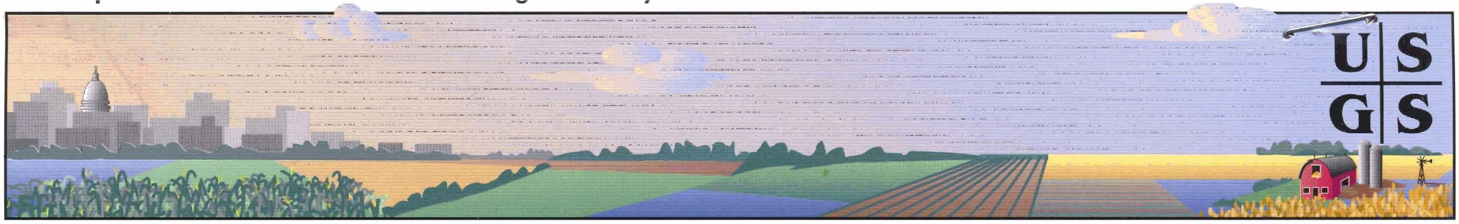

Hydrology and Water Quality of Park Lake, South-Central Wisconsin

by P.A. Kammerer, Jr.

Introduction

Park Lake extends to the northeast from the village of Pardeeville in Columbia County (fig. 1). Local residents perceive water-quality problems in the lake that include excessive algae and aquatic plant growth. Algae and plant growth in a lake are controlled, in part, by the availability of phosphorus in the water. However, no measurements of phosphorus entering the lake or of other factors that affect lake-water quality had been made, and available data on water quality were limited to 2 years of measurements at one site in the lake in 1986-87. To obtain the data and information needed to address the water-quality problems at Park Lake and to develop a management plan that would limit the input of phosphorus to the lake, the U.S. Geological Survey, in cooperation with the Park Lake Management District, studied the hydrology of the lake and collected data needed to determine sources and amount of phosphorus entering the lake. This Fact Sheet summarizes the results of that study. Data collected during the study were published in a separate report (Holmstrom and others, 1994, p. 70-85).

The Lake and its Watershed

Park Lake is an impoundment on the Fox River created by two dams (fig. 2). The southernmost dam is at an electric powerplant. Discharge from the powerplant drains to Spring Lake, which is immediately downstream. The northernmost dam drains to the Fox River. The deepest point in the lake, 27 ft (feet), is near the northernmost dam. Depths greater than 20 ft are found only near the northernmost dam and occupy less than 0.2 percent of the lake's total surface area of 312 acres (0.49 mi^2 (square miles)). The average depth of the lake is 7 ft. Most of the large eastern basin is less than 10 ft deep, and most of the smaller western basin is slightly more than 10 ft deep. The volume of the lake is 2,187 acre-feet.

Park Lake watershed encompasses 53.8 mi^2. Approximately 3 percent of this area (1.7 mi^2) drains directly to the lake and 97 percent (52.1 mi^2) drains to the Fox River.

Land use in the watershed is predominately agricultural, with approximately 78 percent of the land in cropland and pasture, 18 percent in woodland, 1.3 percent in lakes, 1.3 percent in wetlands, and 1.2 percent in developed areas (such as buildings and roads). Land use in the watershed was determined from interpretations of satellite (Landsat-5 Thematic Map-

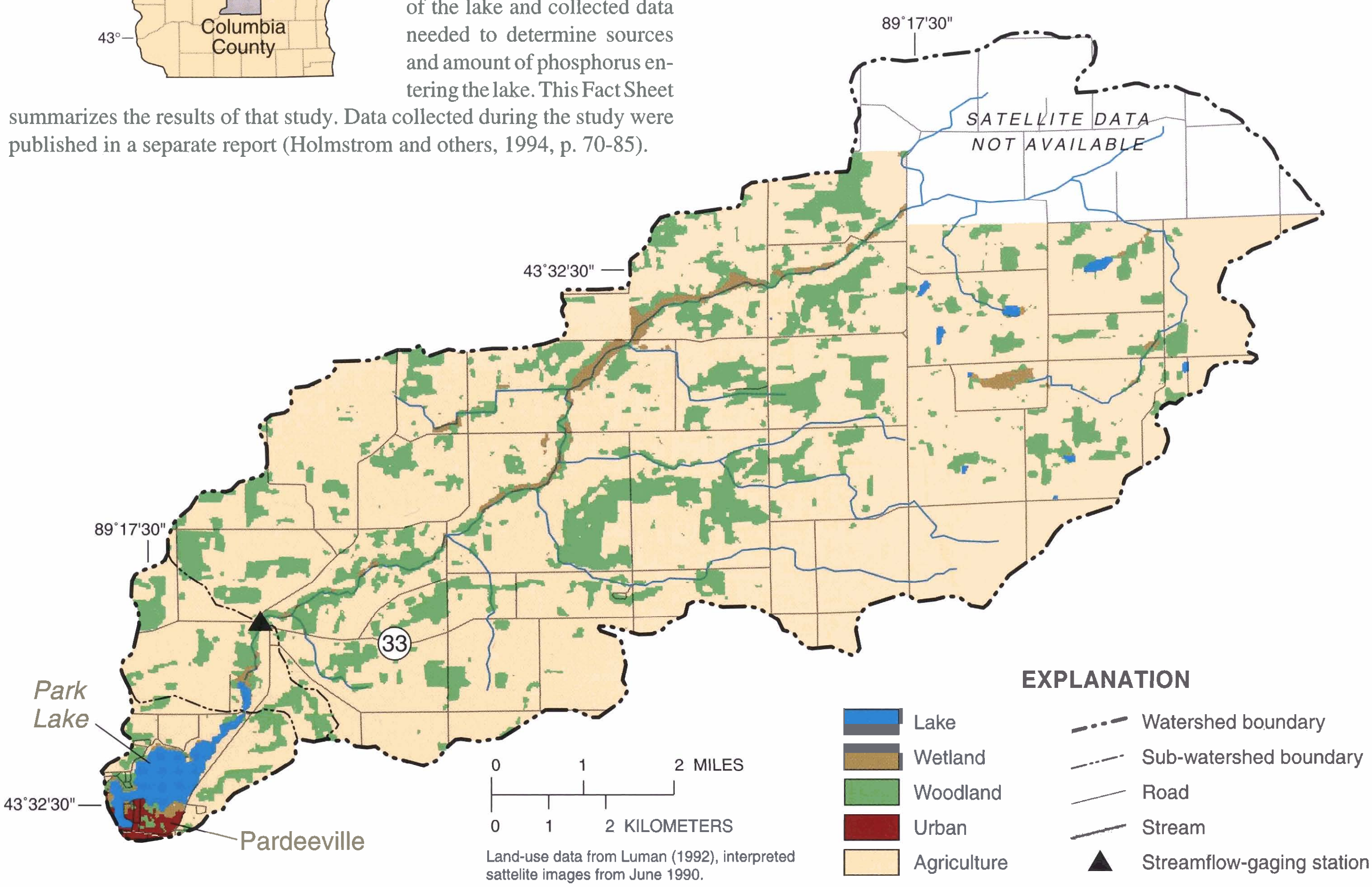

Figure 1. Location of Park Lake and land use in the Park Lake watershed.

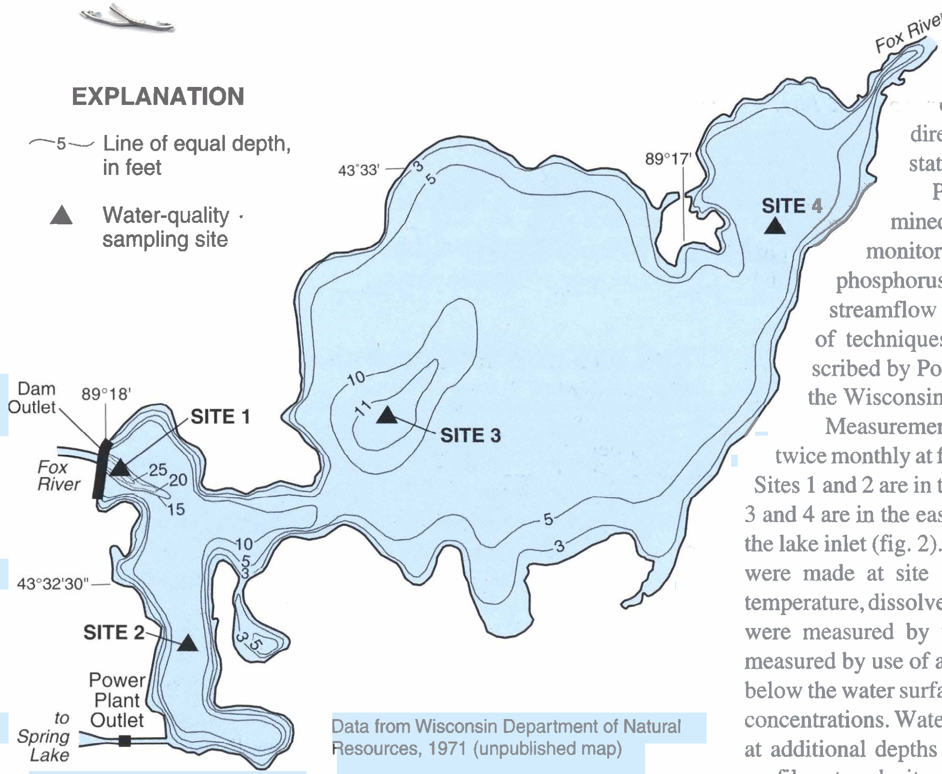

Figure 2. Map of Park Lake, south-central Wisconsin, showing data-collection sites and depth contours.

per) data from June 1990 by Luman (1992) (fig. 1). Coverage is available for only 87 percent of the watershed (the area in Columbia County), but examination of other older and less detailed information from other sources indicates that relative percentages of major land uses in the remaining 13 percent of the watershed is similar to that determined for the area in Columbia County.

Data Collection and Analysis

Data needed to describe lake hydrology and water quality and to determine the phosphorus input to the lake were collected during the 12-month period November 1992 through October 1993. The hydrology of the lake can be described by means of a water budget that identifies the sources and amounts of water entering and leaving the lake. The water budget for Park Lake for a selected time period may be represented by the equation

$$DS = (P + SI + GI) - (E + SO + GO),$$

where the change in the volume of water stored in the lake during the time period (DS) is equal to the sum of the volumes of water entering the lake minus the sum of the volumes of water leaving the lake. Sources of water entering the lake are precipitation (P), surface-water inflow (SI), and ground-water inflow (GI). Water can leave the lake by evaporation (E), surface-water outflow (SO), and ground-water outflow (GO). Budget components were either measured directly or estimated from data for nearby sites or from other budget components.

DS was determined from records of daily lake-stage readings maintained by powerplant employees. P is the average of daily readings from weather stations at Arlington (south), Portage (west), and Dalton (northwest) that are within a 10-14 mi radius of Pardeeville (Pamela Naber-Knox, University of Wisconsin Extension, Geological and Natural History Survey, written commun., 1994). Precipitation records collected by a local observer were used to confirm that records from these stations represented conditions in the Park Lake Watershed. SI was calculated from streamflow measured at a streamflow-gaging station on the Fox River at State Highway 33 (fig. 1). Streamflow measured at this station accounts for runoff from 93 percent of the lake's watershed (96 percent of the area within the watershed draining to the Fox River) and for virtually all runoff to the lake for periods of no direct overland runoff. SO, GO, and GI were not measured directly. Daily records of pan evaporation from the weather station at Arlington were used as an estimate of E.

Phosphorus input to the lake from runoff was determined by collecting periodic water samples at the streamflow-monitoring station on the Fox River for analysis of total phosphorus concentration. Concentration data and records of streamflow were used to compute daily phosphorus loads by use of techniques for integrating streamflow and concentration described by Porterfield (1972). All water samples were analyzed by the Wisconsin State Laboratory of Hygiene.

Measurements of lake-water quality were made approximately twice monthly at four sites in the lake during May 3–November 9, 1993. Sites 1 and 2 are in the western basin of the lake near the outlets, and sites 3 and 4 are in the eastern basin, at the deepest point in the basin, and near the lake inlet (fig. 2). Measurements of lake-water quality during 1986–87 were made at site 1. At each sampling site, depth profiles of water temperature, dissolved oxygen concentration, specific conductance, and pH were measured by use of a multiparameter meter. Water clarity was measured by use of a Secchi disc, and water samples were collected 1.5 ft below the water surface for analysis for total phosphorus and chlorophyll *a* concentrations. Water samples for total phosphorus analysis were collected at additional depths as needed to define total phosphorus-concentration profiles at each site. Samples were collected at sites 1 and 3 on May 3 for analysis for common dissolved mineral constituents to provide a general characterization of the lake-water chemical quality.

Hydrology

Precipitation during the study period was about 50 percent above normal. Resulting runoff in the area of the State that includes the Park Lake watershed was approximately 150–250 percent of normal runoff (Holmstrom and others, 1994, p. 2–6). The average precipitation for the three nearby weather stations was 48.08 in. (inches) compared to an average of 32.11 in. for corresponding 1-year periods from 1963 through 1993. Daily precipitation and inflow to the lake from the Fox River are shown in figure 3. No historical streamflow records are available for the streamflow station for comparison with streamflow data during the study period. However, the mean discharge for a monitoring station on the Fox River at Berlin for water year 1993 (October 1992–September 1993) was twice the mean discharge

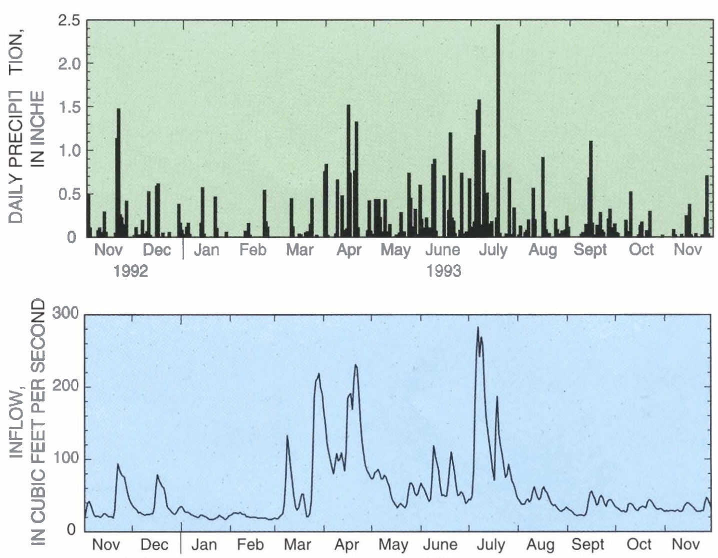

Figure 3. Graph showing daily precipitation and inflow from Fox River to Park Lake.

for water years 1898 through 1993 (Holmstrom and others, 1994, p. 96).

Inflow to the lake from the Fox River was highest in March, April, and July (fig. 3). The high flows of the river were the result of runoff from snowmelt in March and early April and from rainfall in April and July.

The water budget for Park Lake, as represented by the terms of the water-budget equation, is dominated by surface-water inflow (SI) from the watershed and surface-water outflow (SO) from the outlets. The volume of water stored in the lake during the study period did not change (DS=0), so the sum of the inflow terms (P + SI + GI) is equal to the sum of the outflow terms (E + SO + GO). The relative magnitude of the terms in the inflow and outflow components of the water budget are shown in figure 4. SI was calculated by use of drainage-area ratios to adjust the streamflow measured at the gaging station to include runoff from the remaining 7 percent of the watershed not monitored at the streamflow-gaging station. GI was estimated by assuming that ground-water inflow to the lake is equivalent to winter streamflow at the gaging station adjusted by using drainage-area ratios to include the ungaged area of the watershed. SI accounts for 94 percent of the inflow to the lake, and GI and P account for 3.5 and 2.5 percent. Assuming that GO is negligible relative to GI (GO = 0), SO is the sum of the inflow terms minus E. SO accounts for 99 percent and E for 1 percent of the outflow from the lake.

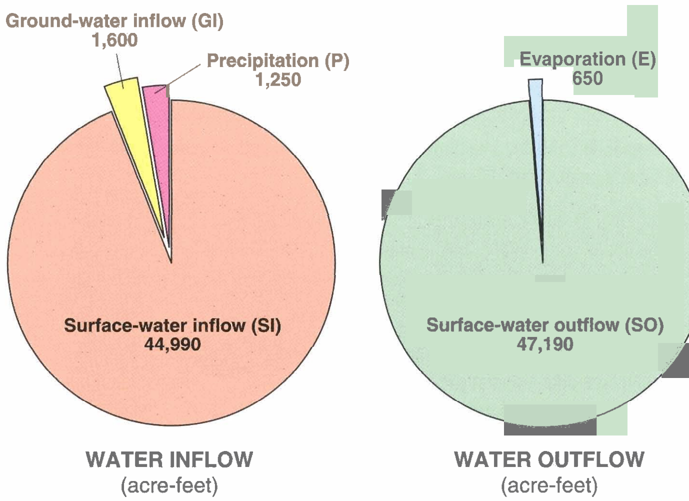

Figure 4. Water inflow and outflow for Park Lake, south-central Wisconsin, November 1992–October 1993.

Inflow from the Fox River is the most important factor in determining the water retention or flushing time of Park Lake which, in turn, is a major influence on lake-water quality. Impoundments like Park Lake, with large ratios of watershed area to lake surface area (110:1 in the case of Park Lake), tend to have shorter retention times and poorer water quality than other types of lakes (Lillie and Mason, 1983, p. 27–29). The average daily discharge from the Fox River during the study period was 58 ft³/s (cubic feet per second). The average retention time of water in the lake for the study period was 19 days on the basis of discharge from the Fox River alone; retention times during periods of high flow would be considerably less. For daily discharges of 100 and 200 ft³/s, average retention times are 11 and 5.5 days. Discharges of these magnitudes were recorded for sustained periods during March, April, and July 1993 (fig. 3).

Phosphorus Loading

Surface runoff from the surrounding watershed is the major source of phosphorus in Park Lake. Figure 5 shows daily phosphorus loads computed from data collected at the gaging station. The total phosphorus load for the monitoring period was 17,000 lb (pounds), which is equivalent to an average of 47 lb/d (pounds per day) of phosphorus, or a yield of 350 lb/mi² (pounds per square mile). Assuming that the ungaged part of the watershed also yields 350 lb/mi², the total phosphorus input to the lake from the watershed was 18,300 lb, or 50 lb/d. The importance of overland runoff in

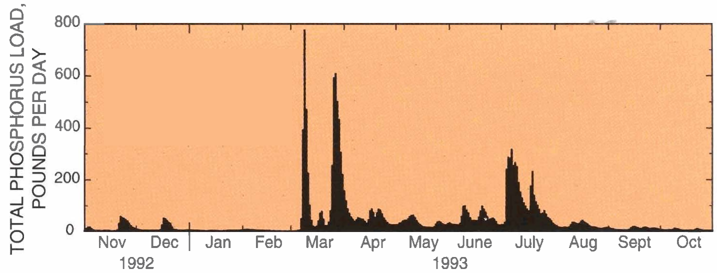

Figure 5. Daily total phosphorus loads from the Fox River to Park Lake.

the delivery of phosphorus to the lake is also shown in figure 5. Approximately one-third of the annual load to the lake was delivered in March, primarily by runoff from snowmelt. An additional one-fourth of the annual load was delivered in July as the result of runoff from rainfall. Daily phosphorus loads exceeded 100 lb/d on 31 days during the year and exceeded 500 lb/d on 4 days (more than the monthly totals for December, January, February, and September).

Phosphorus input to the lake from precipitation and ground-water inflow are insignificant relative to the input from surface runoff from the watershed. Total phosphorus concentrations measured in bulk precipitation and ground water in Wisconsin are generally less than the lowest concentrations measured in water from the Fox River, and precipitation and ground-water inflow combined account for only about 6 percent of the inflow to the lake.

Dissolution and resuspension of phosphorus from bottom sediments (called internal loading) can be an important phosphorus input in some lakes; however, this process does not appear to be an important source of phosphorus in Park Lake. Internal loading becomes important in lakes deeper than Park Lake in which thermal stratification leads to persistent anoxic (oxygen-depleted) conditions in the lowest stratum (the hypolimnion) that cause phosphorus from sediments and decaying organic matter to return to solution. When internal loading occurs, it can be seen in phosphorus-concentration profiles for the lake: phosphorus concentrations in water in the deep, anoxic zones commonly are considerably higher than concentrations at shallower depths. Anoxic or nearly anoxic conditions near the lake bottom were detected at sampling sites 1, 2, and 3 (fig. 2) at many of the sampling visits during July and August (Holmstrom and others, 1994, p. 77–85), but phosphorus-concentration profiles were virtually uniform from top to bottom except for those at site 1. At site 1, anoxia and high total phosphorus concentrations persisted at depths greater than about 12 ft from late May into September. Because of the small size of this deep area relative to the area of the lake, and its proximity to the outlet to the Fox River, the conditions here are of minor importance to overall water-quality conditions in the lake.

Average total phosphorus concentrations in the lake for the days of sampling visits were equal to or less than the total phosphorus concentrations in the Fox River. This is an additional indication of the importance of the Fox River as a source of phosphorus to the lake.

Lake-Water Quality

Chemical and physical measurements of water quality are used in various ways to describe and classify lakes and to compare their water quality. Measures of water quality that are useful for these purposes include dissolved mineral content, which is influenced by the geologic and hydrologic setting of a lake, and water clarity and concentrations of chlorophyll and total phosphorus, which indicate the trophic state of the lake.

Principal dissolved minerals in Park Lake as measured in May 1993 (Holmstrom and others, 1994, p. 76–79) are calcium, magnesium, and bicarbonate derived from the dolomitic bedrock and calcareous glacial deposits that underlie southern and eastern Wisconsin. The concentrations of these constituents and the minor constituents sulfate and chloride are within the general concentration ranges reported by Lillie and Mason (1983, p. 23) for lakes in southern Wisconsin.

Two methods commonly used to classify Wisconsin lakes are a water-quality index developed by Lillie and Mason (1983) and Carlson's (1977) trophic state index as modified by Lillie and others (1993). Both methods use water clarity (as measured by Secchi-disc depth), chlorophyll *a* concentration (an indicator of algal population), and near-surface total phosphorus concentration to classify lake-water quality. These three measures of lake-water quality are related to each other in complex ways that differ seasonally and among lakes. Simply stated, water clarity is influenced by algal population which, in turn, is influenced by phosphorus concentration.

Lillie and Mason used data from late summer (July-August) samples collected from randomly-selected Wisconsin lakes to develop the classifications shown below:

Water-quality index	Approximate total phosphorus range (milligrams per liter)	Approximate chlorophyll *a* range (micrograms per liter)	Approximate water clarity range (Secchi-disc depth, in feet)
Excellent	<0.001	<1	>19.7
Very good	.001-.01	1-5	9.8-19.7
Good	.01-.03	5-10	6.6-9.8
Fair	.03-.05	10-15	4.9-6.6
Poor	.05-.15	15-30	3.3-4.9
Very poor	>.15	>30	<3.3

(<, less than; >, greater than)

On the basis of average concentrations and depths measured July through August, water quality in Park Lake would be classified as "poor" according to total phosphorus concentration (0.11 milligrams per liter), and "very poor" according to chlorophyll *a* concentration (65 micrograms per liter) and Secchi-disc depth (about 2.3 ft).

The modified trophic state index used by the Wisconsin Department of Natural Resources (Lillie and others, 1993) groups Wisconsin lakes in one of three classes—oligotrophic, mesotrophic, and eutrophic—on the basis of their "trophic state" or degree of nutrient enrichment and biological productivity. Oligotrophic lakes are typically clear and low in algal population and total phosphorus concentration, and their water contains dissolved oxygen at all depths throughout the year. Mesotrophic lakes typically have moderate total phosphorus concentrations and algal populations and occasional anoxia in deep water. Eutrophic lakes typically have high concentrations of phosphorus, poor clarity, seasonal oxygen depletion in deep water, and frequent algal blooms.

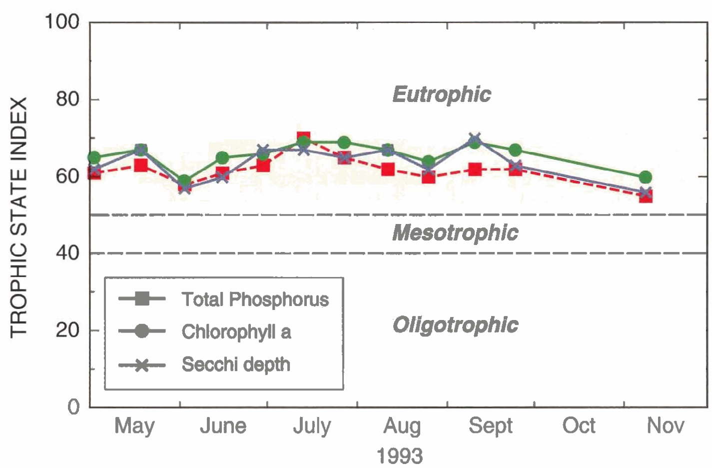

Figure 6. Trophic state index plot for site 3, Park Lake, south-central Wisconsin.

Trophic state index values calculated for Park Lake indicate that the lake was eutrophic during the entire sampling period. Trophic state index values for site 3 (fig. 2) are shown in figure 6; plots for sites 1,2, and 4 are similar to those for site 3.

Conclusions

Park Lake is a eutrophic lake with perceived water-quality problems that are due primarily to large inputs of phosphorus from its watershed. The major source of phosphorus in the lake is the Fox River. Large quantities of phosphorus are delivered to and pass through the lake during relatively short periods of overland runoff, but phosphorus loads delivered during periods of low flow are sufficient to cause eutrophic conditions and poor water quality as measured by trophic state index and Lillie and Mason's water-quality index.

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Banner graphic: Karen Lonsdorf

U.S. Department of the Interior
U.S. Geological Survey
Fact Sheet FS-197-96