic particles, including sediment, algae, and decaying plant matter, suspended in the water column and is often related to the transparency of the water. Measured concentrations of TSS ranged from 1.0 mg/L to 6.0 mg/L. The geometric mean of the TSS concentration was 1.5 mg/L for all samples and did not vary substantially with depth or location in the lake (table 7). TSS values from the Bauman Park Lake are below the Illinois Lake Assessment Criteria (Illinois Pollution Control Board, 1989) for moderate use impairment of 15 to 25 mg/L.

Turbidity is a measure of the amount of light scattered by dissolved and suspended substances in the water column or the color of the water, and is related to the degree of water transparency. Turbidity values in the Bauman Park Lake are affected by the amount of sediment from shoreline erosion and bottom resuspension, as well as algae and other organic matter in the water column. The geometric mean of the turbidity values was 1.8 Nephelometric Turbidity Units (NTU) for all samples and did not vary substantially with depth or location (table 7). All values are below the Illinois Lake Assessment Criteria for moderate turbidity of 7 to 15 NTU.

Mean values of turbidity generally increased with increased TSS at sites 1S and 2S but had no clear relation to Secchi readings. Typically, turbidity and Secchi values are inversely related (Sefton and others, 1980). The absence of a correlation at the lake may be a function of the comparatively small data set or may indicate that other factors (color, plant growth) are affecting the Secchi readings.

Conductivity is the capacity of a unit area of water to convey electrical current and is related to the type and concentration of dissolved solids in the lake water. The geometric mean for the values of field conductivity measured at the lake declined from 441 μS/cm on April 30, 1996, to 336 μS/cm on August 23, then rose to 367 μS/cm on October 7, 1996. The mean field-measured conductivity of the samples collected at the surface of the lake (368 μS/cm) was lower than that of the samples collected near the bottom of the lake (419 μS/cm) (table 7).

Alkalinity is an indication of the acid-neutralizing capability of water and typically is related to the concentration of carbonate compounds dissolved in water. During the period of measurement, alkalinity values from the lake samples ranged from 102 to 188 mg/L. Alkalinity of the lake samples increased with increasing field conductivity, indicating that carbonate compounds are an important dissolved constituent in the lake water. Unlike the conductivity values, the geometric mean of the values of total alkalinity (137 mg/L at site 1S, 156 mg/L at site 1D, 128 mg/L at site 2S) showed no clear patterns with depth or location (table 7).

The negative log of the concentration of hydrogen ion, or pH, ranged from 7.35 pH units at site 1D on August 23, 1996, to 9.35 pH at site 1S on August 23, 1996. The geometric mean of the pH values was higher at the lake surface (8.71 at site 1S, 8.66 at site 2S) than near the bottom of the lake (8.02 at site 1D) (table 7). pH values at sites 1S and 2S increased consistently from April 30 to August 23, then declined by October 7. In temperate lakes, pH values greater than 8.0 can be an indication that the photosynthetic activity of algae and aquatic macrophytes is consuming dissolved carbonate compounds faster than it is being replaced by plant and animal respiration, breakdown of organic matter, and atmospheric diffusion (Lampert and Sommer, 1997). Bicarbonate ion, formed from the dissolution of carbon dioxide in water, may be used for photosynthesis under these conditions, which has the effect of decreasing the concentration of hydrogen ion in the water and increasing pH. Trends in pH indicate that the rate of photosynthetic activity in the shallow

Table 7. Mean concentration of constituents in the Bauman Park Lake, Cherry Valley, Ill.

[mg/L, milligrams per liter; na, not applicable; mS/cm, microsiemens per centimeter; NTU, Nephelometric Turbidity Units; alkalinity expressed as milligrams per liter of calcium carbonate]

	Mean concentrations by location					Mean concentrations by date					
	Surface-water sampling site name					Date of sample collection					
Analyte	**Site 1S**	**Site 1D**	**Site 2S**	**Sites 1S and 1D**	**All sites**	**April 30, 1996**	**June 11, 1996**	**July 23, 1996**	**August 23, 1996**	**September 30, 1996**	**October 7, 1996**
Alkalinity, phenolphthalein (mg/L)	na	na	na	na	na	0	0	16.9	0	na	0
Alkalinity, total (mg/L)	137	156	128	162	150	159	160	120	126	na	138
Field conductivity (µS/cm)	368	419	368	393	588	441	426	362	336	na	367
Field pH	8.71	8.71	8.66	8.36	8.46	8.33	8.2	8.7	8.61	na	8.52
Nitrate and nitrite as nitrogen (mg/L)	.006	.008	.006	.007	.006	.013	.005	.005	.005	0.005	.008
Nitrogen, ammonia (mg/L)	.023	.024	.01	.023	.017	.052	.006	.005	.061	.026	.016
Nitrogen, total kjeldahl (mg/L)	.50	.377	.394	.434	.419	.352	.254	.32	.785	.544	.538
Phosphorus, dissolved (mg/L)	.005	.007	.006	.006	.006	.0046	.0076	.0033	.0052	na	.011
Phosphorus, total (mg/L)	.019	.015	.011	.019	.015	.0174	.0098	.0088	.0152	.0278	.024
Secchi transparency (inches)	138	na	127	na	na	108	210	162	96	na	114
Solids, total suspended (mg/L)	1.6	1.7	1.4	1.7	1.6	2	1.6	1	1.59	1	4.93
Solids, volatile suspended (mg/L)	.8	.8	.6	.8	.7	1	.8	.5	.63	.5	1.59
Turbidity (NTU)	1.7	1.8	1.7	1.8	1.8	2.4	.7	.6	1.17	na	2.29

part of the lake during the spring and summer exceeded the production of carbon dioxide until sometime between August 23 and October 7, when algal productivity decreased. Phosphorus desorption from certain iron complexes have been noted at pH values above 8.0 (Stauffer and Armstrong, 1986), creating the potential for release of phosphorus into the water column. pH was related inversely to alkalinity concentration in the lake water, which would be expected if photosynthetic uptake of carbonate species was responsible for the increase in pH. pH concentrations also were related inversely to field conductivity. The spatial trends between pH and field conductivity also were related inversely but showed no clear correlation to the spatial trends in alkalinity.

Nitrogen in the form of nitrate and nitrite is used readily by algae as a growth nutrient. Concentrations of nitrate and nitrite as nitrogen measured in the lake water ranged from below the detection limit of 0.01 mg/L to 0.02 mg/L on April 30, and October 7, 1996 (fig. 12). By arbitrarily setting the nondetects to one-half the detection limit, the geometric mean of nitrate and nitrite as nitrogen was less than the detection limit at all sites (table 7). The mean concentration of nitrate and nitrite as nitrogen in all samples was 0.013 mg/L on April 30, below the detection limit on June 11, July 23, August 23, and September 30, and 0.008 mg/L on October 7, 1996. The absence of nitrate and nitrite during the summer months indicates that these compounds were being consumed by physical, chemical, and biological processes during this period.

Nitrogen in the form of ammonia also is used readily by phytoplankton and algae as a growth nutrient. Concentrations of ammonia nitrogen measured in the lake ranged from below the detection limit of 0.01 mg/L to 0.65 mg/L in the sample at site 1S collected on August 23, 1996 (fig. 12). The geometric mean of the ammonia nitrogen concentration was 0.02 mg/L for all samples and did not vary substantially with depth or location in the lake (table 7). The mean concentrations of ammonia showed no trend with time.

During the period of measurement, concentrations of TKN in the lake water ranged from 0.17 mg/L to 1.2 mg/L (fig. 12). The mean value of TKN was 0.42 mg/L for all samples and showed no clear variations with location or depth (table 7). TKN concentrations typically are substantially greater than ammonia concentrations, indicating that most of the nitrogen in this lake is organic nitrogen, which has not been shown to be used by algae (Vollenweider, 1968). The mean concentrations of TKN showed no clear trend with time but were somewhat higher from August to October than from April to July (table 7).

During the period of measurement, concentrations of total phosphorus in the Bauman Park Lake ranged from 0.004 mg/L to 0.042 mg/L (fig. 12). The geometric mean of the concentrations of total phosphorus was 0.015 mg/L for all samples and showed no clear spatial trends (table 7). The mean concentration of total phosphorus in all samples decreased from April to July 1996, then increased from August to October 1996.

Dissolved phosphorus is the form most readily used for algae and macrophyte growth. During the period of measurement, concentrations of dissolved phosphorus ranged from 0.002 mg/L to 0.011 mg/L (fig. 12). The geometric mean of the concentrations of dissolved phosphorus was slightly lower in the samples from sites 1S and 2S (0.005 mg/L) than at the sample from site 1D (0.007 mg/L). The geometric mean of the concentration of dissolved phosphorus showed no clear trends with time during the period of sampling (table 7). Concentrations of dissolved phosphorus typically are less than one-half the concentration of total phosphorus, indicating that most of the phosphorus in the lake is bound to particulate matter and, therefore, not readily used for plant and algae growth.

The geometric mean of the concentration of nitrate and nitrite as nitrogen, ammonia, TKN, dissolved phosphorus and total phosphorus in samples of ground water collected on June 27, 1997, was greater than the mean concentration of these compounds in samples of lake water collected on June 11 and July 23, 1997. These are the only comparable time periods for which both lake and ground-water quality data are available. A comparison of the data indicates that nutrients in the water column of the lake were being removed by processes (for example, photosynthesis, incorporation into lake sediment) that were not taking place in the ground water, and that ground water flowing into the lake has higher nutrient concentrations than lake water flowing out to ground water.

Chlorophyll *a* is a photosynthetic pigment that is necessary for photosynthesis in most plants and in blue-green, green, yellow-green, and yellow-brown algae; diatoms; eulenoids; and dinoflagellates. Blue-green algae contain only chlorophyll *a*. Chlorophyll *b* is an accessory photosynthetic pigment present in

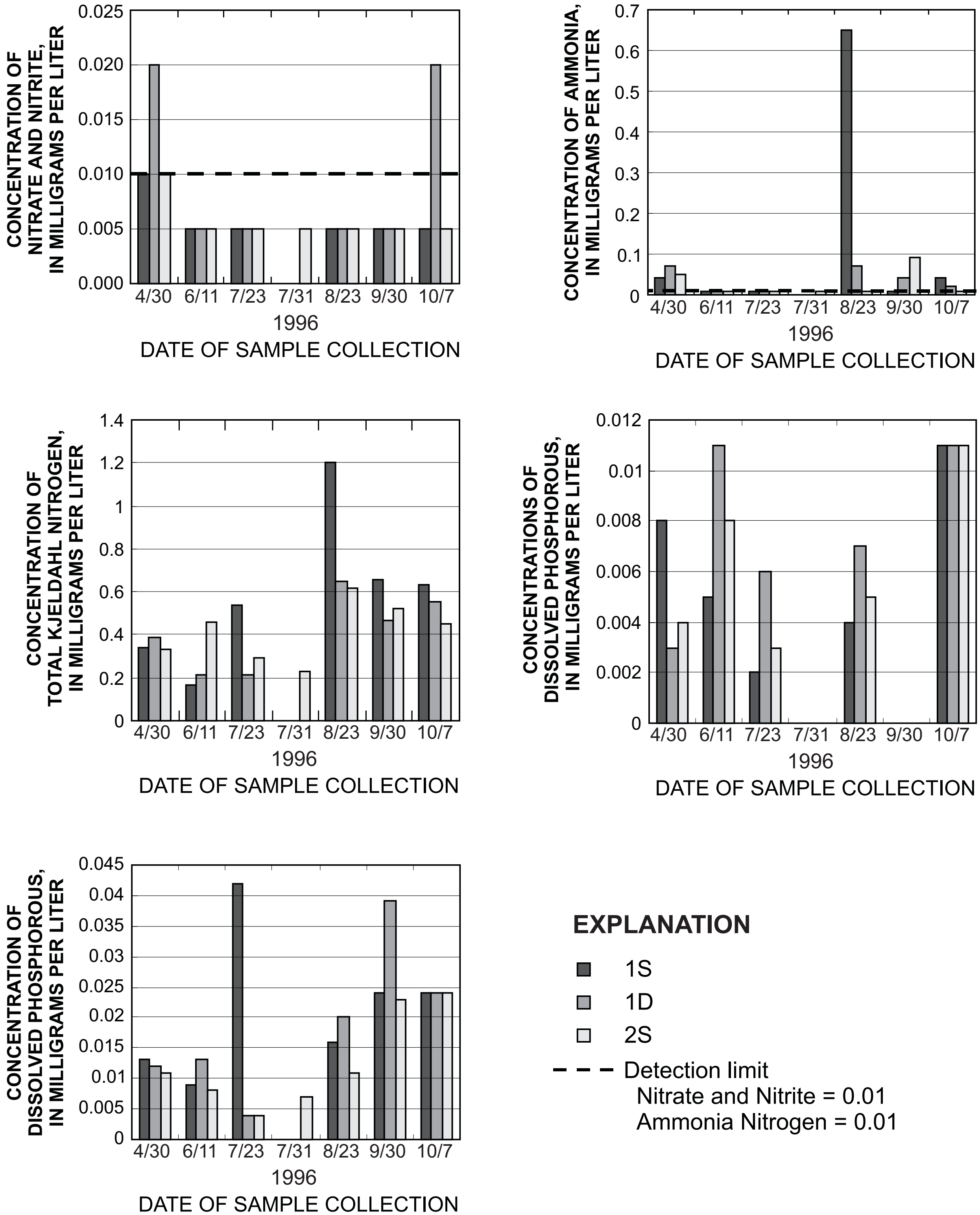

Figure12. Nutrient concentrations in the Bauman Park Lake, Cherry Valley, Ill., April 30–October 7, 1996.

green algae and euglenoids. Chlorophyll *c* is an accessory photosynthetic pigment present in diatoms, yellow-green and yellow-brown algae, and dinoflagellates. Pheophytin a is a breakdown product of chlorophyll *a*. High concentrations of pheophytin are indicative of a stressed algal population or a recent algae die off. Chlorophyll *a* values must be corrected for pheophytin to determine the amount of living biomass in the sample. Concentrations of chlorophyll *a* (corrected), chlorophyll *b*, chlorophyll *c*, and pheophytin *a* measured at site 1 increased overall between April 30 and October 7, 1996, and increased substantially between July 23 and October 7, 1996 (table 8). Concentrations of chlorophyll *a* (corrected), were less than 4.0 µg/L on April 30 and July 23, 1996, greater than 11 µg/L on June 11, 1996, and greater than 28 µg/L on August 23 and October 7, 1996, at site 2 (table 8). Chlorophyll *b*, chlorophyll *c*, and pheophytin were detected at less than 1 µg/L on April 30, 1996, greater than 1.5 µg/L on June 11, 1996, were not detected, or detected at less than 1.3 µg/L on July 23 and August 23, 1996, and were detected at greater than 2.5 µg/L on October 7, 1996 at site 2. Concentrations of chlorophyll *a* (corrected), chlorophyll *b*, chlorophyll *c*, and pheophytin at site 2 were substantially greater than at site 1, except for the July 23 samples. Chlorophyll concentrations are representative of a moderately productive lake (James Labaugh, U.S. Geological Survey, written commun., 1997). The presence of elevated concentrations of pheophytin *a* in the samples collected on October 7 indicates the algal population was under some stress at that time.

Results of the algae sampling indicate that total algae counts were less than 2,500 per ml, and blue-green algae were the most abundant algae in the lake during most of the sampling events (Larry O’Flaherty, Western Illinois University, written commun., 1997). Diatoms and green algae were present at concentrations greater than 100 per ml, whereas euglenoids and dinoflagellates always were present at concentrations less than 100 per ml. This is consistent with the types of photosynthetic pigments detected in the lake.

Concentrations of chlorophyll *a* (corrected) at sites 1 and 2 showed an overall increase with increasing concentrations of total phosphorus, TKN, and, perhaps, dissolved phosphorus. Concentrations of nitrate and nitrite as nitrogen and ammonia nitrogen generally were below the detection limit during most of the measurement periods. However, assuming a value of 0.005 mg/L for the nondetects, chlorophyll *a* concentrations increased with decreasing concentrations of nitrate and nitrite as nitrogen and ammonia. Concentrations of chlorophyll *a* (corrected) showed no clear correlation with the stage of the Bauman Park Lake.

Algae require a variety of elements to grow, including nitrogen, phosphorus, carbon, and hydrogen. In freshwater lakes, all of these elements except phosphorus or nitrogen typically are available in sufficient quantity for algal growth. Because certain forms of algae can obtain nitrogen from the atmosphere, phosphorus is the nutrient that limits algal growth in most lakes (the limiting algal nutrient) (Schindler, 1977). If

Table 8. Results of lake-water-quality sampling from site 1 at a depth of 18 feet and site 2 at a depth of 14 to 18 feet, Bauman Park Lake, Cherry Valley, Ill., April 30–October 7, 1996

[µg/L, micrograms per liter; NS, no sample collected]

Analyte	Date of sample collection				
	April 30, 1996	June 11, 1996	July 23, 1996	August 23, 1996	October 7, 1996
Site 1					
Chlorophyll *a* (µg/L)	2.73	2.06	3.71	NS	11.03
Chlorophyll *a* uncorrected (µg/L)	2.61	2.10	3.69	NS	11.55
Chlorophyll *b* (µg/L)	.00	.49	.67	NS	1.13
Chlorophyll *c* (µg/L)	.00	.18	.35	NS	1.51
Pheophytin *a* (µg/L)	.00	.00	.00	NS	.35
Site 8					
Chlorophyll *a* (µg/L)	4.36	11.14	3.02	31.45	28.58
Chlorophyll *a* uncorrected (µg/L)	4.88	12.91	3.85	24.70	32.10
Chlorophyll *b* (µg/L)	.03	2.49	.39	.00	4.15
Chlorophyll *c* (µg/L)	.36	1.56	.00	.00	2.58
Pheophytin *a* (µg/L)	.60	2.56	1.21	.00	4.57

the concentration of dissolved phosphorus in lake water is less than 0.005 mg/L, phosphorus concentrations may limit algal growth (United Nations Educational, Scientific, and Cultural Organization, 1989). If the total concentration of biologically available nitrogen (ammonia, nitrate, nitrite) in lake water is less than 0.020 mg/L, nitrogen concentrations may limit algal growth. Dissolved phosphorus concentrations in the Bauman Park Lake typically were slightly greater than 0.005 mg/L (table 6). Ammonia nitrogen and nitrate and nitrite as nitrogen concentrations in the samples of lake water typically were present below the detection limit of 0.01 mg/L or detected at concentrations greater than 0.020 mg/L. There is no clear indication if algal growth in the Bauman Park Lake is limited by the concentration of nitrogen or phosphorus compounds.

The limiting nutrient for a lake usually can be determined by comparing the weight ratio of total nitrogen (TKN and nitrate and nitrite as nitrogen) to total phosphorus. The N:P atomic ratio in algal cell tissue is about 16:1 (16 nitrogen atoms for every phosphorus atom) (United Nations Educational, Scientific, and Cultural Organization, 1989). If nutrient concentrations are measured in milligrams per liter, the atomic ratio of 16 mol/L of nitrogen to 1 mol/L of phosphorus converts to 224 g/L of nitrogen and 31 g/L of phosphorus, a mass ratio of 7.2:1 (United Nations Educational, Scientific, and Cultural Organization, 1989). If it is assumed that the algal populations use the nutrients in this ideal ratio, a mass ratio of less than 5:1 indicates nitrogen is the limiting algal nutrient and a ratio greater than 10:1 indicates phosphorus is the limiting algal nutrient (Marsden, 1989, p. 153). The N:P mass ratios for samples collected from the Bauman Park Lake during the investigation (table 9) were greater than 7.2:1 for all of the samples collected, indicating that phosphorus is the probable nutrient limiting algal biomass.

The trophic state indices (TSI) devised by Carlson (1977) use Secchi depths, total phosphorus concentrations at the lake surface, and chlorophyll *a* concentrations at the lake surface to determine the trophic status of lakes with nonalgal turbidity and minimal aquatic vegetation. The higher the TSI, the more eutrophic, or nutrient enriched, is the lake. The index is based on the amount of algal biomass in the water using a scale of 0 to 110, with each major division of the index (10, 20, 30) representing a theoretical doubling of the algal biomass. Lakes having TSI values greater than 50 are classified as eutrophic (high algal production). Lakes having a mean TSI greater than 60

Table 9. Ratios of the concentration of total nitrogen to total phosphorus in water from the Bauman Park Lake, Cherry Valley, Ill.

[mg/L, milligrams per liter; k, compound present below detection limit; ns, no sample collected]

	Date of sample collection						
	April 30, 1996	**June 11, 1996**	**July 23, 1996**	**July 31, 1996**	**August 23, 1996**	**September 30, 1996**	**October 7, 1996**
Site 1S							
Nitrate and nitrite, as nitrogen (mg/L)	0.01	0.01k	.01k	ns	0.01k	0.01k	0.01k
Nitrogen, total kjeldahl (mg/L)	.34	.17	.54	ns	1.2	.66	.63
Nitrogen, total (TN) (mg/L)	.35	17	.54	ns	1.2	.66	.63
Phosphorus, total (TP) (mg/L)	.04	.009	.042	ns	.016	.024	.024
Ratio TN/TP (rounded)	9	19	13	ns	75	28	26
Site 1D							
Nitrate and nitrite, as nitrogen (mg/L)	.02	.01k	.01k	ns	.01k	.01k	.02
Nitrogen, total kjeldahl (mg/L)	.39	.21	.21	ns	.65	.47	.55
Nitrogen, total (TN) (mg/L)	.41	.21	.21	ns	.65	.47	.57
Phosphorus, total (TP) (mg/L)	.012	.013	.004	ns	.02	.039	.024
Ratio TN/TP (rounded)	34	16	53	ns	33	12	24
Site 2S							
Nitrate and nitrite, as nitrogen (mg/L)	.01	.01k	.01k	0.01k	.01k	.01k	.01k
Nitrogen, total kjeldahl (mg/L)	.33	.46	.29	0.23	.62	.52	.45
Nitrogen, total (TN) (mg/L)	.34	.46	.29	.23	.62	.52	.45
Phosphorus, total (TP) (mg/L)	.011	.008	.004	.007	.011	.023	.024
Ratio TN/TP (rounded)	31	57	73.000	33	56	23	19

and less than 70 are characterized as being moderately to highly eutrophic (Illinois Environmental Protection Agency, 1990). This index is not strictly applicable to lakes with water coloration or suspended materials other than algae, which is typical of lakes dominated by aquatic macrophytes (such as the Bauman Park Lake), and may underestimate eutrophication.

The TSI determined from the Secchi readings ranged from 35 to 47, with a mean value of about 42 (table 10). The TSI determined from the total phosphorus in the samples collected from near the lake surface ranged from 24 to 58, with a mean value of about 41. The mean TSI determined from the total phosphorus concentrations in the samples from the bottom of the lake was about 43. The TSI calculated from the corrected chlorophyll *a* concentrations collected from samples near the bottom of the lake, although not strictly applicable, ranged from 40 to 64, with a mean value of about 48. All TSI values indicate that the Bauman Park Lake is mesotrophic or marginally eutrophic.

Although collected during a 6-month period only, the temperature and dissolved oxygen data indicate that the Bauman Park Lake is subject to thermal stratification (fig. 13). The uniform distribution of temperature with depth in the lake on April 30, 1996, indicates that the lake was in the spring turnover stage at that time. The spring turnover stage is characterized by well mixed water of uniform temperature and dissolved oxygen concentration.

Table 10. Calculated trophic state indices for water samples from the Bauman Park Lake, Cherry Valley, Ill., April 30–October 7, 1996

[ns, not sampled; >, greater than; na, not applicable; mg/m^3, milligrams per cubic meter]

	April 30, 1996	June 11, 1996	July 23, 1996	July 31, 1996	August 23, 1996	September 30, 1996	October 7, 1996
			Site 1S				
Secchi depth (inches)	108	216	183	ns	96	ns	>120.00
Trophic state indice	45.46	35.43	37.83	na	47.12	ns	43.91
Phosphorus, total (mg/m^3)	13	9	42	ns	16	24	24
Trophic state indice	41.15	35.85	58.07	na	44.15	50	50
			Site 2S				
Secchi depth (inches)	108	204	144	ns	96	ns	108
Trophic state indice	45.46	36.27	41.32	na	47.13	ns	45.46
Phosphorus, total (mg/m^3)	11	8	4	7	11	23	24
Trophic state indice	38.74	34.15	24.15	32.22	38.74	49.39	50
			Site 1D				
Phosphorus, total (mg/m^3)	12	13	4	ns	20	39	24
Trophic state indice	40	46.94	24.15	na	47.37	57	50
			Site 1I				
Depth (feet)	18	18	18	ns	ns	ns	19
Chlorophyll *a* (mg/m^3)	2.73	2.06	3.71	ns	ns	ns	11.03
Trophic state indice	40.42	37.66	43.43	na	na	na	54.12
			Site 2I				
Depth (feet)	17	17	14	ns	16	ns	18
Chlorophyll *a* (mg/m^3)	4.36	11.14	3.02	ns	31.45	ns	28.58
Trophic state indice	45.01	54.22	41.41	na	64.4	na	63.46
Mean trophic state indice from Secchi depth	42						
Mean trophic state indice from shallow phosphorus data	41						
Mean trophic state indice from chlorophyll *a* data	48						
Mean trophic state indice from all phosphorus data	43						

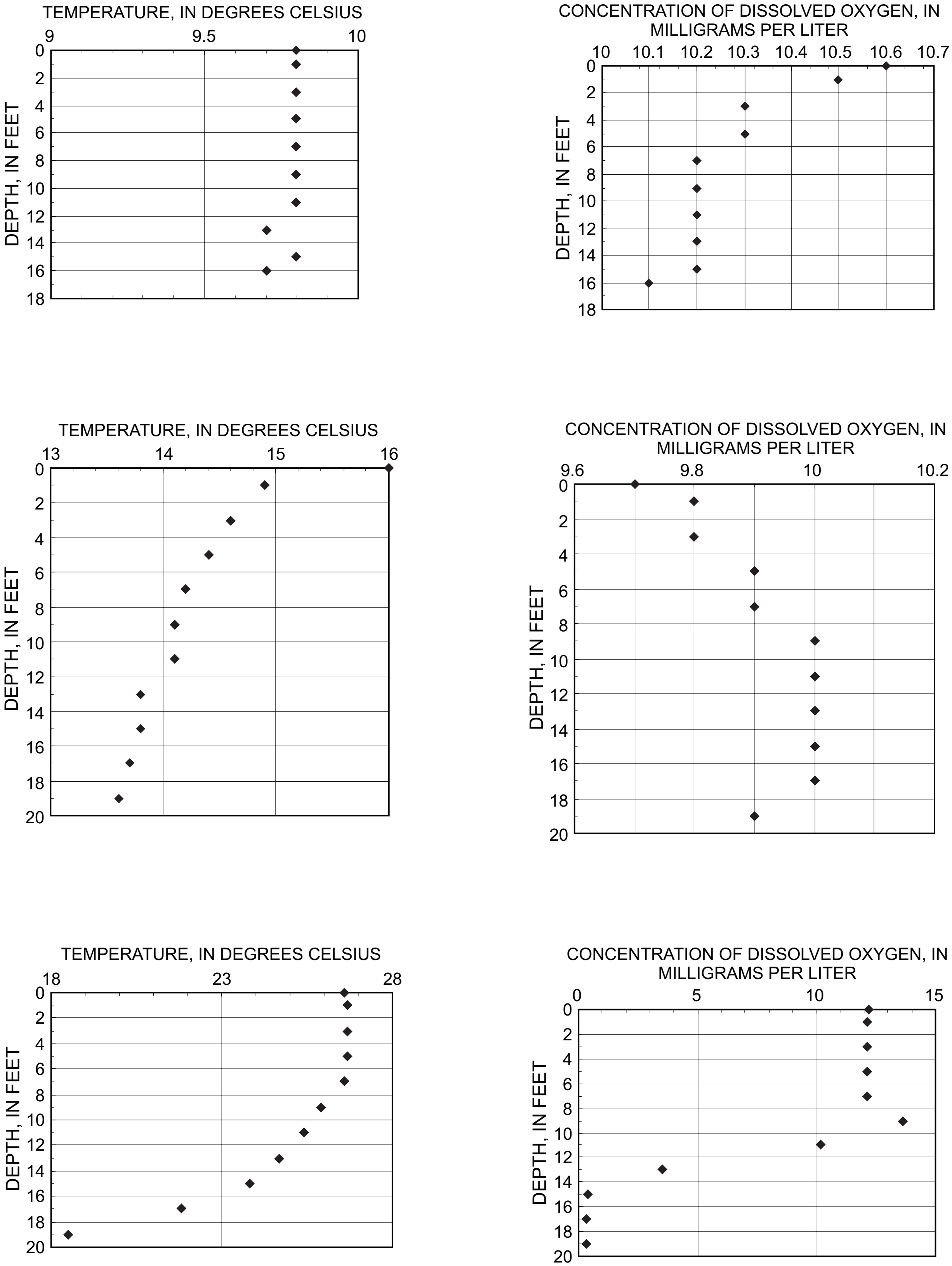

Figure 13. Selected temperature and dissolved oxygen profiles at site 2, Bauman Park Lake, Cherry Valley, Ill., April 30–October 7, 1996.

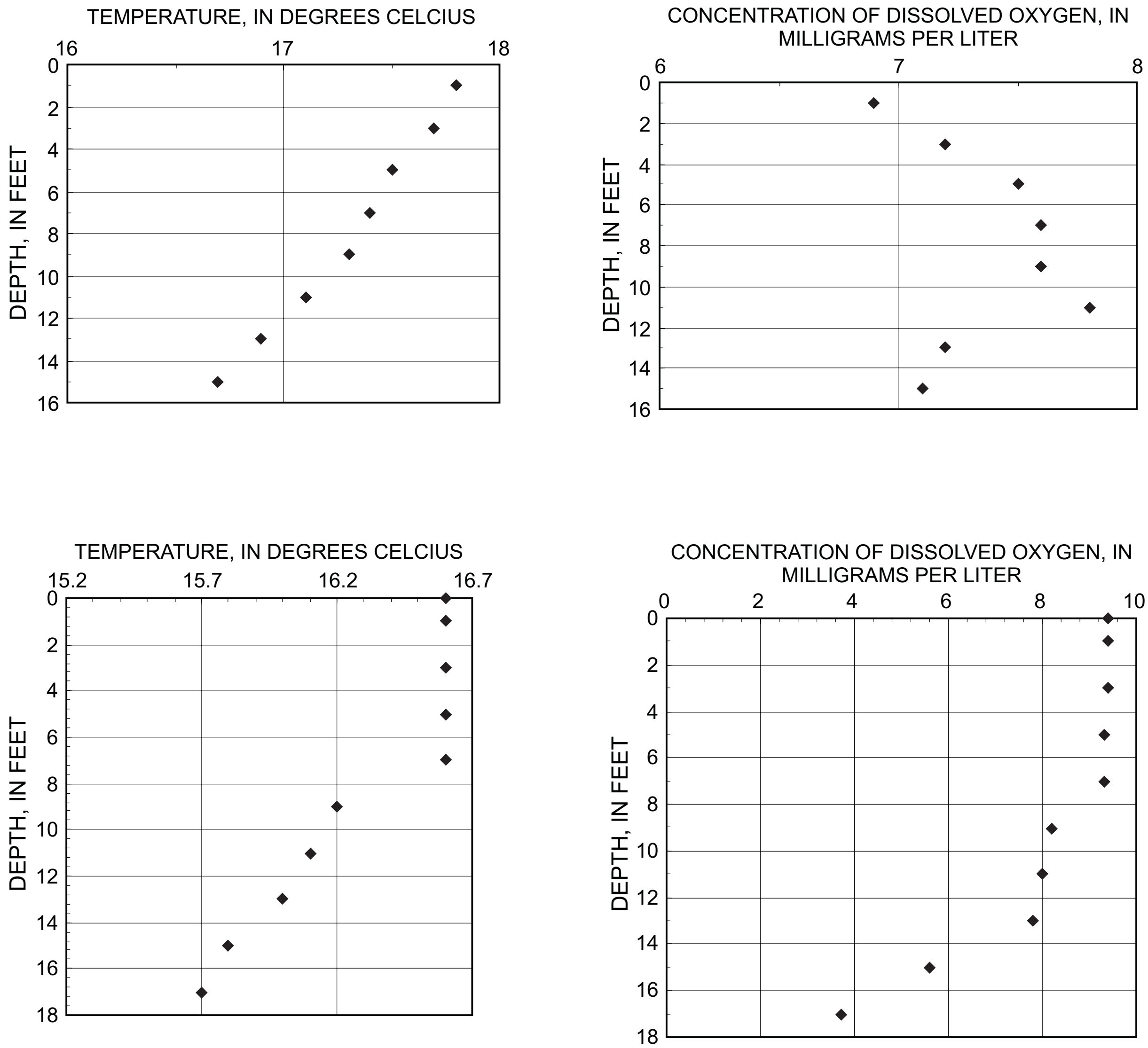

Figure 13. Continued.

Rising air temperatures heated the surface of the lake from about 10°C on April 30 to more than 26°C on August 23, 1996. Water at depth was heated more slowly, and water temperatures began to decrease with depth by May 15, 1996. This developing temperature variation began the summer stratification stage, which continued through August 23 and into early September. By June 11, the upper part of the lake (the epilimnion) was from 3.5 to 5.0°C warmer than the bottom of the lake (the hypolimnion), and was separated by a zone of water with a large temperature gradient (the thermocline), from about 13 to 17 ft below the lake surface. The density difference caused by this thermal stratification prevents oxygenated water at the top of the lake (dissolved oxygen concentrations in the upper part of the lake typically were greater than 9.4 mg/L) from mixing with water at the bottom of the lake. As dissolved oxygen was consumed during the breakdown of plant material on the lake bottom, the concentration of dissolved oxygen in the water near the lake bottom decreased to below 5.0 mg/L at site 2 on June 11 and July 23, and decreased to below 1.0 mg/L at sites 1 and 2 on August 23 (fig. 13).

Stratification of the lake water can be overcome by high winds or storms, which can mix the water, thereby producing the comparatively uniform temperaure and dissolved oxygen profiles observed on July 31, 1996. Lake turnover associated with storms can result in the redistribution of nutrients from the hypolimnion to the epilimnion, producing algal blooms (Stauffer and Lee, 1973; Kortman and others, 1982).

Between August 23 and October 7, the temperature of the water at the surface of the lake decreased from about 26°C to about 16.5°C as air temperature decreased. By September 30, the difference in temperature between the top and bottom of the lake was about 1°C. Under these conditions, the difference in water density appears to have decreased to a point at which the lake had become nearly isothermal and unstratified. The loss of thermal stratification resulted in well mixed lake water with a fairly uniform and comparatively low dissolved-oxygen content on September 30 (fig. 13). This is characteristic of the fall turnover stage. Although water temperature did not vary substantially with depth on October 7, concentrations of dissolved oxygen decreased from 3.1 to 5.7 mg/L from the top to the bottom of the lake, and were measured at less than 5.0 mg/L at site 2. The decrease in dissolved-oxygen concentration with depth on October 7 may be related to oxygen consumption during the breakdown of organic matter at the bottom of the lake after a recent die off of algae. The elevated concentrations of dissolved phosphorus and pheophytin *a* present in the October 7 samples support this interpretation.

As air temperature continued to decrease through autumn and ice covered the lake in the winter, it is probable that the water temperature in the upper part of the lake also decreased. Because water has maximum density at 4°C, it is likely that the lake would have stratified into an upper, less dense layer with a temperature below 4°C and a lower, more dense layer with a temperature near 4°C. Assuming this point was reached, the lake would have entered the winter stratification stage. The winter stratification stage is characterized by an overall increase in water temperature to 4°C at depth coupled with a decrease in dissolved-oxygen concentrations near the bottom of the lake.

The concentrations of dissolved oxygen in lake water tend to decline in the winter, particularly during the period of ice cover. This decline is caused by a number of factors. Light penetration is reduced during autumn and winter, and virtually eliminated by snow cover, thus reducing or eliminating oxygen production from photosynthesis. Ice cover also reduces the diffusive exchange of oxygen between lake water and the atmosphere. Meanwhile, oxygen is still consumed in the breakdown of organic matter, causing an overall decrease in the concentration of dissolved oxygen in the lake and increasing the possibility of a fishkill. It is probable, therefore, that the concentration of dissolved oxygen in the Bauman Park Lake during the winter months was below the 9–11 mg/L range in concentrations measured in the spring through autumn.

NUTRIENT LOADS

Nutrients are added to the Bauman Park Lake from external sources, including precipitation, groundwater inflow to the lake, waterfowl excrement, and sediment from shoreline erosion and internal sources, primarily regeneration of nutrients from decomposing organic matter. Nutrients are removed from the lake by outflow to ground water, denitrification, and nutrient uptake from algae and aquatic macrophytes. Nutrients taken up by plants are recycled to the lake sediments and the water column when the plants die. Calculation of the amount of nutrient derived from each source and the amount of the nutrients entering and exiting the lake will help determine the overall health of the lake and the most effective methods for improving the quality of the lake.

External Loads

Precipitation falling on the surface of the lake and entering the lake from overland runoff contains nitrogen and smaller amounts of phosphorus derived from atmospheric gasses. Data on the concentrations of nitrate and ammonia in precipitation for a National Atmospheric Deposition Program (NADP) monitoring station in Shabbona, Ill., for 1993–95 were obtained from the World Wide Web at

http://nadp.nrel.colostate.edu/nadp/cgi_scripts/sitepics.cgi?IL18

During the 1993–95 period, an average of 3.75 (lb/acre)/yr of ammonia and 11.86 (lb/acre)/yr of nitrate was deposited from precipitation at Shabbona. The station at Shabbona is about 40 mi south of Cherry Valley. The NADP data indicate that about 103 lbs of ammonia and 325 lbs of nitrate were added to the Bauman Park Lake from precipitation directly onto the lake during the investigation. Isopleth maps of the concentration of nitrogen and ammonia in precipitation available from the NADP site on the World Wide Web at

http://nadp.nrel.colostate.edu/nadp/isopleth.maps/95maps.html indicate the Shabbona data is representative of concentrations at the Bauman Park Lake.

Concentrations of phosphorus in precipitation at this station typically were below the detection limit of 1 mg/L. However, phosphorus concentrations of 0.03 mg/L were reported in precipitation in southern Ohio (Vollenweider, 1968) indicating that about 8.2 lbs of phosphorus would have been added to the Bauman Park Lake directly from precipitation during the investigation.

During the investigation, approximately 2.6×10^6 gal of water also were added to the lake as overland runoff from precipitation. Data from the Shabbona station indicate that the mean annual concentration of ammonia and nitrate in precipitation averaged 0.49 and 1.52 mg/L, respectively, from 1993 to 1995. If the conservative assumption is made that no nutrients were added or removed from the precipitation that constitutes the overland runoff before it entered the lake, about 11 lbs of ammonia, 33 lbs of nitrate, and 0.65 lb of phosphorus would have entered the lake in overland runoff from May 1, 1996, to April 30, 1997.

Particulate matter in the atmosphere that settles on the lake (dry deposition) also is a source of nutrients. The loading rates of total phosphorus and total nitrogen from dry deposition at the Bauman Park Lake were assumed to be 0.37 lb/acre/yr, respectively, based on measurements of air in northeastern Illinois with total suspended particulates at a concentration of 50 µg/L (Quon, 1977). Because the Bauman Park Lake has an area of 27.4 acres, 10.1 lbs of phosphorus and 162 lbs of nitrogen, from dry deposition, were calculated to have been added to the lake during the 1-year period of the investigation.

Waterfowl excrement is another source of nutrients to the Bauman Park Lake. The number of waterfowl in the Bauman Park Lake were estimated at the same time surface-water levels were collected by personnel from the Village of Cherry Valley. During the investigation, Canada geese and mallard ducks were the principal waterfowl observed on the lake. The number of individual geese and ducks were totaled and normalized to obtain the number of bird-days per month. Fewer than 150 ducks and geese were observed on the lake from May to August 1996. The number of waterfowl began to increase with the beginning of the fall migration in September and peaked at more than 4,000 birds in November 1996. No birds were observed from December 1996 to March 1997 after the end of the fall migration and during the period ice covered the lake. More than 200 waterfowl were sighted at the lake in April 1996.

The average dry weight of mallard duck and Canada goose droppings is 0.059 and 0.18 lb/d, respectively (Sanderson and Anderson, 1978; Terres, 1987). The nitrogen concentration in the droppings is assumed to be 3.0 percent of the dry weight (Johnson, 1989). The phosphorus concentration in the droppings is assumed to be 1.87 percent of the dry weight (Scherer and others, 1995). Using these values, the average mallard excretes 0.0018 lb of nitrogen and 0.0011 lb of phosphorus per day, whereas the average Canada Goose excretes 0.0054 lb of nitrogen and 0.0034 lb of phosphorus per day. It is assumed that all ducks excrete that same amount of droppings, nitrogen, and phosphorus as mallards. Because the area surrounding the lake is not suited for nesting, waterfowl do not spend the entire day on the lake. The daily load of nitrogen and phosphorus in waterfowl droppings were multiplied by 0.75 when nutrient loads to the lake were calculated to correct for the fact that some of the daily droppings are not into the lake. Multiplying the waterfowl count at the lake by the adjusted daily nutrient content of the droppings resulted in an estimate of 16.17 lbs of nitrogen and 12.38 lbs of phosphorus being added to the lake from waterfowl droppings during the investigation (table 11).

Approximately 75 percent of the nitrogen and phosphorus input to the lake from waterfowl droppings were deposited in October and November 1996. During these months, nutrient uptake by aquatic macrophytes and algae would be minimal. Under these conditions, most of the nutrients in the droppings would not be used by plant life and would have little effect on water quality in the short term. Most of the nutrients would be incorporated into the lake sediment, where they could have a long-term effect on water quality.

Sediment samples were collected from the lakeshore near the NE, SE, NW, and SW shoreline erosion transects by USGS personnel on February 19, 1997 (fig. 2). These samples were analyzed by the IEPA laboratory for total organic carbon (TOC), nutrients, and metals (table 12). TOC concentrations in the samples ranged from 0.9 to 4.2 mg/kg and were higher in the samples from the north side of the lake. Phosphorus concentrations ranged from 130 to 431 mg/kg, averaged 234 mg/kg, and were higher in the samples from the southern part of the lake than in the samples from the northern part of the lake. TKN concentrations in the sediments ranged from 94 to 966 mg/kg and

Table 11. Estimated nutrient loads from waterfowl to the Bauman Park Lake, Cherry Valley, Ill., May 1, 1996–April 30, 1997

[na, not applicable]

Type of waterfowl	Effective user days for the month	Estimated daily load of nitrogen to lake from droppings (pound)	Estimated daily load of phosphorus to lake from droppings (pound)	Total nitro-gen added (pounds)	Total phospho-rus added (pounds)
May 1996					
Mallard ducks	76	0.0013	0.00081	0.099	0.062
Canada goose	24	.0040	.0025	.096	2.3
Monthly total	100	na	na	.195	2.4
June 1996					
Mallard ducks	12	.0013	.00081	.016	.0097
Canada goose	31	.0040	.0025	.124	.0775
Monthly total	43	na	na	.140	.0872
July 1996					
Mallard ducks	24	.0013	.00081	.031	.0194
Canada goose	69	.0040	.0025	.276	.1725
Monthly total	93	na	na	.307	.1919
August 1996					
Mallard ducks	115	.0013	.00081	.150	.0932
Canada goose	27	.0040	.0025	.108	.0675
Monthly total	142	na	na	.258	.1607
September 1996					
Mallard ducks	249	.0013	.00081	.324	.20
Canada goose	79	.0040	.0025	.316	.20
Monthly total	328	na	na	.640	.40
October 1996					
Mallard ducks	1,108	.0013	.00081	1.44	.90
Canada goose	370	.0040	.0025	1.48	.93
Monthly total	370	na	na	2.92	1.82
November 1996					
Mallard ducks	1,767	.0013	.00081	2.30	1.43
Canada goose	2,237	.0040	.0025	8.95	5.59
Monthly total	4,004	na	na	11.25	7.02
December 1996					
Mallard ducks	0	.0013	.00081	.00	.00
Canada goose	0	.0040	.0025	.00	.00
Monthly total	0	na	na	.00	.00
January 1997					
Mallard ducks	0	.0013	.00081	.00	.00
Canada goose	0	.0040	.0025	.00	.00
Monthly total	0	na	na	.00	.00
February 1997					
Mallard ducks	0	.0013	.00081	.00	.00
Canada goose	0	.0040	.0025	.00	.00
Monthly total	0	na	na	.00	.00
March 1997					
Mallard ducks	0	.0013	.00081	.00	.00
Canada goose	0	.0040	.0025	.00	.00
Monthly total	0	na	na	.00	.00

Table 11. Estimated nutrient loads from waterfowl to the Bauman Park Lake, Cherry Valley, Ill., May 1, 1996–April 30, 1997—Continued

[na, not applicable]

Type of waterfowl	Effective user days for the month	Estimated daily load of nitrogen to lake from droppings (pound)	Estimated daily load of phosphorus to lake from droppings (pound)	Total nitrogen added (pounds)	Total phosphorus added (pounds)
		April 1997			
Mallard ducks	134	.0013	.00081	.17	.11
Canada goose	74	.0040	.0025	.30	.19
Monthly total	208	na	na	.47	.29
Annual total (May 1, 1996–April 30, 1997)	5,288	na	na	16.170	12.38

Table 12. Results of sediment samples from the shoreline and lake bottom, Bauman Park Lake, Cherry Valley, Ill.

[mg/kg, milligrams per kilogram; na, not analyzed; k, concentration below detection limit]

Analyte	Sample location				
	SE shoreline erosion transect	SW shoreline erosion transect	NW shoreline erosion transect	NE shoreline erosion transect	Lake bottom at site 1
Arsenic (mg/kg)	1k	2	1	1k	6
Barium (mg/kg)	7	29	14	14	60
Cadmium (mg/kg)	1k	1k	1k	1k	1k
Carbon, total organic (mg/kg)	.9	1.8	2.6	4.2	3.3
Chromium (mg/kg)	3	7	4	4	18
Copper (mg/kg)	5k	6	5k	5k	37
Iron (mg/kg)	2,600	5,900	5,200	5,000	24,000
Lead (mg/kg)	10k	10k	10k	10k	14
Manganese (mg/kg)	67	86	120	160	510
Mercury (mg/kg)	.10k	.10k	.10k	.10k	.10k
Nickel (mg/kg)	5k	6	5k	5k	20
Nitrogen, total kjeldahl (mg/kg)	155	94	378	966	2,515
Phosphorus, total (mg/kg)	200	431	130	174	591
Potassium (mg/kg)	220	320	310	340	1,100
Silver (mg/kg)	1k	1k	1k	1k	1k
Solids, percent	87	58	87.4	86.4	45.8
Solids, percent volatile	1	7.2	1.2	1.2	na
Zinc (mg/kg)	10k	21	11	13	80

averaged 398 mg/kg. TKN concentrations in sediments from the lakeshore on the southern part of the lake were substantially lower than concentrations in sediments from the northern part of the lake.

About 4,715 ft^3 of sediment was determined to have eroded into the lake from January 23 to November 14, 1997. If the density of the shore sediment is 71 lbs/ft^3, based on the average of samples collected at the NW and SE transects (fig. 2), the mass of the sediment that eroded into the lake was 334,765 lbs. If the average concentration of phosphorus and TKN in the sediment samples collected at the transects is 234 and 398 mg/kg, respectively; then 78 lbs of phosphorus and 133 lbs of nitrogen were added to the lake from shoreline erosion. Although these nutrients are bound to solid particles and are not readily used by plants and algae under normal conditions; these nutrients remain in the bottom sediments and can be released to the water column, given the proper geochemical conditions.

Ground water flowing into the lake carries phosphorus and nitrogen compounds, which can become available for utilization by algae and aquatic macrophytes. The nutrient load resulting from the inflow of ground water to the lake was calculated by multiplying the volume of ground-water discharge from May 1 to August 30, 1996, by the mean concentration of dissolved phosphorus, total phosphorus, ammonia, TKN, and nitrate and nitrite as nitrogen in ground-water samples collected on June 27, 1996, and by multiplying the volume of ground-water discharge from September 1, 1996, to April 30, 1997, by the mean concentration of these nutrients in ground-water samples collected on November 13, 1996, February 19, 1997, and April 29, 1997. A calculation of about 31 lbs of nitrate and nitrite as nitrogen, 2,851 lbs of TKN (of which 230 lbs is ammonia), and 534 lbs of total phosphorus (13 lbs dissolved) were added to the lake by recharge from ground water during the period of investigation (table 13).

Water flowing out of the lake to ground water also carries phosphorus and nitrogen compounds, which become unavailable to algae and aquatic macrophytes. The nutrient loss resulting from the discharge of lake water to ground water was calculated by multiplying the volume of lake-water discharge from May 1 to August 30, 1996, by the mean concentration of nutrients in all samples of lake water collected from April 30 to August 23, 1996. The nutrient loss resulting from the discharge of lake water to ground water from September 1, 1996, to April 30, 1997, was calculated by multiplying the volume of lake-water discharge by the mean concentration of nutrients in all samples of lake water collected after August 23, 1996 (table 12). It was determined that 4 lbs of nitrate and nitrite as nitrogen, 314 lbs of TKN (of which 12 lbs is ammonia), and 13 lbs of total phosphorus (4 lbs dissolved) were removed from the lake by flowing out to ground water (table 13).

Internal Loads

A sediment sample was collected from the bottom of the lake by IEPA personnel at site 1 on July 23, 1996. The sample was analyzed by the IEPA laboratory for TOC, nutrients, and metals (table 12). The concentrations of TOC, total phosphorus, and TKN in the bottom sample were 3.3 mg/kg, 591 mg/kg, and 2,515 mg/kg, respectively. These values indicate the presence of substantial quantities of nutrients in lake bottom sediments available for direct uptake by rooted aquatic plants or entering the water column under the proper chemical conditions. The concentrations of all constituents in the bottom sample are within or below the mean levels for sediments in Illinois lakes (Kelly and Hite, 1981).

Concentrations of total phosphorus, TKN, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, and zinc in the sample of the bottom sediment are greater than in the sediment samples from the lake shore. Concentrations of TOC in the sample of the bottom sediment are greater than TOC concentrations in three of the sediment samples from the lake shore. Assuming that the concentrations measured in these samples are representative, this indicates that shoreline erosion is not the only source of the nutrients in the bottom sediments; and nutrients are accumulating in the bottom sediments, possibly from dead plant material (Barko and Smart, 1980; Smith and Adams, 1986).

If the concentration of dissolved oxygen in lake water above the bottom sediment falls below 2.0 mg/L, bacterially mediated anaerobic reduction of organic matter and chemical reduction of metal phosphate complexes can release dissolved phosphorus to the water column (Mortimer, 1971; Marsden, 1989). This process is called internal regeneration. Concentrations of dissolved oxygen at or below 2.0 mg/L were measured at the bottom of the lake at site 2 on July 23, 1996, and were below 1.0 mg/L at sites 1 and 2 on

Table 13. Calculated nutrient loads flowing into the Bauman Park Lake from ground water and flowing out of the Bauman Park Lake to ground water, Cherry Valley, Ill., May 1, 1996–April 30, 1997

[na, not applicable]

Mean concentration of nitrate and nitrite as nitrogen in ground water (milligram per liter)	Mean concentration of ammonia in ground water (milligram per liter)	Mean concentration of total Kjelhdahl nitrogen in ground water (milligrams per liter)	Mean concentration of dissolved phosphorus in ground water (milligram per liter)	Mean concentration of total phosphorus in ground water (milligrams per liter	Volume of ground water flowing into the lake (gallons)	Load of nitrate and nitrite as nitrogen to lake from ground water (pounds)	Load of ammonia to lake from ground water (pounds)	Load of total Kjeldahl nitrogen to lake from ground water (pounds)	Load of dissolved phosphorus to lake from ground water (pounds)	Load of total phosphorus to lake from ground water (pounds)
May 11, 1996–August 30, 1996										
0.102	0.638	10.356	0.0182	1.4847	26,538,797	22	141	2,290	4	328
September 1, 1996–April 30, 1997										
.025	.254	1.607	.0266	.5911	41,922,276	9	89	561	9	206
Total input										
na	na	na	na	na	na	31	230	2,851	13	534

Mean concentration of nitrate and nitrite as nitrogen in lake water (milligram per liter)	Mean concentration of ammonia in lake water (milligram per liter)	Mean concentration of total Kjelhdahl nitrogen in lake water (milligrams per liter)	Mean concentration of dissolved phosphorus in lake water (milligram per liter)	Mean concentration of total phosphorus in lake water (milligrams per liter)	Volume of lake water flowing into the lake (gallons)	Load of nitrate and nitrite as nitrogen to ground from lake water (pounds)	Load of ammonia to ground from lake water (pounds)	Load of total Kjeldahl nitrogen to ground from lake water (pounds)	Load of dissolved phosphorus to ground from lake water (pounds)	Load of total phosphorus to ground from lake water (pounds)
May 11, 1996–August 30, 1996										
0.006	0.016	0.387	0.0005	0.0123	40,239,953	2	5	130	0.2	4.1
September 1, 1996–April 30, 1997										
.006	.02	.541	.011	.0258	40,830,233	2	7	184	4	9
Total outflow										
na	na	na	na	na	na	4	12	314	4	13

Net load of nitrate and nitrite as nitrogen to the lake (pounds)	Net load of ammonia to the lake (pounds)	Net load of total Kjeldahl nitrogen to lake from ground water (pounds)	Load of dissolved phosphorus to the lake (pounds)	Net load of total phosphorus to the lake (pounds)

August 23, 1996. It is possible that internal regeneration of phosphorus was occurring in at least part of the lake during part of the summer. Concentrations of total or dissolved phosphorus at the bottom of the lake, however, did
not substantially exceed concentrations of total or dissolved phosphorus at the top of the lake, except for the total phosphorus sample collected on July 23, 1996. It is not certain, therefore, that phosphorus was being produced from internal regeneration during the investigation. Although dissolved-oxygen data were not collected during the winter, it is assumed that dissolved-oxygen concentrations were below 0.5 mg/L during one-half of the period of ice cover. An internal dissolved-phosphorus loading rate of 0.54 X 10^{-1} lb/acre was assumed for each day that dissolved oxygen concentrations were below 0.5 mg/L at the lake bottom, based on the lowest of the values reported from investigations at other lakes (Nurnberg, 1984, p. 119). Applying this rate to the estimated lake bottom area of 27.4 acres (because of the steep sides of the lake, the area of the hypolimnion approximately equals the surface area of the lake) and assuming anoxic conditions were present for 31 days on and about August 23 and for 31 days during the period of ice cover, 91 lbs of phosphorus were calculated to have been released to the water column by internal regeneration during the investigation.

Internal regeneration of ammonia nitrogen from lake sediment and the decomposition of plant and animal matter (ammoniafication) also has been noted during periods when concentrations of dissolved oxygen are low (Keeney, 1973). If an internal regeneration rate of 1.07 (lb/acre)/d is assumed (Vollenweider, 1968) for 27.4 acres and 62 days, a total of 1,819 lbs of ammonia was calculated to have been produced during the period of low dissolved oxygen concentrations. The elevated concentration of ammonia and (or) TKN detected in the lake samples on August 23, the date of the lowest dissolved oxygen concentrations measured in the lake (table 7), indicates that regeneration of nitrogen by ammoniafication was occurring.

Nitrogen from water is lost to the atmosphere by denitrification, the bacterially mediated utilization of nitrate or nitrite during the oxidation of organic matter. This process takes place in low-oxygen conditions and results in the formation of nitrogen gas (Goering and Dugdale, 1966). Because most lakes are saturated or nearly saturated with nitrogen gas, which can diffuse in from the atmosphere, all of the nitrogen produced by denitrification is assumed to be lost to the atmosphere by volatilization from the lake. The rate of denitrification at the Bauman Park Lake was assumed to be 0.033 (lb/acre)/d based on values from other moderately eutrophic lakes reported by Seitzinger (1988). Because denitrification rates are reduced at lower temperatures, it is assumed that denitrification occurred only during the low-oxygen conditions present for 31 days in the summer of 1996. During the period of investigation, the amount of nitrogen gas calculated to have been produced by denitrification was 28 lbs.

Data obtained from this investigation indicate that about 777 lbs of phosphorus and 4,648 lbs of nitrogen compounds were placed in the Bauman Park Lake from May 1, 1996, to April 30, 1997 (table 14). Phosphorus compounds were derived primarily from inflow from ground water. Substantial amounts of phosphorus also were derived from sediments eroded from the shoreline and internal regeneration. Waterfowl excrement, particulate matter deposited from the atmosphere and direct precipitation and overland runoff were sources of minor amounts of phosphorus compounds to the lake (table 14). Nitrogen compounds in the Bauman Park Lake were derived primarily from inflow from ground water. Internal regeneration from sediments, direct precipitation and overland runoff of precipitation, sediments eroded from the shoreline, and particulate matter deposited from the atmosphere also were substantial sources of nitrogen compounds to the lake (table 14). Waterfowl excrement contributed negligible amounts of nitrogen compounds to the lake. About 13 lbs of total phosphorus and 318 lbs of nitrogen compounds leave the lake by flowing out to ground water; and 28 lbs of nitrogen leave the lake because of denitrification. During the period of investigation, there was a net addition of 764 lbs of phosphorus and 4,302 lbs of nitrogen to the lake. (table 14)

Nutrient loads from internal regeneration of phosphorus and ammonia, denitrification, gaseous diffusion from the atmosphere, and particulate matter deposited from the atmosphere are a substantial part of the calculated nutrient load to the lake. The values that form the basis for the calculation of these nutrient loads were obtained at other lakes and are not necessarily representative of conditions at the Bauman Park Lake. Therefore, care should be taken in making management decisions based on these values.

Nitrogen and phosphorus compounds that enter the Bauman Park Lake are used by algae and aquatic macrophytes. The growth of these plants appears to

Table 14. Nutrient loads to and from the Bauman Park Lake, Cherry Valley, Ill., May 1, 1996–April 30, 1997

[na, not applicable]

Nutrient loads entering the lake	Nitrogen compounds		Phosphorus compounds	
	Load (pounds)	Percent of total load to lake	Load (pounds)	Percent of total load to lake
Nutrient loads entering lake				
Inflow of ground water	2,882	62.1	534	68.7
Shoreline erosion	206.	4.4	121	15.6
Internal regeneration	910	19.6	91	11.7
Waterfowl	16.2	.3	12.3	1.6
Precipitation	428	9.2	8.2	1.1
Overland runoff	44	.9	.7	.1
Particulate matter	162	3.5	10.1	1.2
Total	4,648.2	100	777.3	100
Nutrient loads exiting lake				
Outflow to ground water	318	91.9	13	100
Denitrification	28	8.1	na	na
Total	346	100	13	100
Net load to lake	4,302	na	764.3	na

be limited by the availability of phosphorus in the lake water. The amount of nutrients in the ground water flowing into the lake exceeds the amount of nutrients in the lake water flowing to ground water. It is probable that some of the nutrient load is incorporated into plant material and attached to particulate matter. Nutrient-rich particulate matter and decaying plant material become part of the sediment at the lake bottom, where the nutrients can be recycled by the rooted aquatic macrophytes (Barko and Smart, 1980; Smith and Adams, 1986) or may be released to the water column during reducing conditions.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey, in cooperation with the Village of Cherry Valley, conducted a study of the hydrology and water quality in and around Bauman Park Lake in the Village of Cherry Valley, Winnebago County, Ill., from May 1, 1996, to April 30, 1997. This study was done as part of the Illinois Environmental Protection Agency's Clean Lakes 2000 initiative. The investigation was designed to provide the data that will form the basis for future lake-management strategies. The lake occupies a former sand and gravel quarry and has a surface area of about 27.4 acres, a drainage area of about 54 acres, an average depth of about 18 feet, and a volume of about 1.5×10^8 gallons. The lake is subject to thermal stratification.

Ground water in the vicinity of the lake flows through unconsolidated sand and gravel deposits of the Mackinaw Member of the Henry Formation. These deposits are approximately 100 feet thick in this area and, where saturated, these deposits constitute the sand and gravel aquifer. During typical hydrologic conditions, the water-table configuration indicates the overall direction of ground-water flow was from east to west, toward the Kishwaukee River. During periods of flooding on the Kishwaukee River, the river recharged to ground water and the overall direction of ground-water flow was from north to south, toward the lake. This configuration was only present for a few days during flooding. Following flooding on the Kishwaukee River and the unnamed stream south of the lake, the lake stage and water-table configuration began to return to normal; and the overall direction of ground-water flow was from east to west, away from the lake. During and shortly after the period when the beaver dam was present near the CW gage, the overall direction of ground-water flow was from south to north, from the unnamed stream toward the Kishwaukee River.

During the investigation, the total volume of water added to the lake by inflow from ground water, precipitation, and overland runoff was calculated at 1.02×10^8 gallons. The total volume of water removed from the lake by flow out to ground water and evaporation was calculated at 9.95×10^7 gallons. The residence time of water in the lake was calculated at about 1.5 years.

The mean value of the trophic state index of the Bauman Park Lake, determined from Secchi depth readings, was about 42. The mean value of the trophic state index, determined from the total phosphorus in the water samples from the lake surface, was 41. The trophic state index calculated from the corrected chlorophyll *a* concentrations had a mean value of about 48. The trophic state indices indicate that the lake is mesotrophic or marginally eutrophic. Phosphorus appears to be the limiting algal nutrient.

About 777 pounds of phosphorus and 4,648 pounds of nitrogen compounds were placed in the Bauman Park Lake from May 1, 1996, to April 30, 1997. Phosphorus compounds were derived primarily from inflow from ground water (68.7 percent), sediments derived from shoreline erosion (15.6 percent), internal regeneration (11.7 percent). Waterfowl excrement, particulate matter deposited from the atmosphere and direct precipitation and overland runoff were sources of smaller amounts of phosphorus. Nitrogen compounds were derived primarily from inflow from ground water (62.1 percent), internal regeneration from sediments (19.6 percent), and direct precipitation and overland runoff of precipitation (10.1 percent). Sediments eroded from the shoreline, particulate matter deposited from the atmosphere, and waterfowl excrement accounted for smaller amounts of nitrogen compounds. About 13 pounds of total phosphorus and 318 pounds of nitrogen compounds leave the lake by flowing out to ground water; and 28 pounds of nitrogen leave the lake because of denitrification, leaving a net addition of 777 pounds of phosphorus and 4,302 pounds of nitrogen to the lake during the period of investigation.

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APPENDIX

APPENDIX 1. CALCULATED HYDRAULIC PARAMETERS IN THE SAND AND GRAVEL AQUIFER ALONG LINES OF FLOW TRANSECT IN THE VICINITY OF THE BAUMAN PARK LAKE, CHERRY VALLEY, ILL., MAY 11, 1996–APRIL 29, 1997

[–, denotes flow from lake to ground water]

Line of flow and direction of flow (measurement point 1-measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Lengt h of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizon-tal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measure-ment periods (cubic feet)
May 11, 1996												
Well5-lake	717.08	715.84	1.24	25	0.0496	78	3.87	1,500	26.8	40,200	155,526	1,088,680
Well6-lake	717.77	715.84	1.93	260	.00742	78	.579	875	26.8	23,450	13,578	95,043
Well8-lake	718.12	715.84	2.28	350	.00651	78	.508	2,000	26.8	53,600	27,235	190,644
Well9-lake	716.15	715.84	.31	250	.00124	78	.0967	1,000	26.8	26,800	2,592	18,145
Lake-CW	715.84	715.39	.45	150	–.00300	78	–.234	1,325	26.8	35,510	-8,309	–58,165
May 18, 1996												
CE-lake	716.68	716.12	.48	140	.00343	78	.267	900	27.1	24,390	6,523	45,658
Well6-lake	716.72	716.12	.60	300	.00200	78	.156	900	27.1	24,390	3,805	26,634
Lake-well2	716.12	715.95	.19	875	–.000217	78	–.0169	2,075	27.1	56,233	–952	–6,667
Lake-well10	716.12	715.23	.89	425	–.00209	78	–.163	750	27.1	20,325	–3,320	–23,239
Lake-CW	716.12	715.28	.84	150	–.00560	78	–.437	2,075	27.1	56,233	–24,562	–171,936
May 25, 1996												
Lake-CE	717.60	716.76	.84	140	–.00600	78	–.468	1,500	28.6	42,900	–20,077	–140,540
Lake-well6	717.60	716.87	.73	200	–.00365	78	–.285	900	28.6	25,740	–7,328	–51,297
Lake-well8	717.60	715.92	1.68	400	–.00420	78	–.328	2,175	28.6	62,205	–20,378	–142,649
Lake-well9	717.60	715.98	1.62	250	–.00648	78	–.505	1,000	28.6	28,600	–14,456	–101,189
Lake-CW	717.60	716.03	1.57	150	–.0105	78	–.816	1,125	28.6	32,175	–26,268	–183,874

Line of flow and direction of flow (measurement point 1-measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
June 1, 1996												
Lake-CE	717.80	716.78	1.02	140	−0.00729	78	−0.568	950	30.0	28,500	−16,196	−113,373
Well6-lake	719.77	717.80	1.97	250	.00788	78	.615	950	30.0	28,500	17,517	122,621
Well2-lake	721.91	717.80	4.11	750	.00548	78	.427	2,150	30.0	64,500	27,570	192,989
Lake-well10	717.80	715.33	2.47	625	−.00395	78	−.308	1,025	30.0	30,750	−9,479	−66,352
Lake-CW	717.80	715.75	2.05	150	−.0137	78	−1.07	1,675	30.0	50,250	−53,566	−374,965
June 8, 1996												
Well5-CE	718.17	716.82	1.35	115	−.0117	78	−.916	1,400	30.0	42,000	−38,457	−153,830
Well6-lake	719.17	717.80	1.37	250	−.00548	78	−.427	1,250	30.0	37,500	−16,029	−64,116
Well8-well1	721.72	718.03	3.69	250	−.0148	78	−1.15	2,000	30.0	60,000	−69,077	−276,307
Well3-well10	717.77	715.21	2.56	600	−.00427	78	−.333	1,850	30.0	55,500	−18,470	−73,882
Lake-CW	717.80	716.18	1.62	150	−.0108	78	−.842	1,500	30.0	45,000	−37,908	−151,632
June 12, 1996												
Lake-CE	717.80	716.68	1.12	140	−.00800	78	−.624	1,075	30.0	32,250	−20,124	−60,372
Well6-lake	718.05	717.80	.25	250	.00100	78	.0780	1,000	30.0	30,000	2,340	7,020
Well1-well2	717.83	717.63	.20	575	−.000348	78	−.0271	2,200	30.0	66,000	−1,791	−5,372
Lake-well10	717.80	715.94	1.86	600	−.00310	78	−.242	950	30.0	28,500	−6,891	−20,674
Lake-CW	717.80	715.94	1.86	150	−.0124	78	−.967	1,475	30.0	44,250	−42,799	−128,396

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Lengt h of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizon- tal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measure- ment periods (cubic feet)
June 15, 1996												
Lake-CE	717.62	716.67	0.95	140	–0.00679	78	–0.529	1,075	28.6	30,745	–16,273	–113,910
Well6-lake	717.77	717.62	.15	260	.000577	78	.0450	1,000	18.6	18,600	837	5,859
Lake-well2	717.62	716.62	1.00	850	–.00118	78	–.0918	2,200	18.6	40,920	–3,755	–26,285
Lake-well9	717.62	716.15	1.47	250	–.00588	78	–.459	950	18.6	17,670	–8,104	–56,729
Lake-CW	717.62	716.02	1.60	150	–.0107	78	–.832	1,475	18.6	27,435	–22,826	–159,781
June 22, 1996												
Lake-CE	717.42	716.69	.73	140	–.00521	78	–.407	1,075	28.4	30,530	–12,417	–37,251
Well6-lake	717.60	717.42	.18	250	.000720	78	.0562	1,000	28.4	28,400	1,595	4,785
Well1-lake	717.71	717.42	.29	120	.00242	78	.189	2,000	28.4	56,800	10,707	32,120
Lake-well9	717.42	716.51	.91	300	–.00303	78	–.237	1,125	28.4	31,950	–7,559	–22,678
Lake-CW	717.42	716.11	1.31	150	–.00873	78	–.681	1,500	28.4	42,600	–29,019	–87,057
June 25, 1996												
Lake-CE	717.20	716.69	.51	130	–.00392	78	–.306	1,050	28.2	29,610	–9,061	–54,364
Well6-lake	717.41	717.20	.21	280	.000750	78	.0585	1,000	28.2	28,200	1,650	9,898
Lake-well2	717.20	716.60	.60	875	–.000686	78	–.0535	2,200	28.2	62,040	–3,318	–19,910
Lake-well9	717.20	716.12	1.08	260	–.00415	78	–.324	1,000	28.2	28,200	–9,137	–54,821
Lake-CW	717.20	715.69	1.51	150	–.0101	78	–.785	1,450	28.2	40,890	–32,107	–192,641

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Lengt h of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizon- tal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measure- ment periods (cubic feet)
July 1, 1996												
Lake-CE	716.68	716.64	0.04	140	–0.000286	78	–0.0223	500	27.7	13,850	–309	–2,778
Well6-lake	716.92	716.68	.24	250	.000960	78	.0749	1,000	27.7	27,700	2,074	18,668
Lake-well2	716.68	715.63	1.05	700	–.00150	78	–.117	2,200	27.7	60,940	–7,130	–64,170
Lake-well9	716.68	715.40	1.28	300	–.00427	78	–.333	1,000	27.7	27,700	–9,219	–82,967
Lake-CW	716.68	715.53	1.15	150	–.00767	78	–.598	2,000	27.7	55,400	–33,129	–298,163
July 10, 1996												
CE-lake	716.67	716.04	.63	140	.00450	78	.351	500	27.0	13,500	4,738	47,385
Well6-lake	716.38	716.04	.34	250	.00136	78	.106	1,000	27.0	27,000	2,864	28,642
Lake-well2	716.04	715.08	.96	800	–.00120	78	–.0936	2,200	27.0	59,400	–5,560	–55,598
Lake-well9	716.04	714.87	1.17	300	–.00390	78	–.304	1,100	27.0	29,700	–9,035	–90,347
Lake-CW	716.04	715.44	.60	150	–.00400	78	–.312	1,900	27.0	51,300	–16,006	–160,056
July 20, 1996												
Lake-CE	716.96	716.76	.20	140	–.00143	78	–.111	500	27.0	13,500	–1,504	–10,530
Well6-lake	718.17	716.96	1.21	250	.00484	78	.378	1,000	27.0	27,000	10,193	71,351
Well2-lake	718.33	716.96	1.37	800	.00171	78	.134	3,000	27.0	81,000	10,820	75,737
Well9-lake	717.09	716.96	.13	300	.000433	78	.0338	500	27.0	13,500	456	3,194
Lake-CW	716.96	715.69	1.27	150	–.00847	78	–.660	1,700	17.0	28,900	–19,086	–133,599

Line of flow and direction of flow (measurement point 1-measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
July 27, 1996												
Lake-CE	716.68	716.63	0.05	140	−0.000357	78	−0.0279	500	27.7	13,850	−386	−5,016
Lake-well6	716.68	716.00	.68	250	−.00272	78	−.212	1,000	27.7	27,700	−5,877	−76,399
Lake-well2	716.68	715.81	.87	750	−.00116	78	−.0905	2,200	27.7	60,940	−5,514	−71,680
Lake-well9	716.68	713.88	2.80	270	−.0104	78	−.809	1,100	27.7	30,470	−24,647	−320,409
Lake-CW	716.68	715.55	1.13	150	−.00753	78	−.588	1,900	27.7	52,630	−30,925	−402,030
August 10, 1996												
CE-lake	716.68	716.62	.06	140	.000429	78	.0334	800	27.6	22,080	738	5,167
Well6-lake	717.39	716.62	.77	250	.00308	78	.240	1,000	27.6	27,600	6,631	46,414
Well2-lake	716.67	716.62	.05	800	.0000625	78	.00488	2,000	27.6	55,200	269	1,884
Lake-well9	716.62	715.98	.64	300	−.00213	78	−.166	1,200	27.6	33,120	−5,511	−38,578
Lake-CW	716.62	716.13	.49	150	−.00327	78	−.255	1,700	27.6	46,920	−11,955	−83,687
August 17, 1996												
CE-lake	716.67	716.32	.35	140	.0025	78	.195	1,150	27.3	31,395	6,122	42,854
Well6-lake	717.28	716.32	.96	230	.00417	78	.326	1,000	27.3	27,300	8,888	62,216
Lake-well2	716.32	715.69	.63	850	−.000741	78	−.0578	2,200	27.3	60,060	−3,472	−24,305
Lake-well9	716.32	715.16	1.16	300	−.00387	78	−.302	1,200	27.3	32,760	−9,880	−69,163
CW-lake	716.51	716.32	.19	150	.00127	78	.0988	1,150	27.3	31,395	3,102	21,713

Line of flow and direction of flow (measurement point 1-measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
August 24, 1996												
CE-lake	716.89	716.11	0.78	140	0.00557	78	0.435	1,150	27.1	31,165	13,543	135,434
Well6-lake	717.17	716.11	1.06	230	.00461	78	.359	1,000	27.1	27,100	9,742	97,419
Lake-well2	716.11	714.88	1.23	750	–.00164	78	–.128	2,000	27.1	54,200	–6,933	–69,333
Lake-well9	716.11	714.75	1.36	260	–.00523	78	–.408	1,400	27.1	37,940	–15,480	–154,795
CW-lake	716.89	716.11	.78	150	.00520	78	.406	1,150	27.1	31,165	12,641	126,405
September 3, 1996												
CE-lake	716.91	715.88	1.03	140	.00736	78	.574	1,150	26.9	30,935	17,752	124,266
Well6-lake	716.30	715.88	.42	230	.00183	78	.142	1,000	26.9	26,900	3,831	26,820
Lake-well2	715.88	714.66	1.22	850	–.00144	78	–.112	2,000	26.9	53,800	–6,023	–42,161
Lake-well9	715.88	714.59	1.29	300	–.00430	78	–.335	1,400	26.9	37,660	–12,631	–88,418
CW-lake	716.89	715.88	1.01	150	.00673	78	.525	1,100	26.9	29,590	15,541	108,785
September 10, 1996												
CE-lake	716.86	715.72	1.14	140	.00814	78	.635	1,150	26.7	30,705	19,502	136,514
Well6-lake	716.42	715.72	.70	260	.00269	78	.210	1,000	26.7	26,700	5,607	39,249
Lake-well2	715.72	714.58	1.14	850	–.00134	78	–.105	2,150	26.7	57,405	–6,005	–42,037
Lake-well9	715.72	714.47	1.25	375	–.00333	78	–.260	1,325	26.7	35,378	–9,198	–64,387
CW-lake	716.81	715.72	1.09	150	.00727	78	.567	1,075	26.7	28,703	16,269	113,880

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Lengt h of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizon- tal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measure- ment periods (cubic feet)
September 17, 1996												
CE-lake	716.71	715.55	1.16	140	0.00829	78	0.646	1,150	26.6	30,590	19,770	138,389
Well6-lake	716.49	715.55	.94	275	.00342	78	.267	1,000	26.6	26,600	7,092	49,644
Lake-well2	715.55	714.62	.93	800	−.00116	78	−.0907	2,150	26.6	57,190	−5,186	−36,300
Lake-well9	715.55	714.35	1.20	250	−.00480	78	−.374	1,325	26.6	35,245	−13,196	−92,370
CW-lake	716.60	715.55	1.05	150	.00700	78	.546	1,075	26.6	28,595	15,613	109,290
September 24, 1996												
CE-lake	716.66	715.46	1.20	140	.00857	78	.669	1,150	26.5	30,475	20,375	285,246
Well6-lake	716.57	715.46	1.11	250	.00444	78	.346	1,000	26.5	26,500	9,177	128,485
Lake-well2	715.46	714.28	1.18	825	−.00143	78	−.112	2,150	26.5	56,975	−6,356	−88,989
Lake-well9	715.46	714.30	1.16	250	−.00464	78	−.362	1,325	26.5	35,113	−12,708	−177,911
CW-lake	716.61	715.46	1.15	150	.00767	78	.598	1,075	26.5	28,488	17,036	238,497
October 8, 1996												
CE-lake	716.78	715.49	1.29	140	.009214	78	.719	1,150	26.5	30,475	21,903	284,737
Well6-lake	716.00	715.49	.51	350	.00146	78	.114	1,000	26.5	26,500	3,012	39,155
Lake-well2	715.49	714.37	1.12	1,000	−.00112	78	−.087	2,150	26.5	56,975	−4,977	−64,705
Lake-well9	715.49	714.33	1.16	250	−.00464	78	−.362	1,325	26.5	35,113	−12,708	−165,203
CW-lake	715.87	715.49	.38	150	.00253	78	.198	1,075	26.5	28,488	5,629	73,179

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Lengt h of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizon-tal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measure-ment periods (cubic feet)
October 21, 1996												
CE-lake	716.98	715.48	1.50	140	0.0107	78	0.836	1,150	26.5	30,475	25,468	178,279
Well6-lake	716.09	715.48	.61	250	.00244	78	.190	1,000	26.5	26,500	5,043	35,304
Lake-well2	715.48	714.43	1.05	825	–.00127	78	–.0993	2,150	26.5	56,975	–5,656	–39,592
Lake-well9	715.48	714.36	1.12	250	–.00448	78	–.349	1,325	26.5	35,113	–12,270	–85,888
CW-lake	715.75	715.48	.27	150	.00180	78	.140	1,075	26.5	28,488	4,000	27,998
October 28, 1996												
CE-lake	717.08	715.56	1.52	140	.0109	78	.847	1,150	26.5	30,475	25,808	412,928
Well6-lake	716.02	715.56	.46	300	.00153	78	.120	1,000	26.5	26,500	3,169	50,710
Lake-well2	715.56	714.36	1.20	825	–.00145	78	–.113	2,150	26.5	56,975	–6,464	–103,425
Lake-well9	715.56	714.31	1.25	300	–.00417	78	–.325	1,325	26.5	35,113	–11,412	–182,585
CW-lake	715.60	715.56	.04	150	.000267	78	.0208	1,075	26.5	28,488	593	9,481
November 13, 1996												
CE-lake	717.09	715.68	1.41	140	.0101	78	.786	1,000	26.6	26,600	20,896	689,575
Well6-lake	716.24	715.68	.56	250	.00224	78	.175	1,000	26.6	26,600	4,648	153,369
Lake-well2	715.68	714.55	1.13	825	–.00137	78	–.107	2,250	26.6	59,850	–6,394	–211,007
Lake-well9	715.68	714.51	1.17	250	–.00468	78	–.365	1,000	26.6	26,600	–9,710	–320,432
Lake-CW	715.68	715.65	.03	150	–.000200	78	–.0156	1,450	26.6	38,570	–602	–19,856

Line of flow and direction of flow (measurement point 1-measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
December 14, 1996												
CE-lake	717.23	715.86	1.37	140	0.00979	78	0.763	725	26.9	19,503	14,886	208,404
Well6-lake	716.87	715.86	1.01	275	.00367	78	.286	1,000	26.9	26,900	7,706	107,886
Lake-well2	715.86	714.39	1.47	875	–.00168	78	–.131	2,250	26.9	60,525	–7,931	–111,037
Lake-well9	715.86	714.45	1.41	250	–.00564	78	–.440	1,000	26.9	26,900	–11,834	–165,674
Lake-well4	715.86	715.66	.20	60	–.00333	78	–.260	1,450	26.9	39,005	–10,141	–141,978
December 28, 1996												
CE-lake	717.14	715.94	1.20	140	.00857	78	.669	725	27.0	19,575	13,087	693,626
Well6-lake	715.95	715.94	.01	275	.0000363	78	.00283	1,000	27.0	27,000	76	4,052
Lake-well2	715.94	714.29	1.65	800	–.00206	78	–.161	2,050	27.0	55,350	–8,904	–471,935
Lake-well9	715.86	714.22	1.64	250	–.00656	78	–.512	1,200	27.0	32,400	–16,578	–878,657
Lake-CW	715.94	715.89	.05	150	–.000333	78	–.0260	1,725	27.0	46,575	–1,211	–64,180
February 19, 1997												
CE-lake	717.40	715.20	2.20	140	.0157	78	1.23	1,725	26.2	45,195	55,396	387,773
Well6-lake	716.32	715.20	1.12	275	.00407	78	.318	1,000	26.2	26,200	8,323	58,261
Well2-lake	717.38	715.20	2.18	650	.00335	78	.262	2,200	26.2	57,640	15,079	105,550
Well9-lake	715.49	715.20	.29	300	.000967	78	.0754	775	26.2	20,305	1,531	10,717
CW-lake	715.95	715.20	.75	150	.00500	78	.390	1,000	26.2	26,200	10,218	71,526

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
March 27, 1997												
Well5-lake	716.71	716.58	0.13	25	0.00520	78	0.406	1,000	26.6	26,600	10,789	323,669
Well6-lake	716.60	716.58	.02	275	.0000727	78	.00567	1,000	26.6	26,600	151	4,525
Lake-well2	716.58	715.78	.80	875	–.000914	78	–.0713	2,150	26.6	57,190	–4,078	–122,354
Lake-well9	716.58	715.35	1.23	250	–.00492	78	–.384	750	26.6	19,950	–7,656	–229,680
Lake-well4	716.58	716.42	.16	60	–.00267	78	–.208	1,800	26.6	47,880	–9,959	–298,771
April 5, 1997												
CE-lake	716.92	716.38	.54	140	.00386	78	.301	1,000	27.4	27,400	8,243	74,191
Well6-lake	717.68	716.38	1.30	240	.00542	78	.422	1,000	27.4	27,400	11,576	104,188
Lake-well2	717.68	715.60	2.08	650	–.00320	78	–.250	2,000	27.4	54,800	–13,678	–123,103
Lake-well9	716.38	716.31	.07	275	–.000255	78	–.0199	900	27.4	24,660	–490	–4,407
Lake-CW	716.38	715.65	.73	150	–.00487	78	–.380	1,800	27.4	49,320	-18,722	–168,497
April 11, 1997												
CE-lake	716.73	716.08	.65	140	.00464	78	.362	750	27.1	20,325	7,361	44,163
Well6-lake	716.59	716.08	.51	275	.00185	78	.145	1,000	27.1	27,100	3,920	23,521
Lake-well2	716.08	715.15	.93	875	–.00106	78	–.0829	2,150	27.1	58,265	–4,830	–28,982
Lake-well9	716.08	715.06	1.02	250	–.00408	78	–.318	750	27.1	20,325	–6,468	–38,809
Lake-CW	716.08	715.27	.81	150	–.00540	78	–.421	2,050	27.1	55,555	–23,400	–140,399

Line of flow and direction of flow (measurement point 1- measurement point 2)	Water level at point 1 (feet above sea level)	Water level at point 2 (feet above sea level)	Change in water level between points (feet)	Length of flow line (feet)	Horizontal hydraulic gradient (foot per foot)	Horizontal hydraulic conductivity (feet per day)	Product horizontal hydraulic gradient and horizontal hydraulic conductivity (square feet per day)	Length of lakeshore through which flow is occurring along flow transect (feet)	Depth of lake (feet)	Area of lake through which flow is occurring along flow transect (square feet)	Specific discharge (cubic feet per day)	Volume of flow along flow transect between measurement periods (cubic feet)
April 17, 1997												
CE-lake	716.72	715.98	0.74	140	0.00529	78	0.412	750	27.0	20,250	8,349	50,093
Well6-lake	716.02	715.98	.04	275	.000145	78	.0113	1,000	27.0	27,000	306	1,838
Lake-well2	715.98	714.36	1.62	875	–.00185	78	–.144	2,150	27.0	58,050	–8,383	–50,299
Lake-well9	715.98	714.31	1.67	250	–.00668	78	–.521	750	27.0	20,250	–10,551	–63,306
Lake-CW	715.98	714.63	1.35	150	–.00900	78	–.702	2,050	27.0	55,350	–38,856	–233,134
April 29, 1997												
CE-lake	715.72	715.60	.12	140	.000857	78	.0669	750	26.6	19,950	1,334	17,339
Well6-lake	716.26	715.60	.66	275	.00240	78	.187	1,000	26.6	26,600	4,980	64,734
Lake-well2	715.60	715.00	.60	875	–.000686	78	–.0535	2,150	26.6	57,190	–3,059	–39,765
Lake-well9	715.60	714.60	1.00	250	–.00400	78	–.312	750	26.6	19,950	–6,224	–80,917
Lake-CW	715.60	714.57	1.03	150	–.00687	78	–.536	2,050	26.6	54,530	–29,206	–379,681

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