HYDROLOGY AND WATER QUALITY OF WHITEWATER AND RICE LAKES IN SOUTHEASTERN WISCONSIN, 1990-91

By Gerald L. Goddard and Stephen J. Field

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter
inch (in.)	25,400	micrometer
mile (mi)	1.609	kilometer
pound (lb)	453.6	gram
acre	0.4048	hectare
foot (ft)	0.3048	meter
acre-foot (acre-ft)	1,233	cubic meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre-foot per square mile (acre-ft/mi^2)	476	cubic meter per square kilometer
pound per square mile (lb/mi^2)	0.175	kilogram per square kilometer
gallon per day (gal/d)	3.785	liter per day
pound per square foot	4,882	gram per square meter

Other Conversions

microgram per liter (µg/L)	0.001	milligram per liter (mg/L)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by use of the following equation:

$$°C = 5/9\ (°F - 32)$$

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 the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The hydrology and water quality of Whitewater and Rice Lakes was studied by the U.S. Geological Survey during November 15, 1990-November 14, 1991, in cooperation with the Whitewater-Rice Lakes Management District, Walworth County, Wis. Whitewater and Rice Lakes are small, shallow lakes; surface areas are 697 and 162 acres and mean depths are 8.4 feet and 5.8 feet, respectively. Although both lakes have surface outlets, water levels were below the dam crests during the study, and no water left the lake through the outlets. The drainage basin of Whitewater Lake is 10.9 square miles and that of Rice Lake is 11.8 square miles; but, because of large amounts of depressional areas, only 1.4 square miles and 0.2 square mile, respectively, contribute surface runoff to the lakes. Whitewater Lake is an artificial lake created in 1947 by the damming of three smaller lakes. Rice Lake is an artificial lake created in 1954 by the damming of Whitewater Creek, which drains Whitewater Lake. Maintaining the lake levels at the elevations of their dam crests has been difficult since the lakes were created. For most years, water levels were below the lakes' dam crests.

Ground water, precipitation, and evaporation are important components in the hydrologic budgets of the lakes. For Whitewater Lake, ground water was the dominant source of water, accounting for 57 percent of the inflow budget; precipitation accounted for 26 percent. Ground water also dominated the outflow, accounting for 81 percent of the outflow budget. The remaining 19 percent of the outflow budget was evaporation. For Rice Lake, precipitation was the dominant source of water, accounting for 88 percent of the inflow budget; ground water accounted for 8 percent. Evaporation dominated the outflow budget, at 70 percent, whereas ground water accounted for 30 percent.

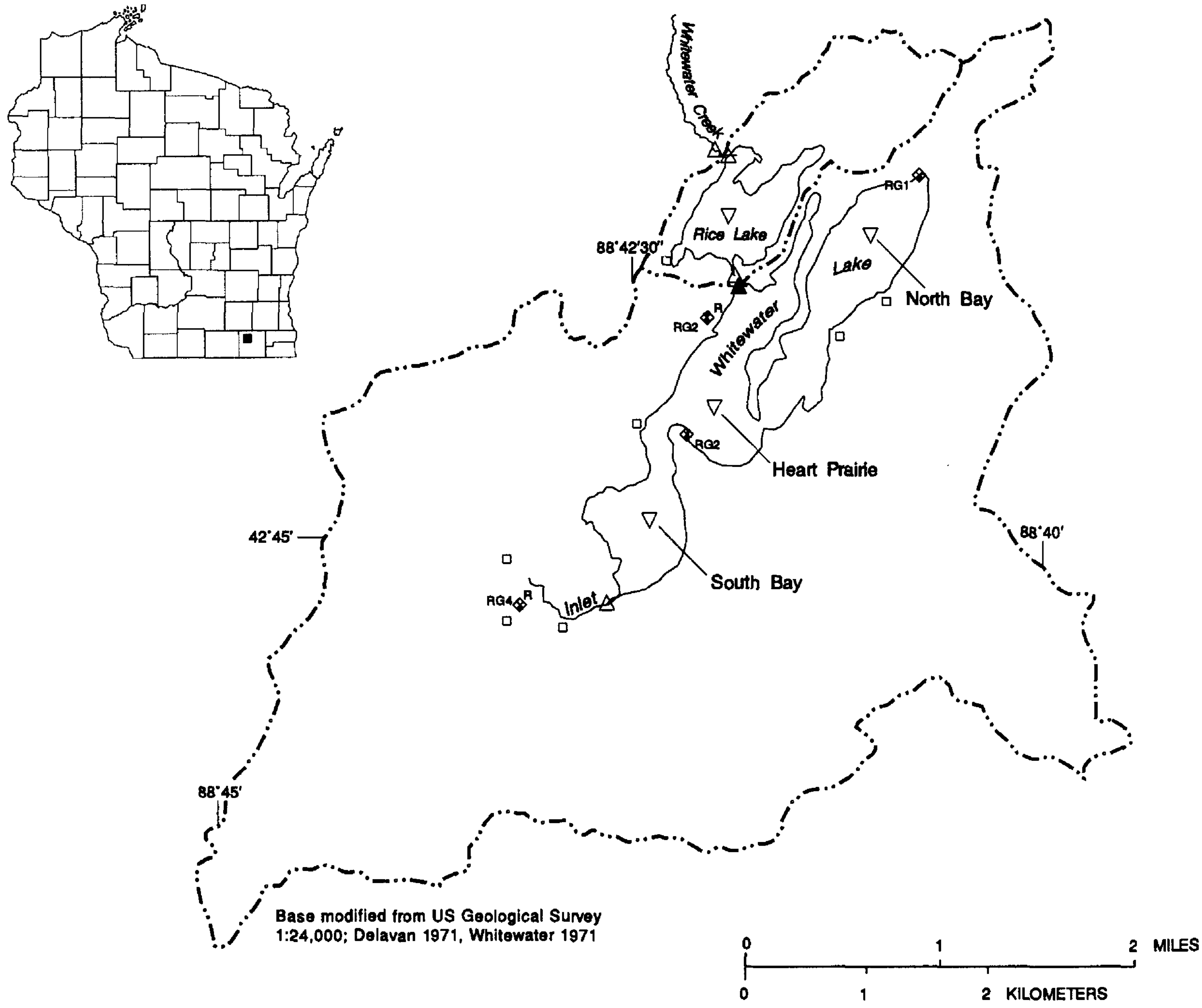
The external phosphorus budget for Whitewater Lake showed that shoreline drainage was the largest source of phosphorus to the lake–42 percent of the total input of 558 pounds. Other sources of phosphorus were septic systems, 19 percent of the total; precipitation, 18 percent; a spring inlet at base flow, 13 percent; and ground water, 8 percent. The external phosphorus budget for Rice Lake showed that shoreline drainage also was the largest source of phosphorus to the lake–59 percent of the total input of 63 pounds; other sources were precipitation, 38 percent of the total; and ground water, 3 percent. Application of Vollenweider's phosphorus loading model fairly accurately predicted the lakes' spring turnover phosphorus concentrations and suggested that the external loading of phosphorus would result in mesotrophic to eutrophic conditions for Whitewater Lake and mesotrophic conditions for Rice Lake. Dillon and Rigler's model further suggested additional phosphorus from internal recycling was required to result in the high chlorophyll-*a* concentrations experienced in both systems during summer. Internal recycling of phosphorus in addition to external loading seems to also cause water-quality problems in both lakes. The amount of phosphorus recycled from the lake sediments was estimated from a mass-balance approach for April 1-November 14, 1991. For Whitewater Lake, the internal load of 582 pounds was slightly greater than the annual external load of 558 pounds. For Rice Lake, the internal load of 295 pounds far exceeded the annual external load of 63 pounds.

INTRODUCTION

Whitewater and Rice Lakes (fig. 1) are **eutrophic**[1] lakes in Walworth County in southeastern Wisconsin and are used primarily for recreation–fishing, swimming, and boating. Both lakes have intermittent surface-water outlets. Rice Lake is downstream from Whitewater Lake and is connected to Whitewater Lake by a 300-ft-long intermittent stream.

Whitewater Lake is a kettle **moraine** lake created in 1927 by impoundment of the outlet of

[1]Terms defined in the glossary are shown in bold type the first time that they are used in the text.



EXPLANATION

- Drainage-basin boundary
- Continuous record lake-stage gage
- Nonrecording lake-stage gage
- Lake-sampling site
- Streamflow-measurement site
- Streamwater-sampling site
- RG1 Nonrecording precipitation gage and identification number
- RG4 R Recording precipitation gage and identification number
- RG2 R Recording precipitation gage, evaporation pan, precipitation sampling site, and identification number

Figure 1. Locations of Whitewater and Rice Lakes, drainage basins, and data-collection sites.

three smaller lakes. Legal action later forced removal of the impounding gates until the county acquired the dam site and created a park in 1946 (Poff and Threinen, 1961; Lundin and others, about 1972). A dam crest was then built to accommodate outflow 12 ft above the original lake level. On February 13, 1947, the dam was closed. After 11 months, the lake filled 7.2 ft. The next reported observation was on May 12, 1960, when the lake level was 2 ft below the spillway crest. Not until 1973, however, did water **discharge** from the outlet of Whitewater Lake. Water discharged intermittently from the lake during 1973-86. No outflow has been observed since 1986.

Water-quality monitoring of Whitewater Lake began in 1986, when the Wisconsin Department of Natural Resources (WDNR) chose it as a long-term trend lake. Total-phosphorus concentrations for Whitewater Lake for 1986 ranged from 40 to 60 μg/L. Lakes in which spring turnover concentrations are greater than 20 μg/L are considered to be eutrophic (Wisconsin Department of Natural Resources, 1983; G.C. Gerloff, University of Wisconsin, written commun., 1984).

Water quality of Whitewater Lake was poor as soon as the lake was created (Lundin and others, 1972). During June-October 1971, planktonic **algae** dominated over aquatic **macrophytes** in the lake, averaging 54,000 organisms per liter. In 1971, only 1.2 percent (8 acres) of the lake area was occupied by macrophytes. The vegetation shifted from an algae-dominated system in the 1970's to a macrophyte-dominated system by 1988. During 1950-68, an average of 6.7 percent of the lake was sprayed to control macrophytes. A survey of aquatic macrophytes by the WDNR in 1988 found that 91 percent of the lake was colonized by aquatic plants.

Rice Lake was created in 1954 by construction of an 8-ft-high dam across Whitewater Creek below Whitewater Lake. Little other historical information is available on Rice Lake.

The Whitewater-Rice Lakes Management District was concerned with the lakes' water quality. In response to this concern, the U.S. Geological Survey (USGS), in cooperation with the Whitewater-Rice Lakes Management District, studied the **hydrology** and water quality of Whitewater and Rice Lakes from November 15, 1990-November 14, 1991.

Purpose and Scope

This report summarizes the results of the data-collection program at Whitewater and Rice Lakes and in their **drainage basins** during November 15, 1990-November 14, 1991, and provides an evaluation and interpretation of the data. The report describes (1) the **hydrologic budgets** for Whitewater and Rice Lakes, (2) the phosphorus budgets for the lakes, (3) the physical and chemical characteristics of the lakes' water, (4) the phosphorus **loads** from **internal recycling**, and (5) the **trophic** status of each lake.

Acknowledgments

The authors thank the following people who contributed to the study: Dr. William Norris, chairman of the Whitewater-Rice Lakes Management District, who supervised field-observer duties and provided a site for a rain gage and **evaporation pan**; Mr. Ray Heger, who read the Rice Lake staff gage and evaporation pan and collected **runoff** and precipitation samples; Mr. Wayne Stork, who collected runoff samples; and Mr. Charles Cruse, Mr. Lowell Wilson, and Ms. Elizabeth Haenisch who read rain gages.

LAKE CHARACTERISTICS

Whitewater Lake is about 2.6 mi long and 0.6 mi wide. The lake has a shoreline length of 10.0 mi, a surface area of 692 acres, and a **maximum depth** of 40 ft. In Whitewater Lake, an esker-like feature (fig. 1) extends 1.3 mi south from the north shore to near the center of the lake. The maximum depth of the north bay, east of this feature, is 13 ft. Bogs are present near the center of the bay. The south bay has a maximum depth of 7 ft and contains abundant emergent aquatic vegetation.

Rice Lake has a maximum depth of 11 ft near the center of the lake and is generally oval-shaped. The characteristics of Whitewater and Rice Lakes and their drainage basins are summarized in table 1.

Water levels of both lakes are controlled by dams. The Whitewater Lake dam is a 9.9 ft wide, broad-crested concrete dam. The Rice Lake dam is a concrete drop-inlet structure.

Table 1. Characteristics of Whitewater and Rice Lakes, Wisconsin

Characteristic	Whitewater Lake	Rice Lake
Total surface area of drainage basin (mi^2)	10.9	11.8
Contributing surface area of drainage basin (mi^2)	1.4	[a]1.6
Surface area of lake (acres)[b]	[c]697	[d]162
Length of shoreline (miles)	[c]10.0	[d]3.3
Volume (acre-feet)	[c]5,806	[d]933
Mean depth (feet)	[c]8.3	[d]5.8
Maximum depth (feet)	[c]40	[d]11

[a]See text for explanation.
[b]Planimetered on a map prepared by the University of Wisconsin-Whitewater, Department of Geology, and provided by the Whitewater-Rice Lakes Management District.
[c]Characteristic for water surface of 891.13 feet above sea level.
[d]Characteristic for water surface of 884.47 feet above sea level.

Drainage Basins

Drainage areas of Whitewater and Rice Lakes are 10.9 and 11.8 mi^2, respectively. Because of the rough, broken topography and the many depressions in this region, the drainage areas contributing to **surface runoff** are only 1.4 mi^2 for Whitewater Lake and 1.6 mi^2 for Rice Lake when **surface water** flows from Whitewater Lake (fig. 2). The contributing drainage area of Rice Lake is only 0.2 mi^2 when there is no surface-water outflow from Whitewater Lake. Both lakes had no surface-water outflow for the study period.

The unconsolidated deposits overlying **bedrock** in Walworth County are largely glacial **sediments** of **Quaternary** age. The drainage basins of Whitewater and Rice Lakes drainage basins are in a **pitted outwash plain** of stratified deposits consisting of gravel, sand, silt, and clay laid down by water from melting ice of the Green Bay glacier lobe (Borman, 1976). The thickness of these unconsolidated glacial deposits ranges from 100 to 250 ft.

The types of soil textures in the Whitewater and Rice Lakes drainage basins include clay loams, gravelly sandy loams, and silty clay loams (Haszel, 1971) in three soil associations: Cosco-Rodman, Cosco-Fox, and Miami-McHenry. The soils adjacent to the lakes are in the Cosco-Rodman association. Most are well to excessively drained soils that have a subsoil of clay loam and gravelly sandy loam. A photograph of unconsolidated deposits along a road cut on the southeastern side of Whitewater Lake is presented as figure 3. Soils in the eastern and the western parts of the Whitewater Lake drainage basin are in the Cosco-Fox association. These well-drained soils have a subsoil of clay loam. Soils in a small area of the southern part of the drainage basin are in the Miami-McHenry association. These well-drained soils have a subsoil of clay loam and silty clay loam.

Aquatic Macrophytes

Aquatic macrophytes have been harvested in Whitewater and Rice Lakes since 1988. In 1992, the Whitewater-Rice Lakes Management District estimated the wet weight of the macrophytes removed from the lakes was 2,750 tons in 1990 and 1,810 tons in 1991. Most of the removal was from Whitewater Lake (William Norris, President Whitewater-Rice Lakes Management District, written commun., 1992); only 2.5 percent came from Rice Lake in 1990 and 0.8 percent in 1991.

The WDNR surveyed aquatic macrophytes in Whitewater Lake in 1988. Ninety-one percent of the lake was colonized with aquatic plants. The nondiverse plant community is dominated by a

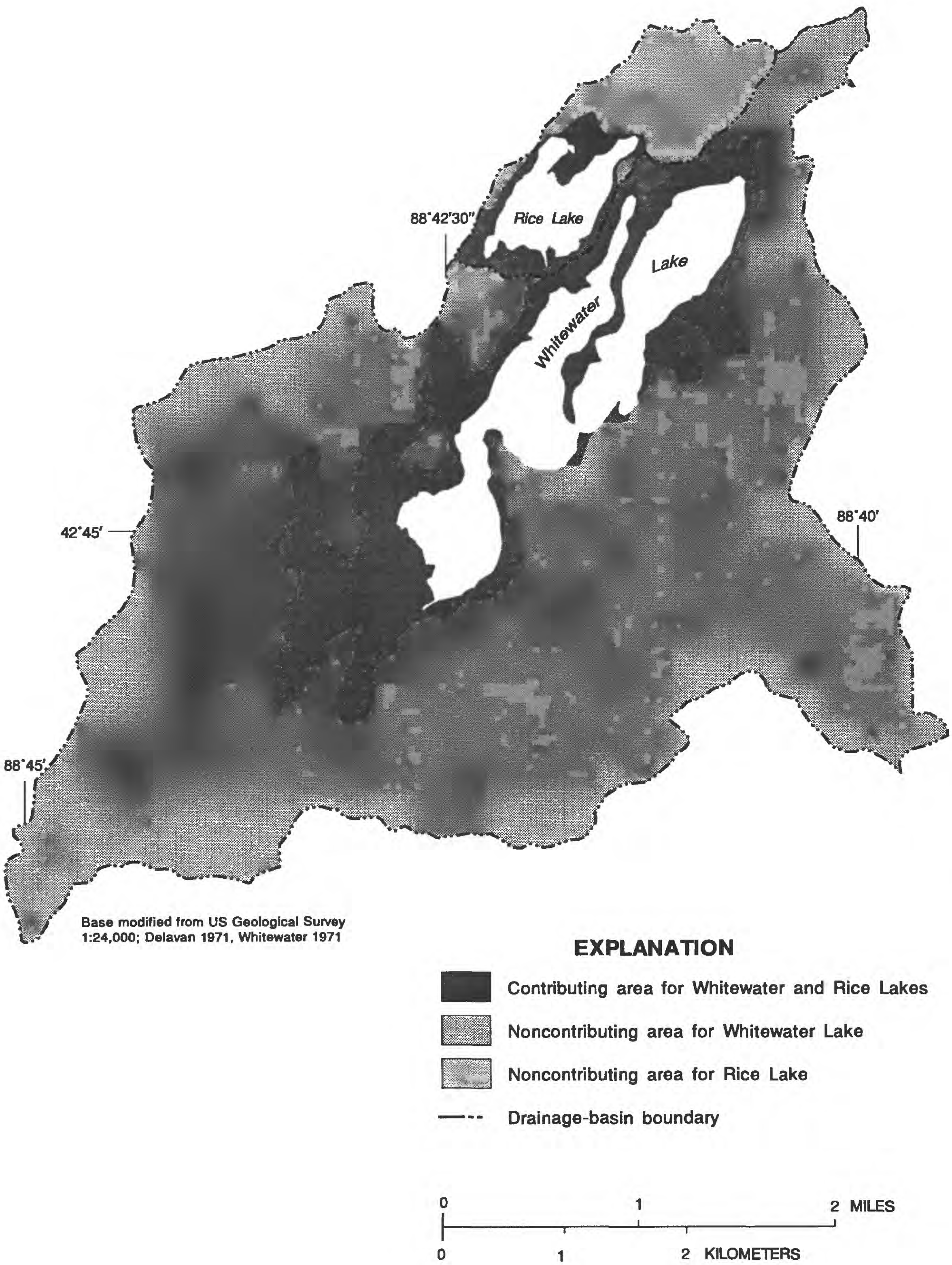


Figure 2. Contributing and noncontributing drainage areas of Whitewater and Rice Lakes.

Figure 3. Photograph showing unconsolidated deposits along a road cut on the southeastern side of Whitewater Lake.

submerged species, eurasian watermilfoil (*Myriophyllum spicatum*). From 77 to 96 percent of the plots sampled contained eurasian watermilfoil (Bob Wakeman, Wisconsin Department of Natural Resources, written commun., 1991). Although the aquatic macrophytes of Rice Lake have not been studied, field observations in 1991 suggest that less than 20 percent of the lake was colonized with aquatic plants.

METHODS OF DATA COLLECTION AND ANALYSIS

Measurement of Precipitation and Evaporation

Precipitation was measured at four sites when temperatures were above freezing (fig. 1). Two of the gages, equipped with 8-in.-diameter collectors, continuously recorded precipitation at 5-minute intervals. The remaining two gages–nonrecording, wedge-type collectors–were read by local observers. Precipitation records from the National Weather Service stations at Whitewater and Lake Geneva, about 5 mi northwest and 18 mi southeast, respectively, of the study area were used when these gages were not operating (U.S. Department of Commerce, 1990, 1991). Samples of combined atmospheric wet and dry fallout were collected from a bulk-precipitation collector located at the site of the precipitation gage on the west-central side of Whitewater Lake (fig. 1). These samples were analyzed by the U.S. Geological Survey central laboratory according to standard analytical methods described by Fishman and Friedman (1985).

Evaporation from both lakes was estimated by use of a Class A evaporation pan located on the west-central side of Whitewater Lake (fig. 1). A local observer recorded pan readings daily from mid-April through October 1991. An annual pan coefficient of 0.77 was used to convert pan-evaporation readings to estimated lake surface evaporation (U.S. Department of Commerce, 1982). Because evaporation-pan data were not available for November and December 1990 and parts of March, April, and November 1991, evaporation data were estimated by prorating daily average evaporation rates for periods in the fall from the last pan measurement until lake freeze-up and in spring from ice-out time until the first pan measurement. Evaporation in January and February, when the lakes were ice-covered, was assumed to be zero.

Measurement of Lake Stage

The water level of Whitewater Lake was recorded at 15-minute intervals at a gage near the dam (fig. 1). The datum at 0.00 ft gage height of the gage is 880.98 ft above sea level. The water level of Rice Lake was measured from a staff gage on the dam which was read once per day; the datum at 0.00 ft gage height of the gage is 878.12 ft above sea level. The lake level of Whitewater Lake during the study period was about 8 ft higher than Rice Lake.

Measurement of Streamflow

Water inflow to and outflow from Whitewater and Rice Lakes were measured at three locations (fig. 1). Whitewater Lake inlet at the south end of the lake is the only major inflow source to the lake. Monthly discharge measurements at this site were used to estimate a base-flow **hydrograph** for November 15, 1990-November 14, 1991. No outflow from Whitewater Lake or Rice Lake was observed during the study period. Flow-integrated samples for total phosphorus were collected manually at Whitewater Lake inlet by use of the **equal-width-increment (EWI) method** described by Guy and Norman (1970).

Surface runoff was estimated by use of a computerized sliding-interval hydrograph-separation technique (R.A. Sloto, U.S. Geological Survey, written commun., 1988). The hydrograph-separation technique was applied to the discharge record from the USGS gaging station on the Mukwonago River at Mukwonago, Wis. (05544200), for the period November 15, 1990-November 14, 1991. This gaging station is about 20 mi northeast of Whitewater Lake in a drainage basin whose geologic setting is similar to that of Whitewater and Rice Lakes.

Swale and rivulet discharge to Whitewater Lake and Rice Lake were monitored for concentrations of total phosphorus (fig. 1) in shoreline storm and snowmelt runoff. Six sites tributary to Whitewater Lake, identified as Whitewater Lake Tributaries 1 through 6, were monitored. One site, Rice Lake Tributary 1, was monitored in the Rice Lake drainage basin. Multistage point samplers described by Guy and Norman (1970) were installed at each of these sites. Concentration analyses of total phosphorus were done by the U.S. Geological Survey central laboratory according to standard analytical methods described by Fishman and Friedman (1985).

Estimation of Ground-Water-Flow Directions and Rates

Twelve small-diameter wells installed along the shoreline of Whitewater Lake and four small-diameter wells installed along the shoreline of Rice Lake (fig. 4) were used to determine the direction of and to estimate the rate of local ground-water flow. Ground-water levels in the wells were measured monthly. Water samples for determination of orthophosphate concentration were collected from wells using a peristaltic pump to estimate the phosphorus load to each lake from ground water.

Ground-water inflow and outflow were estimated by use of the Darcy equation,

$$Q = KIA, \qquad (1)$$

where Q is discharge (L^3/T),
K is hydraulic conductivity (L/T),
I is hydraulic gradient (L/L), and
A is the area through which the flow is passing (L^2).

Several simplifying assumptions and techniques were necessary because the scope of the study did not allow for a rigorous or detailed analysis. Ground-water exchange with each lake was assumed to be at steady state; that is, the rate and direction of flow through the lake bottom at any location does not change with time. This assumption was made because the hydraulic gradient was known for many dates and did not vary significantly. An average hydraulic gradient was used for the entire study period. Ground-water flow was estimated by a method used by Rose (1993) in a similar study of a northwestern Wisconsin lake.

All the wells were installed within 24 ft of the shoreline. Rose typically installed wells offshore

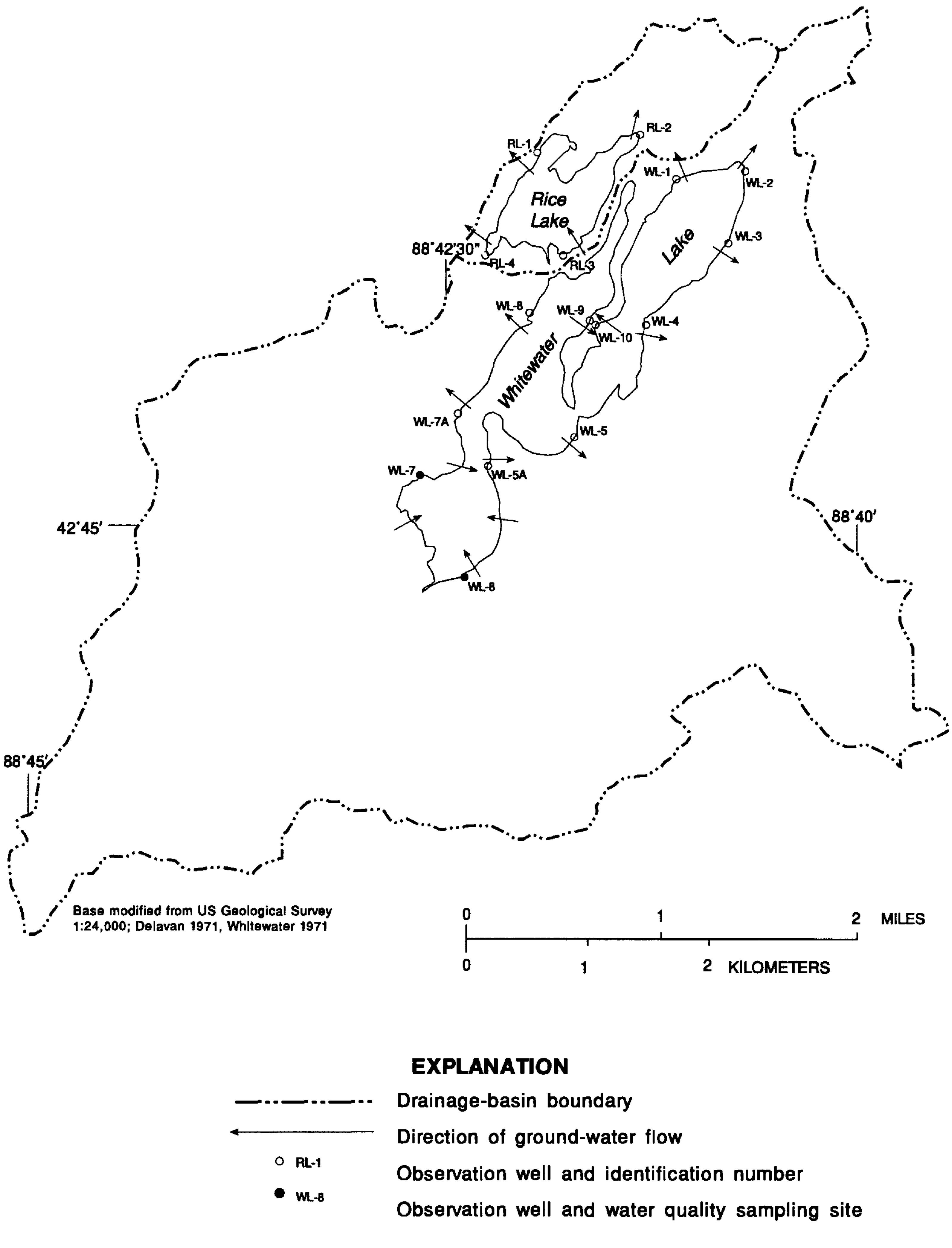


Figure 4. Locations of observation wells and direction of ground-water flow in Whitewater and Rice Lake drainage basins.

in the lakebed. At Whitewater and Rice Lakes, wells were installed near the shore so that water levels could be measured throughout the year. The wells were assumed to be offshore to simplify the ground-water-flow calculations. Average depths of the wells were 9.8 ft for Whitewater Lake and 9.1 ft for Rice Lake. The average hydraulic gradient was determined at each of the wells. Average hydraulic gradients for Whitewater Lake and Rice Lake for inflow areas ranged from 0.07 to 0.10 ft/ft and for outflow areas, from -0.01 to -0.29 ft/ft.

Lake Sampling

Physical and chemical sampling of Whitewater and Rice Lakes was done once each month in April, October, November, and twice each month in May through September. Three sites on Whitewater Lake were sampled (fig. 1); the North Bay site in the northeast part of the lake, which has a depth of 13 ft, the Heart Prairie site near the center of the lake which has a depth of 40 ft, and the South Bay site at the south end of the lake which has a depth of 7.0 ft. One site was sampled on Rice Lake near the center of the lake at a depth of 11 ft (fig. 1).

Depth profiles of water temperature, **specific conductance**, **pH**, and dissolved oxygen were determined at all sites by use of a Hydrolab Surveyor II meter[2]. The meter was calibrated to known standards before lake monitoring. The dissolved-oxygen function of the meter was calibrated by use of the air-calibration method and was checked on the lake by the Winkler method. Depth-profile readings were made at 3-ft intervals at the Heart Prairie site on Whitewater Lake and at 1-ft intervals at the other three sites.

Discrete water samples were collected 1.5 ft below the lake surface and 1.5 ft above the lake bottom using a peristaltic pump and polyethylene tubing. Two additional samples were collected at varying depths on the basis of **thermal stratification**–one near the bottom of the **epilimnion** and the other at about the middle of the **hypolimnion**. Samples collected for dissolved constituents were filtered in the field by use of an in-line filtering unit equipped with a 0.45-µm filter. Samples for determination of chlorophyll-*a* concentration were collected from the top 1.5 ft of the lake at each site by use of a Kemmerer sampler and filtered through a 5.0-µm filter.

[2]Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Water samples collected from Whitewater and Rice Lakes were analyzed by the Wisconsin State Laboratory of Hygiene for total phosphorus, dissolved orthophosphorus, and chlorophyll-*a* concentration.

HYDROLOGY

Precipitation and Evaporation

Precipitation at the four rain gages around Whitewater Lake (table 2) averaged 32.88 in. from November 15, 1990-November 14, 1991. Precipitation at the National Weather Service Station at Whitewater was 32.91 in. for the same period (U.S. Department of Commerce, 1990, 1991). The long-term, average annual precipitation at this station is 31.71 in. (U.S. Department of Commerce, 1991). Evaporation from the surfaces of Whitewater and Rice Lakes was calculated as 22.85 in. Monthly evaporation totals are listed in table 2.

Lake Stage

Lake stages for Whitewater and Rice Lakes from November 15, 1990-November 14, 1991 are shown in figure 5. The maximum lake stage for Whitewater Lake of 10.30 ft was recorded on April 16, 1991 and the minimum lake stage of 8.90 ft was recorded on September 30, 1991. The maximum lake stage for Rice Lake of 4.84 ft was recorded on April 15, 16, and 30, 1991. The minimum lake stage of 3.64 ft was recorded on September 30, 1991. The lake stages did not reach the spillway crest elevations in either lake. Rice Lake stage closely follows the stage of Whitewater Lake, and outflow from Rice Lake may have occurred in the same years as was observed in previous years for Whitewater Lake. Daily lake-stage data are published in the U.S. Geological Survey annual data publication (Holmstrom and others, 1992).

Lake stages below the dam crest of Whitewater Lake seem to be correlated with ground-water levels. In most lakes during periods of high ground-water levels, ground-water discharge to

Table 2. Precipitation and evaporation-pan data for Whitewater and Rice Lakes, November 15, 1990-November 14, 1991

[RG, rain gage–locations on figure 1; NWS, National Weather Service]

Period	Precipitation (inches)					Evaporation pan data (inches)
	RG 1	RG 2	RG 3	RG 4	Whitewater (NWS)	
November 15-30, 1990	1.10	[a]1.19	1.27	[a]1.19	1.19	[b]0.60
December	[c]2.47	[c]2.47	[c]2.47	[c]2.47	[c]2.47	[b].28
January 1991	[a]1.21	[a]1.21	[a]1.21	[a]1.21	1.21	[b]0
February	[a].17	[a].17	[a].17	[a].17	.17	[b]0
March	[a]3.76	[a]3.76	[a]3.76	[a]3.76	3.76	[b].14
April	4.05	4.16	3.56	3.85	3.34	[b]2.64
May	[b]2.18	2.47	2.25	2.61	2.48	4.04
June	1.85	1.60	1.76	1.85	1.97	6.15
July	2.90	3.20	3.16	2.77	4.54	5.77
August	1.85	1.92	1.99	2.04	2.34	5.19
September	3.45	3.34	[b]3.11	3.63	3.74	2.93
October	6.30	7.20	6.48	7.76	4.94	1.44
November 1-14, 1991	[b].79	.79	[b].79	[b].67	.76	[b].49
Totals	32.08	33.48	31.98	33.98	32.91	29.67
Pan coefficient						x 0.77
Evaporation						22.85

[a]Daily precipitation record from National Weather Service station at Whitewater, Wis.
[b]Estimated.
[c]Daily precipitation record from National Weather Service station at Lake Geneva, Wis.

the lakes increases (James Krohelski, U.S. Geological Survey, oral commun., 1992). Annual average ground-water levels in WK-31, a well in Niagara **Dolomite** of **Silurian** age, are given in figure 6. WK-31 is in Waukesha County, 28 miles northeast of Whitewater Lake. The well record began in 1948, 1 year after Whitewater Lake began to fill. Comments about the lake filling before 1972 are given in a report of the Ecology Committee on Whitewater Lake (Lundin and others, 1972). Notes on the illustration from 1977 to 1986 are from William Norris, President, Whitewater Lake Association, (oral commun., 1993).

From the data in figure 6, one can conclude that lake levels in Whitewater Lake (and probably Rice Lake) depend, in part, on ground-water levels. The first year that water flowed over the spillway was 1973–the year of the highest ground-water level since the dam was closed in 1947. The intermittent filling of the lake during 1973-86 was partly due to the rise and fall of ground-water levels throughout this period. After

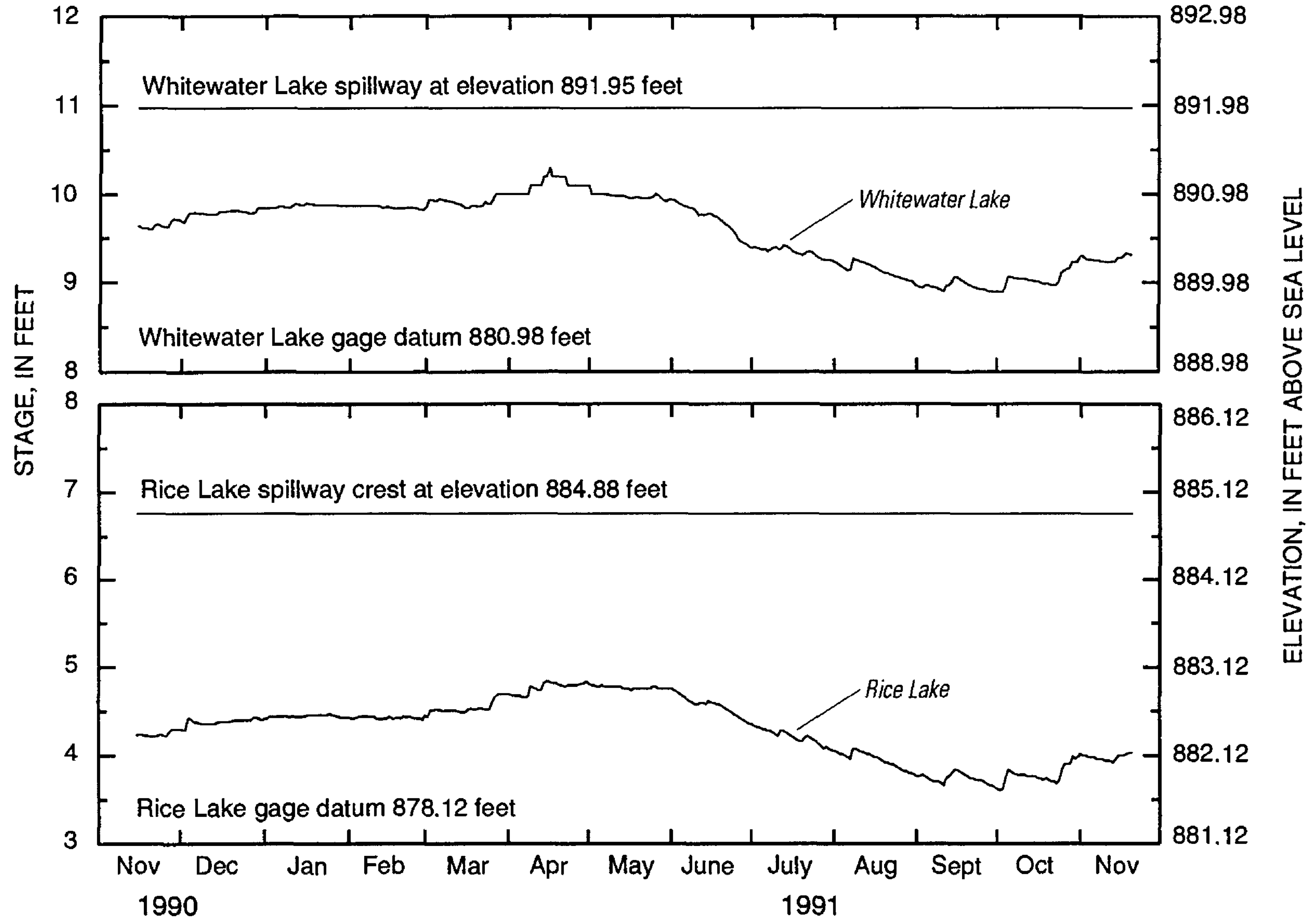


Figure 5. Stages of Whitewater and Rice Lakes, November 1990-November 1991.

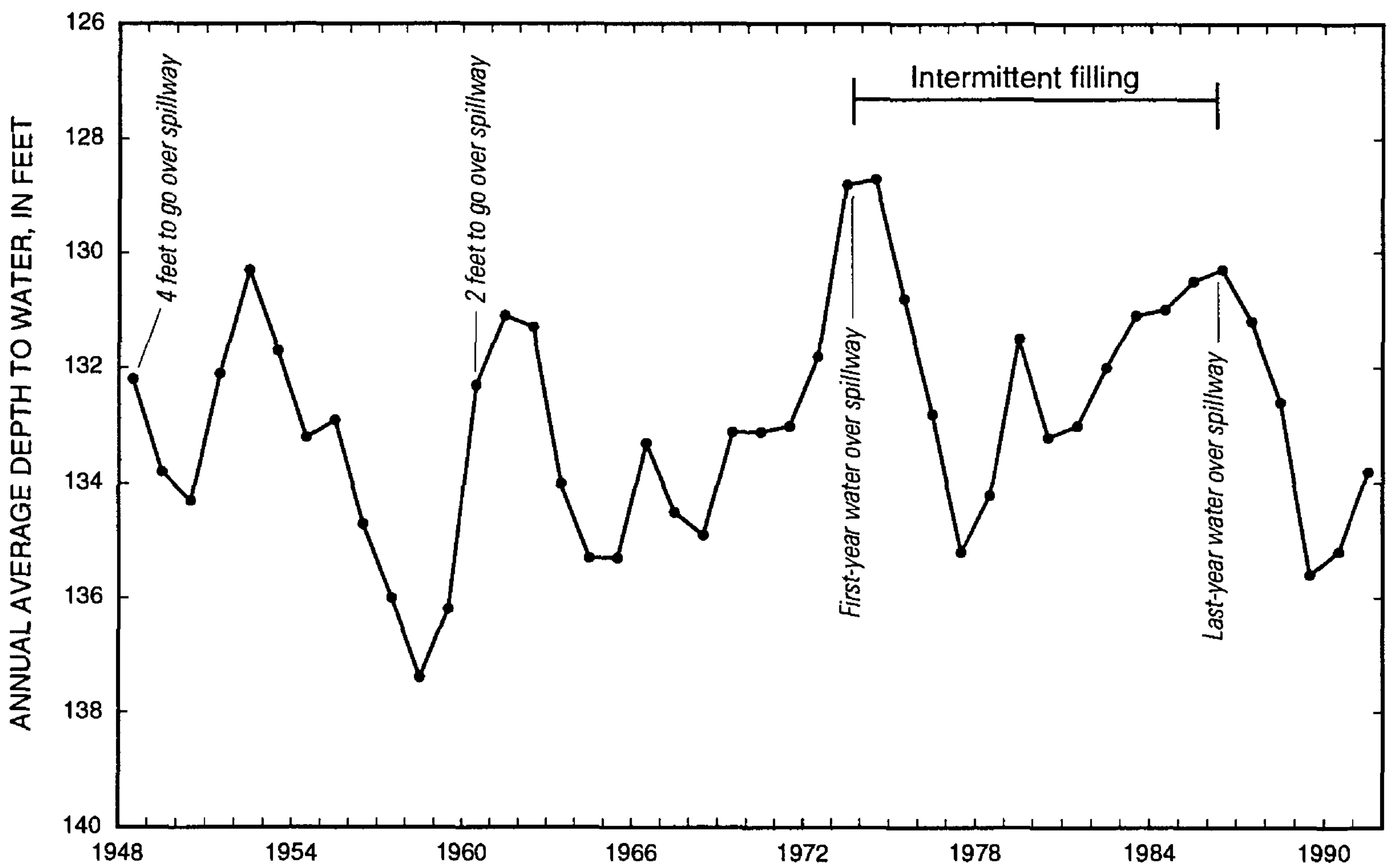


Figure 6. Ground-water levels in well WK-31, 1948-91, and notes in reference to the filling of Whitewater Lake.

1986, ground-water levels declined. In 1990 and 1991, ground-water levels rose again.

Streamflow and Runoff

Streamflow in Whitewater Lake inlet consists mainly of flow from several springs at the south end of the lake. The drainage area of this basin is 0.50 mi^2. Monthly discharge measurements made near the mouth of the inlet ranged from 1.2 to 1.8 ft^3/s and averaged 1.5 ft^3/s (Holmstrom and others, 1992). Streamflow was greatest in spring and early summer and declined through the summer. Streamflow increased slightly during the fall in response to increased precipitation in October. Annual baseflow runoff for the inlet during November 15, 1990-November 14, 1991, was estimated to be 1,050 **acre-ft**.

Storm runoff from the 1.4 mi^2 of drainage area contributing to Whitewater Lake (does not include Whitewater inlet baseflow) was estimated to be 1.80 in. or 141 acre-ft during November 15, 1990-November 14, 1991. Runoff from the 0.2 mi^2 of drainage area contributing to Rice Lake was estimated to be 1.94 in. or 22 acre-ft. Runoff was greatest during winter and spring in response to snowmelt or rain on frozen ground.

Ground-Water Flow

Ground-water levels were higher than the surfaces of Whitewater and Rice Lakes at wells WL-5A, WL-6, WL-7, and RL-3, an indication of ground-water flow to the lakes at these locations (fig. 4). Ground-water levels were lower than the lakes' surfaces at all other wells, which indicates ground-water flow away from the lakes at these locations.

Net ground-water flow is the difference between ground-water inflow and ground-water outflow. Hydrologic data for February 1991 were used to estimate net ground-water flow for Whitewater and Rice Lakes because surface-water elements that affect the hydrologic budget were negligible or zero. During February 1991, evaporation (E) was negligible and was assumed to be zero. The changes in lake storage (ΔS) and precipitation (P) also were low. Surface-water inflow (Qi) to Whitewater Lake was measured at Whitewater Lake inlet and surface-water outflow (Qo) was zero. Surface-water inflow (Qi) to and outflow (Qo) from Rice Lake were zero. Therefore, the hydrologic budget for Whitewater Lake can be defined as

$$Gi - Go = \Delta S - P - Qi \qquad (2a)$$

and the hydrologic budget for Rice Lake can be defined as

$$Gi - Go = \Delta S - P, \qquad (2b)$$

where Gi - Go is the net ground-water flow. Measurements of ΔS, P, Qi, and Qo were assumed to be errorless, and the average of Gi minus Go, calculated as the residual, was -2.36 ft^3/s for Whitewater Lake and -0.13 ft^3/s for Rice Lake.

Hydrologic Budgets

The annual hydrologic budget for Whitewater and Rice Lakes can be determined as follows:

Change in storage = inflow - outflow.

The budget can be rewritten as

Change in storage - inflow + outflow = 0.

The terms considered are

Change in storage = ΔS,
Inflow = P + Qi + Gi, and
Outflow = E + Q_o + Go,

where
- ΔS is change in volume of stored water,
- P is volume of precipitation falling directly on the lake,
- Qi is surface-water inflow,
- Qo is surface-water outflow,
- E is volume of water evaporation from the lake,
- Gi is ground-water inflow, and
- Go is ground-water outflow.

Surface-water outflow from Whitewater Lake during the study period was zero. Therefore, the hydrologic budget for Whitewater Lake is written as

$$\Delta S - P - Qi - Gi + E + G_o = 0. \qquad (3a)$$

Surface-water inflow and outflow for Rice Lake during the study period also were zero, so the hydrologic budget for Rice Lake is written as

$$\Delta S - P - Gi + E + G_0 = 0. \quad (3b)$$

The hydrologic budgets (table 3) were calculated for November 15, 1990-November 14, 1991, on the basis of the data collected at the sites previously described. Each term in the hydrologic budget was measured or estimated.

Errors in measurement and interpretation affect each term in the hydrologic-budget equation. As an aid in evaluating these errors, the hydrologic budget can be written as

$$r = \Delta S - (P + Qi + Gi) + (Qo + E + Go), \quad (4)$$

where r is a net residual term.

The net residuals were 4 and 21 percent of the total inflow to Whitewater Lake and Rice Lake, respectively. Errors in individual components can be greater than or less than these percentages; the net residual term is simply a reflection of the overall integrity of the hydrologic budget.

Ground water dominates inflow and outflow of the hydrologic budget for Whitewater Lake for November 15, 1990-November 14, 1991. Ground-water inflow accounts for 57 percent of the total inflow volume, and ground-water outflow accounts for 81 percent of the total outflow volume. Precipitation accounts for 88 percent of the total inflow volume of the hydrologic budget for Rice Lake in the same period, and evaporation accounts for 70 percent of the total outflow volume.

Hydraulic Residence Time

Knowledge of the hydraulic residence time is necessary for determining the response time of the lake to changes in **nutrient** loadings. The smaller the lake volume and (or) the greater the stream inflow, the shorter the hydraulic residence time. The mean hydraulic residence time (U.S. Environmental Protection Agency, 1988) is calculated as

$$\text{Mean hydraulic residence time} = \frac{\text{lake volume, acre-feet}}{\text{mean outflow, in acre-feet/year}}.$$

The calculated hydraulic residence time for Whitewater Lake for November 15, 1990-November 14, 1991, 1.02 years, is based on ground-water outflow of 5,720 acre-ft. The calculated hydraulic residence time for Rice Lake for the same period, 7.07 years, is based on an outflow of 132 acre-ft.

WATER QUALITY

The water quality of Whitewater and Rice Lakes depends primarily on the inputs of phosphorus from external and internal sources and the response within the water column to these inputs.

Phosphorus Budget

Phosphorus is the nutrient generally recognized as the cause of most macrophyte and **algal** problems in lakes; therefore, it is important to quantify inputs of phosphorus to and outputs of phosphorus from the lake.

Inputs

Whitewater Lake receives external inputs of total phosphorus from its inlet, overland runoff, precipitation, and ground water, and Rice Lake receives external inputs of total phosphorus from overland runoff, precipitation, ground water, and from Whitewater Lake when its stage exceeds the spillway crest. During November 15, 1990-November 14, 1991, the total-phosphorus loads to Whitewater and Rice Lakes were 558 lb and 63 lb, respectively. Total-phosphorus budgets are given in table 4.

Total-phosphorus loads of base flow at Whitewater Lake inlet were calculated from estimated daily discharges of base flow and concentrations of the discrete samples collected. The total-phosphorus load in base flow for this period was 70 lb; **yield** was 140 lb/mi^2. Storm-runoff loads for the inlet are included in the loads from shoreline drainage.

Samples of runoff for total-phosphorus concentrations were collected at six sites around Whitewater Lake and at one site on Rice Lake (fig. 1). Concentrations from the seven sites ranged from 0.20 to 1.00 mg/L. The mean concentration was 0.61 mg/L. Loads were estimated by using the mean total-phosphorus concentration and daily runoff from the Mukwonago River at Mukwonago, adjusted for drainage area, for each lake.

Table 3. Annual hydrologic budgets for Whitewater and Rice Lakes, November 15, 1990-November 14, 1991

Budget item	Flow volume (acre-feet)	Percent of total inflow or outflow
Whitewater Lake		
Inflow:		
Precipitation	1,850	26
Inlet	[a]1,050	15
Near-lake drainage	141	2
Ground water	4,010	57
Total inflow	7,051	100
Outflow:		
Evaporation	1,330	19
Whitewater Lake outlet	0	0
Ground water	5,720	81
Total outflow	7,050	100
Change in lake storage	-276	
Budget residual	+277	
Rice Lake		
Inflow:		
Precipitation	439	88
Inlet	[b]0	0
Near-lake drainage	22	4
Ground water	38	8
Total inflow	499	100
Outflow:		
Evaporation	308	70
Rice Lake outlet	0	0
Ground water	132	30
Total outflow	440	100
Change in lake storage	-45	
Budget residual	+104	

[a]Whitewater Lake inlet base flow.
[b]Rice Lake inlet (Whitewater Lake outlet).

Table 4. Total-phosphorus budgets for Whitewater and Rice Lakes, November 15, 1990-November 14, 1991

Budget item	Total-phosphorus load (pounds)	Percent of total inputs or outputs
	Whitewater Lake	
Inputs:		
Precipitation	101	18
Inlet	[a]70	13
Shoreline drainage	237	42
Ground water	44	8
Septic systems	106	19
Total inputs	558	100
	Rice Lake	
Inputs:		
Precipitation	24	38
Inlet	[b]0	0
Shoreline drainage	37	59
Ground water	2	3
Septic systems	0	0
Total inputs	63	100

[a]Whitewater Lake inlet base flow.
[b]Rice Lake inlet (Whitewater Lake outlet).

The total-phosphorus load from shoreline drainage for Whitewater Lake was estimated to be 237 lb, which is equivalent to a yield of 166 lb/mi^2. The total-phosphorus load from shoreline drainage for Rice Lake for the same period was 37 lb; yield was 176 lb/mi^2. The source of most of the total-phosphorus load to each lake was shoreline drainage.

A volume-weighted mean concentration of total phosphorus for precipitation (0.02 mg/L) reported in Field and Duerk's (1988) study of the Delavan Lake basin was used to estimate the concentration of total phosphorus. Total-phosphorus loading to Whitewater and Rice Lakes from precipitation was 101 and 24 lb, respectively, for November 15, 1990-November 14, 1991.

Water levels in wells WL-6, WL-6a, WL-6b, and WL-7 on Whitewater Lake and well RL-3 on Rice Lake (fig. 5) indicate ground-water flow to the lakes at these locations. These wells were sampled to determine the concentrations of dissolved orthophosphate in ground water entering the lakes; concentrations were <0.002, 0.002, 0.008, 0.003, and 0.017 mg/L, respectively. An average concentration of 0.004 mg/L was used for Whitewater Lake and 0.017 mg/L was used for Rice Lake. The phosphorus loads to Whitewater and Rice Lakes were 44 and 2 lb, respectively, for November 15, 1990-November 14, 1991.

Septic systems, if working properly, remove phosphorus by adsorption to soil in the drainfield. The removal capacity increases with decreasing size of soil particles, but all soils have a fixed adsorptive capacity that could eventually become exhausted (Fetter and others, 1977).

Soil types, pattern of seasonal usage, and distance to ground-water levels affect septic-system efficiency in phosphorus removal. Generally, phosphorus-removal capacity increases with decreasing pH, increasing clay content, decreasing sand content, increasing amounts of active soil aluminum and iron, and increasing depth of water table (Garn and Parott, 1977).

Estimates of water use by owners of private septic systems ranged from 42 to 75 gal/d (Siegrist and others, 1976; Probst, 1975; and U.S. Department of Health, 1967). Concentrations of phosphorus in septic-tank effluent have been reported to range from 7.7 to 16 mg/L (Barshied and El-Baroudi, 1974; Otis and others, 1973). Field and Graczyk (1990) found a phosphorus concentration of 19 mg/L in untreated sewage from a malfunctioning municipal sewage-treatment plant.

Phosphorus loads to the lake from septic systems were estimated on the basis of the following assumptions and data:

1. Phosphorus from properly-working septic systems can only drain to the lake if there is a ground-water gradient to the lake. Malfunctioning septic systems flowing directly into the lake or over the ground surface were not accounted for in this study. In Rice Lake there were no homes where ground water showed a positive gradient to the lake; in Whitewater Lake there were only 93 dwellings. Therefore, only Whitewater Lake had phosphorus contributions from septic systems.

2. Although no census data are available from Whitewater Lake, the USGS reported 2.5 persons per household in a study of Powers Lake in southeastern Wisconsin (S.J. Field, 1993). This value was used for Whitewater Lake. Approximately 65 percent of the residents of Whitewater Lake are seasonal residents for 6 months (Bill Norris, Whitewater-Rice Lakes Management District, oral commun., 1992).

3. Water use was assumed to be 53 gal/d per capita, based on the average use reported by Siegrist and others (1976), Probst (1975), and U.S. Department of Health (1967). A concentration of 16 mg/L was assumed for phosphorus in the septic effluent; this use and concentration gave an estimated per capita yield of 2.6 lb/yr (pounds per year) of phosphorus. Vollenweider (1968) reported per capita phosphorus inputs from septic systems ranging from 0.52 lb/yr to 3.9 lb/yr and a mean of 1.8 lb/yr.

4. In studies of dwellings near lakes in southeastern Wisconsin, the Southeastern Wisconsin Regional Planning Commission estimated that 15 to 30 percent of the phosphorus load to a septic tank reaches the lake (Dave Kendziorski, Southeastern Wisconsin Regional Planning Commission, oral commun., 1988). The glacial deposits surrounding Whitewater Lake are pitted outwash (Borman, 1976). These deposits contain sand and gravel that are generally well drained (See photograph in fig. 3.) On the basis of the glacial deposit and soil types, these soils are assumed to have a minimum retention factor of 70 percent; therefore, 30 percent of the phosphorus from septic tanks reaches the lake.

5. The dwellings are divided into two categories: those within 200 ft of and those greater than 200 ft from the shoreline. There are 99 dwellings in the area where ground-water gradients are positive to the lake (fig. 3); 73 are within 200 ft of the shoreline, and 26 are more than 200 ft. For the residents within 200 ft of the lake, 47 of 73 dwellings are assumed to be seasonal; the dwellings are occupied from May through October; 26 dwellings are occupied year round. For computational purposes, the seasonal dwellings amount to 23 dwellings (47 dwellings for 0.5 year). The sum of the seasonal (23) and the year-round (26) dwellings is 47 dwellings. By calculations similar to the preceding one, dwellings more than 200 ft from the lake total 16.

6. On the basis of the preceding assumptions, the data are applied to the following formula for those residences within 200 ft of the shoreline: Phosphorus loads from septic

tanks = (number of persons per house = 2.5) X (number of permanent and seasonal homes = 49) X (pounds of phosphorus per person per year = 2.6) X (septic-tank phosphorus = 30 percent). The result of the preceding calculation is that 96 lb of phosphorus is carried from septic systems to the lake.

The phosphorus loadings for the 16 permanent and seasonal homes more than 200 ft from the lake were reduced because of the long flow paths from the septic system to the lake. On the basis of this change and the previously described assumptions, these data are applied to the previous formula for residences more than 200 ft from the shoreline: Phosphorus loads from septic tanks = (number of persons per house = 2.5) X (number of permanent and seasonal homes = 16) X (pounds of phosphorus per person per year = 2.6) X (septic-tank phosphorus = 10 percent (minimum)). The result of the preceding calculation is that 10 pounds of phosphorus is carried from septic systems to the lake. Thus, the load of phosphorus carried to the lake from septic systems is 106 lb.

Outputs

No phosphorus left either lake during the study period via the outlets because there was no outflow from the lakes; phosphorus in the ground-water outflow was not measured but a conservative estimate is 200 to 400 lb per year from Whitewater Lake. The estimate is based on the ground-water outflow (5,000 acre-ft) X the average inlake concentration (30 μg/L) X 1 minus the soil retention factor (0.3).

A considerable amount of phosphorus was removed (mostly from Whitewater Lake) by the macrophyte-harvesting program. In 1991, the estimates of phosphorus removed from Whitewater Lake was 1,671 lb and from Rice Lake was 14 lb of phosphorus. In 1990, the estimates of phosphorus removed were 2,500 lb from Whitewater Lake and 60 lb from Rice Lake (William Norris, President, Whitewater-Rice Lakes Management District, written commun., 1992). Norris used 15 percent to represent weed dry weight as a percentage of wet weight and the phosphorus content of macrophyte dry weight as 0.31 percent. Norris' percentage of dry weight, as a percentage of wet weight, is high when compared to a study in west-central Minnesota. Peterson and others (1974) found the dry weight of wet macrophytes to be 7.1 percent. Norris' phosphorus content of macrophyte dry weight, 0.31 percent, is in agreement with the Minnesota study where Peterson found the phosphorus content to be 0.30 percent.

Physical and Chemical Characteristics of the Water Column

During the study, water in Whitewater and Rice Lakes was sampled only from spring to fall turnover. The resulting water-quality data, including profiles of water temperature, dissolved oxygen, pH, and specific conductance, are published in the U.S. Geological Survey's annual data publication (Holmstrom and others, 1991). Analyses of spring-turnover water samples from Whitewater Lake (when the lake was well mixed) indicate that the water has an average **hardness** of 193 mg/L (as calcium carbonate). The nitrogen to phosphorus ratio, 40:1, indicates that phosphorus is the limiting nutrient; a nitrogen to phosphorus ratio greater than 15:1 indicates phosphorus limitation (Lillie and Mason, 1983, p. 63). An analysis of water during spring-turnover was not done for Rice Lake.

Water Temperature

Whitewater Lake is thermally stratified throughout the summer. In July, the epilimnion extends to a depth of about 12 ft, the **metalimnion** exists from 12 ft to about 25 ft, and the hypolimnion exists from 25 ft to the lake bottom. The **thermocline** begins to develop in early summer, reaches its maximum gradient in late summer, and deepens in the fall as water cools and wind action causes erosion of the thermocline. Rice Lake, in contrast, is generally not stratified because of its shallow depth. Weak stratification developed in August, but a true thermocline did not form.

Dissolved Oxygen

In Whitewater Lake, dissolved-oxygen concentrations are at most times and depths, adequate to support aquatic organisms. As the thermocline develops in late May, however, the epilimnion reduces the surface supply of dissolved oxygen to the hypolimnion. The hypolimnion thus becomes isolated from the atmosphere. As the algal populations that are produced by the nutrient-rich surface waters die, fall to the bottom of the lake and decompose along with that previously deposited, the oxygen demand from these decaying organisms depletes the dissolved-oxygen concentration of the water. Oxygen depletion begins at the lake bottom, then progresses upward but stays confined to the hypolimnion. Depletion can progress until all the oxygen in the hypolimnion is consumed (anoxia). Anoxia in the hypolimnion was observed from May 22 to September 25, 1991. The **anoxic** zone reached a maximum thickness on August 27 when depths greater than 10 ft were devoid of oxygen; that zone represented about 28 percent of the lake-bottom area.

In Rice Lake, dissolved-oxygen concentrations are also generally adequate to support aquatic organisms. Because the lake does not thermally stratify, anoxia seldom occurs; however, anoxia at the lake bottom was observed on June 19 and August 14 and 24, 1991.

Anoxia is common in eutrophic lakes and, in varying degrees, in all the thermally stratified eutrophic lakes in Wisconsin. Anoxia can cause the release phosphorus from the bottom sediments if concentration of phosphorus in the sediments is high.

Dissolved-oxygen concentrations in a 24-hour period (fig. 7) were measured on July 24-25, 1991, at three sites on Whitewater Lake and at the deep hole of Rice Lake. The purpose of the measurements was to determine the effects of macrophyte and (or) algal respiration on the dissolved-oxygen concentration of Whitewater and Rice Lake. For the Whitewater Lake sites, the Heart Prairie site is the deepest site at a depth of about 34 ft, and no macrophytes are present. Some macrophytes are present at the next deepest site, the North Bay site, which is 11 ft deep. Macrophytes are dense at the shallowest site, the South Bay site, which is about 6 ft deep. At Rice Lake, no macrophytes are present at the deep-hole sampling site, which is about 9 ft deep.

In Whitewater Lake, nighttime respiration of macrophytes and (or) algae did not adversely affect the dissolved-oxygen concentration. The largest diurnal change in dissolved oxygen occurred at the 1.5-ft depth in South Bay--the area of the lake sampled where the population of macrophytes was densest. The maximum dissolved-oxygen concentration of 11.9 mg/L was measured at 1710 hours on July 24. The minimum dissolved-oxygen concentration, 6.3 mg/L, was measured at 0500 hours on July 25.

In Rice Lake, nighttime respiration of macrophytes and (or) algae did adversely affect the dissolved-oxygen concentration at the lake bottom. Maximum dissolved-oxygen concentration at the 1.5-ft depth was 13.2 mg/L at 1800 hours on July 24; the minimum concentration was 5.7 mg/L at 0540 on July 25. At night, however, oxygen was depleted at the lake bottom even though temperature gradients were small. This condition can cause phosphorus release from the sediments.

Phosphorus

Historical phosphorus data from Whitewater Lake are shown in figure 8. No historical data are available for Rice Lake; all data are from the WDNR (Robert Wakeman, Wisconsin Department of Natural Resources, Milwaukee, Wis., written commun., 1992). The data, although sparse in early years, indicate a decline in phosphorus concentrations. This decline in phosphorus concentration should be viewed with caution, however, because of possible arsenite interference. From 1950 to 1965, Whitewater Lake was treated with 55,900 lb of sodium arsenite to control macrophytes. Sodium arsenite has been known to cause anomalously high results in determination of phosphorus (Downes, 1978). However, even if the data before 1986 are considered to be suspect, the data for 1986-91 indicate a decline in phosphorus concentrations. This decline is understandable because when the lake was created in 1947 the inundated lands were likely to be high in phosphorus bound up with the terrestial vegetation. A decline in phosphorus concentrations should cause a shift from algal populations to macrophyte populations because of increased light penetration. This happened according to historical account (Lundin and others, 1972). Also Whitewater and Rice Lakes likely lost some phosphorus when water flowed through the lake outlet during 1973-86.

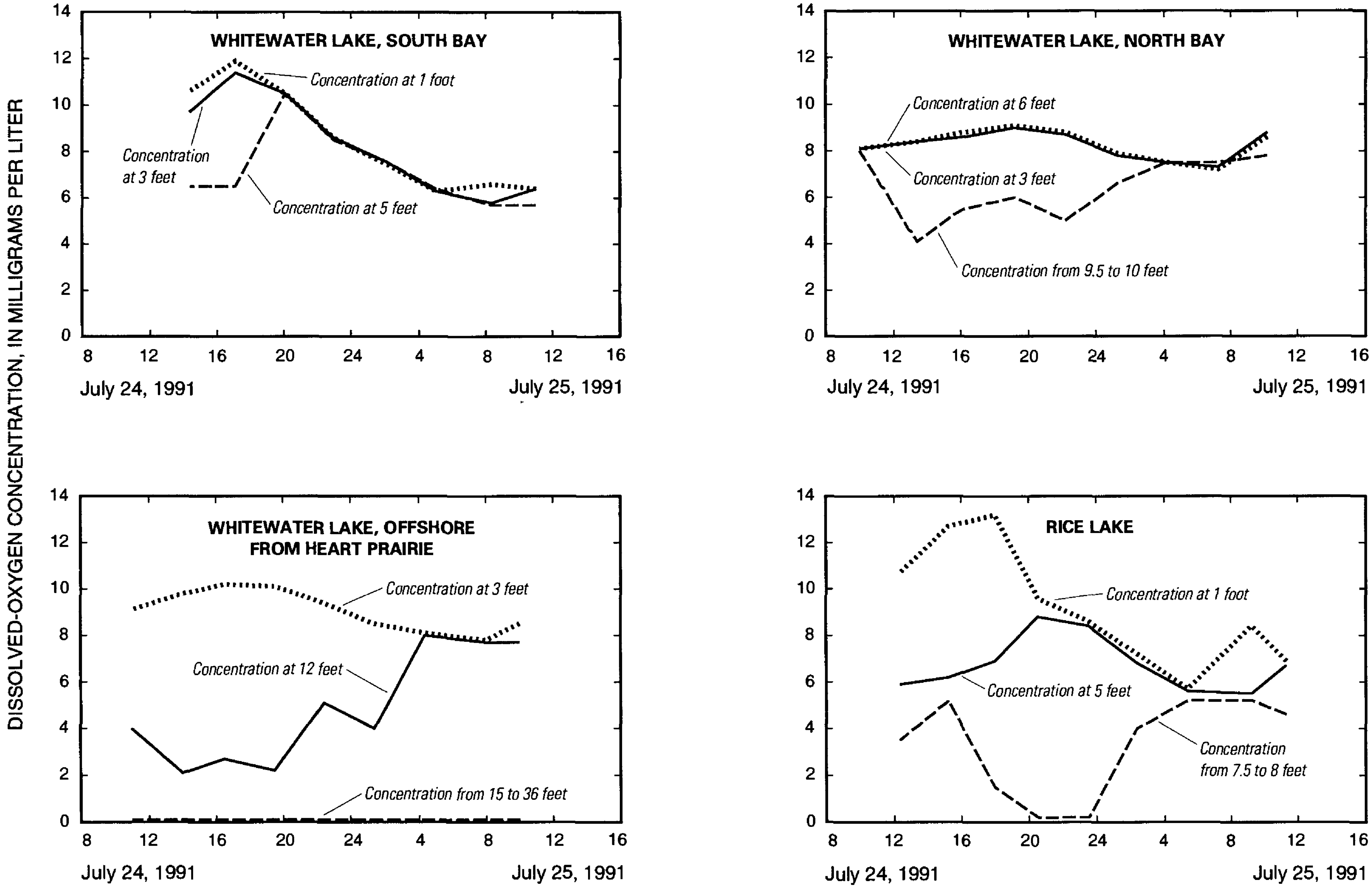


Figure 7. Dissolved-oxygen profiles for Whitewater and Rice Lakes, July 24-25, 1991.

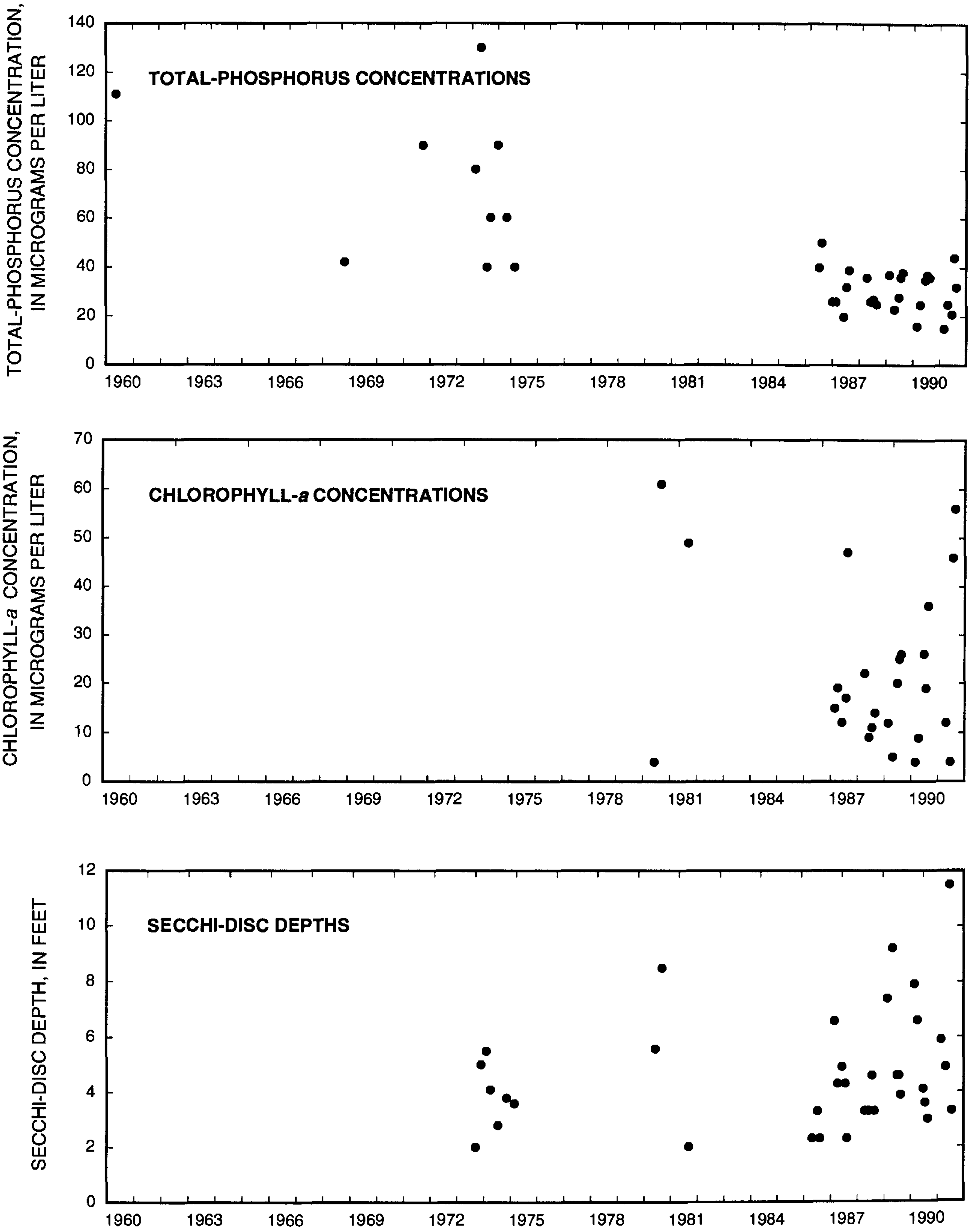


Figure 8. Historical phosphorus, chlorophyll *a*, and Secchi-disc data for Whitewater Lake, 1960-91.

Phosphorus concentrations in Whitewater and Rice Lakes determined during 1991 were lowest in spring and highest in summer. Monthly mean total-phosphorus concentrations, in µg/L, at 1.5-ft depth in Whitewater and Rice Lakes for 1991 are shown in the table that follows:

Site	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Average
Whitewater Lake									
South Bay	23	34	50	43	66	88	43	23	46
North Bay	14	20	15	61	40	38	34	23	31
Heart Prairie	25	26	20	31	47	38	34	29	31
Rice Lake	22	28	38	120	123	124	49	36	68

Rice Lake has a higher average monthly concentration of total phosphorus, 68 µg/L, than any site on Whitewater Lake. In Whitewater Lake, the South Bay site has the highest average monthly concentration, 46 µg/L. South Bay is the area of the lake where macrophyte population is densest. The North Bay and Heart Prairie sites have average monthly concentrations of 31 µg/L. Surface concentrations of total phosphorus in Whitewater Lake ranged from 14 µg/L on April 3, 1991, in North Bay to 119 µg/L on September 25, 1991, in South Bay. Surface concentrations of total phosphorus in Rice Lake ranged from 22 µg/L on April 3, 1991, to 131 µg/L on September 11, 1991.

Phosphorus is released from the sediments in the area of the lake that undergoes oxygen depletion. Most of the phosphorus released is in the dissolved form. Total phosphorus (TP) and dissolved orthophosphate phosphorus (DOP) concentrations, in µg/L, 1.5 ft above the Whitewater Lake sediments at the deep-hole site at Heart Prairie for 1991 are shown in the table that follows:

	Apr.	May		June		July		Aug.		Sept.		Oct.	Nov.
	3	9	22	4	19	9	25	14	27	11	25	24	20
TP	26	68	256	360	360	480	440	530	680	650	600	67	34
DOP	6	25	218	300	276	400	360	410	580	490	500	19	7

Chlorophyll *a*

Chlorophyll *a*, the primary photosynthetic pigment of all oxygen-evolving, photosynthetic organisms, is a component of all algae (Wetzel, 1983, p. 343) and is often used an indicator of algal **biomass**. Historical data of chlorophyll-*a* concentrations are available for Whitewater Lake (fig. 8), but none were available for Rice Lake. Data before 1986 are sparse and no trend was apparent. At Whitewater Lake in 1991, chlorophyll-*a* concentration ranged from 2 µg/L on June 4 and 19 at the North Bay site, to 62 µg/L on August 27, at the Heart Prairie site. At Rice Lake in 1991, chlorophyll-*a* concentration ranged from 3 µg/L on November 20 to 147 µg/L on July 9. Monthly average chlorophyll-*a* concentrations, in µg/L, at Whitewater and Rice Lakes for 1991 are shown in the table that follows:

Site	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Average
Whitewater Lake									
South Bay	9	13	6	18	39	26	9	6	16
North Bay	6	8	2	27	36	26	16	7	16
Heart Prairie	6	8	4	31	58	29	16	5	20
Rice Lake	6	6	19	136	80	67	8	3	41

Rice Lake had the highest, average monthly concentration of chlorophyll *a*, 41 µg/L. The average monthly concentration of chlorophyll *a* from the Whitewater Lake sites were: 16 µg/L at South Bay; 16 µg/L at North Bay; and 20 µg/L at Heart Prairie.

Water Clarity

The depths at which photosynthetic activity occurs depends largely on light penetration, which is influenced by water clarity. Secchi-disc measurements provide a measurement of water clarity. Factors that reduce water clarity are water **color**, turbidity, and concentrations and types of algae and **zooplankton**. Algal concentrations were the dominant factor affecting water clarity in Whitewater and Rice Lakes; therefore, Secchi-disc depths correlate with the algal populations minimum. Minimum Secchi-disc depths generally occur during summer when algal populations are largest and maximum depths generally occur during spring, fall, and winter when algal populations are smallest. Average monthly Secchi-disc depths, in feet, at Whitewater and Rice Lakes for 1991 are shown in the table that follows:

Site	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Average
Whitewater Lake									
South Bay	3.9	3.3	4.9	2.1	2.0	3.1	4.6	3.9	3.5
North Bay	5.0	5.1	9.8	5.6	2.5	3.6	4.6	5.9	5.3
Heart Prairie	4.9	6.2	8.7	3.9	1.6	3.6	4.6	7.9	5.2
Rice Lake	5.5	5.4	4.9	1.0	1.5	1.6	4.9	8.5	4.2

The South Bay site had the lowest average clarity, 3.5 ft, of all sampled sites. This result, however, may not be completely representative because the dense population of macrophytes shaded and partly obscured the Secchi disc. Clarities at the North Bay and the Heart Prairie sites were similar; monthly average readings of 5.3 ft and 5.2 ft. Monthly average clarity at Rice Lake was 4.2 ft.

Historical water-clarity data (fig. 8) were available for Whitewater Lake but not for Rice Lake. Similar to that found for historical phosphorus data, water clarity has also improved as well. However, the collecting of historical water-clarity data only began in 1973; collecting of the phosphorus data began in 1960.

Evaluation of Lake Condition

The water quality of Whitewater and Rice Lakes in 1991 was evaluated using three methods: Lillie and Mason's water-quality evaluation (1983), Carlson's Trophic-State Index (TSI) (1977), and the Vollenweider model (1968). Lillie and Mason's water-quality evaluation and Carlson's TSI can be used to evaluate the in-lake water quality, and Vollenweider's model can be used to evaluate the phosphorus loading to a lake.

Lillie and Mason's Classification

Lakes can be classified according to a classification for Wisconsin lakes by Lillie and Mason (1983). To classify Wisconsin lakes, Lillie and Mason used a random data set consisting of total-phosphorus and chlorophyll-*a* concentrations and Secchi-disc depths collected during summer (July-August). Their classification is shown in the table that follows:

Water-quality index	Approximate total phosphorus equivalent (micrograms per liter)	Approximate chlorophyll-*a* equivalent (micrograms per liter)	Approximate water clarity equivalent (Secchi-disc depth, in feet)
Excellent	<1	<1	>19.7
Very good	1-10	1-5	9.8-19.7
Good	10-30	5-10	6.6-9.8
Fair	30-50	10-15	4.9-6.6
Poor	50-150	15-30	3.3-4.9
Very poor	>150	30	<3.3

Lillie and Mason's criteria were used to evaluate the mean summer (July-August) 1991 data from all sites on Whitewater Lake. Mean concentration of total phosphorus was 48 μg/L; at the upper end of the fair ranking. Mean concentration of chlorophyll *a* was 35 μg/L; just into the very poor ranking. The mean water clarity was 3.3 ft; at the upper end of the poor ranking. On the basis of the average of these rankings, water quality of Whitewater Lake is poor.

The Lillie and Mason criteria were also used to evaluate the data from Rice Lake. Mean summer concentration for total phosphorus in Rice Lake was 120 μg/L, for chlorophyll *a* was 108 μg/L, and for water clarity was 1.2 ft. The mean phosphorus is in the upper end of the poor ranking, whereas chlorophyll *a* and water clarity are well into the very poor classification. On the basis of the average of these rankings, water quality of Rice Lake is very poor.

Carlson's Trophic-State Index

The in-lake trophic condition can be evaluated by use of Carlson's TSI (Carlson, 1977). The TSI is computed from total-phosphorus and chlorophyll-*a* concentrations and Secchi-disc depths for lake ice-free periods. The TSI equation for Secchi-disc depth was developed by Carlson (1977), whereas those for chlorophyll *a* and total phosphorus were developed by the WDNR (Ronald Martin, Wisconsin Department of Natural Resources, oral commun., 1985). Carlson's TSI ranges from 0 for "unproductive" lakes to 100 for "very productive" lakes. Carlson, however, did not label ranges of his index in terms of traditional trophic-state terminology. The WDNR has adopted three TSI classifications of Wisconsin lakes: (1) TSI's of less than 40 define oligotrophy; (2) TSI's from 40 to 50 define mesotrophy; and (3) TSI's greater than 50 define eutrophy (Wisconsin Department of Natural Resources, 1983). G.C. Gerloff (University of Wisconsin, written commun., 1984) also uses these ranges. These ranges are used herein to be consistent with trophic-state evaluations of Wisconsin lakes done by the WDNR.

The three preceding classifications encompass a wide range of water quality. The water of **oligotrophic** lakes is clear, algal populations are low, and the deepest layers of the lake are likely to contain oxygen throughout the year. The water of **mesotrophic** lakes has a moderate supply of nutrients, moderate **algal blooms**, and limited oxygen depletions. Water in eutrophic lakes is nutrient-rich, and water-quality problems such as dense algal blooms and oxygen depletion in parts of the lakes during various seasons are common. Fish kills often result at times if oxygen is severely depleted.

The following equations were used to calculate the TSI values for Whitewater and Rice Lakes:

$$\text{TSI (Secchi)} = 60 - 33.2 \times (\log \text{Secchi-disc depth, in meters})$$

$$\text{TSI (chlorophyll } a) = 33.60 + 17.64 \times (\log \text{chlorophyll-}a \text{ concentration, in micrograms per liter})$$

$$\text{TSI (total phosphorus)} = 60 - 33.2 \times \log \left(\frac{40.5}{\text{Total-phosphorus concentration, in micrograms per liter}} \right)$$

Three trophic levels and the different boundaries in the table that follows:

Trophic level	Trophic state index	Total phosphorus concentration (micrograms per liter)	Secchi-disc depth (meters)	Chlorophyll-*a* concentration (micrograms per liter)
Eutrophic				
	50	20	2.0	8.5
Mesotrophic				
	40	10	4.0	2.3
Oligotrophic				

The calculated TSI's for all sites on Whitewater and Rice Lakes (fig. 9) exhibit similar patterns. TSI's at all sites in April and May range from mesotrophic to somewhat eutrophic. By July the sites are well into the eutrophic range; by November, the lakes' trophic status returns to mesotrophic.

Vollenweider's Model

Several models are available for determining the external phosphorus loads to lakes. Most of the models, however, are designed for drainage lakes (or lakes where water drains through outlets). Although Whitewater and Rice Lakes have outlets, no water drained from them in 1991. Instead, both lakes functioned as seepage lakes or no-outlet lakes. Therefore, the most suitable model applicable for Whitewater and Rice Lakes is Vollenweider's early 1968 model based on the total-phosphorus to **mean-depth** relation (Vollenweider, 1968). This model can be used to predict critical amounts of external total-phosphorus loading to lakes. The external total-phosphorus loading to Whitewater and Rice Lakes for 1990-91, based on the Vollenweider model, is shown in figure 10.

Vollenweider (1968) classifies the rate at which the receiving water would become eutrophic (nutrient rich) or remain eutrophic as "dangerous." This "dangerous" line represents a 20 μg/L phosphorus concentration in spring. Vollenweider classifies the rate at which the receiving water would become mesotrophic as "permissible." This "permissible" line represents a 10 μg/L phosphorus concentration in spring.

For Whitewater Lake, on the basis of the mean lake depth of 8.3 ft (2.5 m), a total phosphorus input of 558 pounds (2.533 x 10^5 g), and a lake surface area of 3.014 x 10^7 ft^2 (2.800 x 10^6 m^2) the calculated phosphorus loading rate of 0.185 x 10^{-4} (lb/ft^2)(0.090 g/m^2) is on the "dangerous" line and would be predicted to result in a mesotrophic to eutrophic condition. The total-phosphorus concentration in spring for Whitewater Lake, 21 μg/L, agrees with the classification on the dangerous line of the Vollenweider model.

On the basis of the mean lake depth of 5.8 ft (1.76 m), a total-phosphorus input of 63 pounds (2.531 x 10^5 g), and a lake surface area of 7.057 x 10^6 ft (6.556 x 10^5 m^2), the calculated phosphorus loading rate for Rice Lake, 0.893 x 10^{-5} lb/ft^2 (0.044 g/m^2), is between the "dangerous" line and- the "permissible" line and would probably result in mesotrophic conditions. The spring concentration of total phosphorus for Rice Lake in spring was 22 μg/L.

Dillon and Rigler's Model

Dillon and Rigler (1974) developed a model to predict summer chlorophyll-*a* concentrations from spring total-phosphorus (TP) concentrations. They used data collected from southern Ontario lakes combined with data reported in the literature from other North American lakes to develop an equation that can be used to predict the average summer chlorophyll-*a* concentrations from a single spring turnover total-phosphorus concentration. The equation is

$$\log_{10} (\text{chl } a) = 1.45 \log_{10} (\text{TP}) - 1.14.$$

Applying the above equation to spring total-phosphorus concentration for both Whitewater and Rice Lakes results in chlorophyll-*a* concentrations of 6.0 and 6.4 μg/L, respectively. These concentrations are considerably lower than those observed during July and August. At Whitewater Lake, the mean chlorophyll-*a* concentration measured was 35 μg/L; at Rice Lake, the mean concentration measured was 108 μg/L. To achieve concentrations of this magnitude, according to the formula, would require spring turnover total-phosphorus concentrations of 71 μg/L in Whitewater Lake and 154 μg/L in Rice Lake. These data therefore suggest that considerable phosphorus must be recycled from the sediments of the lakes during summer to reach high chlorophyll-*a* concentrations.

Internal Recycling of Phosphorus

The exchange of phosphorus between sediments and the overlying water can be a major component of the phosphorus cycle in natural water. Phosphorus released from the sediments has been documented to contribute as much as 91 percent of total-phosphorus input (external and internal) to a lake (Bengtsson, 1978). Phosphorus can be released from the sediments in several ways: **hypolimnetic** anoxia, macrophytes, **benthic invertebrates**, fish, motorboats, and wave action.

Phosphorus released from anoxic hypolimnia in lakes is well documented. Nurnberg and

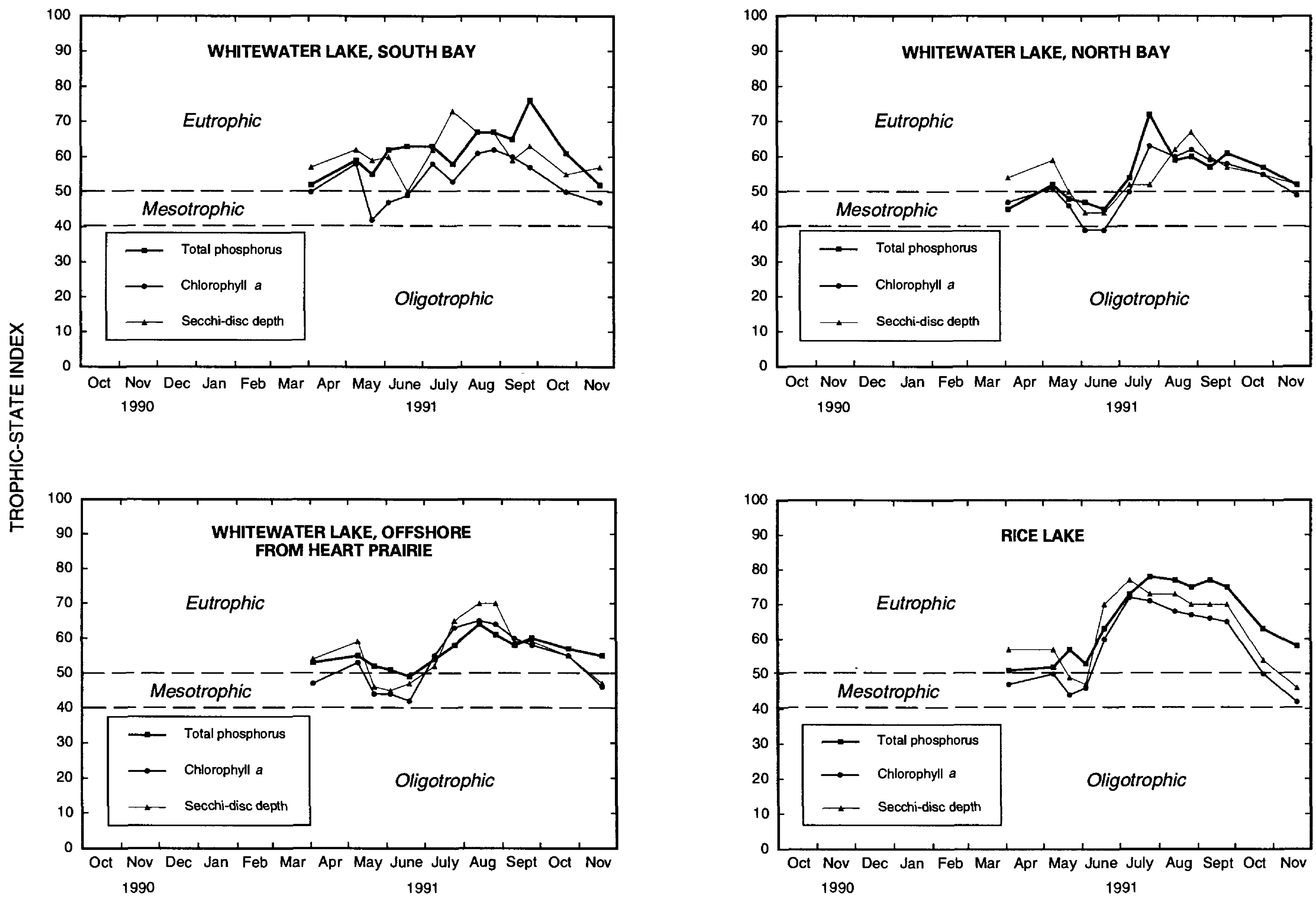


Figure 9. Trophic-State Indices for Whitewater and Rice Lakes.

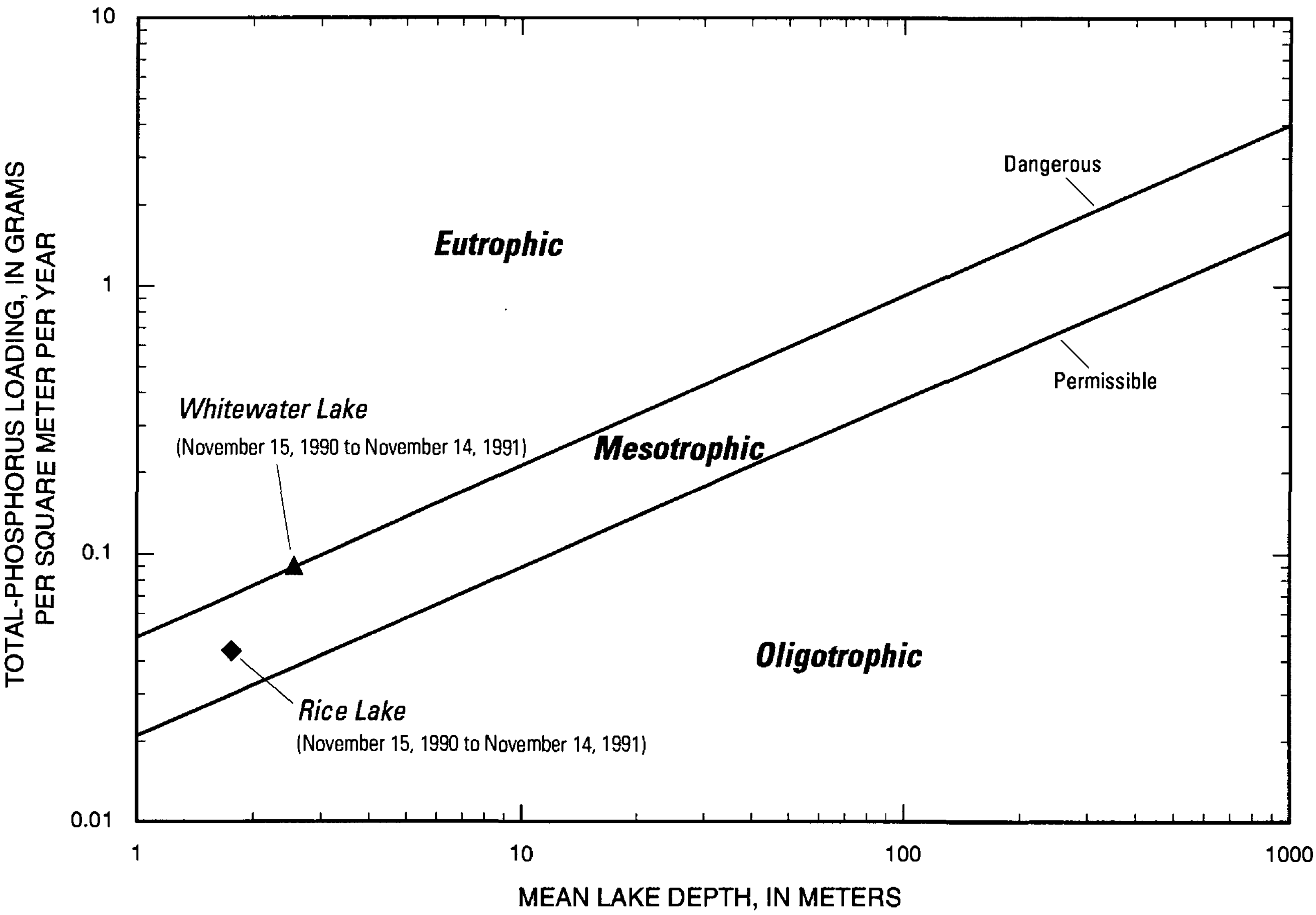


Figure 10. Vollenweider phosphorus-loading classification for Whitewater and Rice Lakes.

Peters (1984) found that, for 23 stratified lakes in this condition, the internal supply of phosphorus contributed an average of 39 percent to the total-phosphorus load. Data from publications of USGS (Holmstrom and others, 1986-91) show that the concentration of phosphorus near the lake sediments for lakes in this condition can be as high as 1,000 µg/L.

Phosphorus released from macrophyte-shoot turnover has been documented in a small lake (Lake Wingra) at Madison, Wis., about 50 mi northwest of Whitewater Lake (Smith and Adams, 1986). *Myriophyllum spicatum*, eurasian watermilfoil, the dominant species in Lake Wingra (and in Whitewater Lake) is an important vector in the movement of phosphorus from the sediments to the water column. The rate of phosphorus release from healthy shoots was insignificant, whereas most of the phosphorus release was from *Myriophyllum* decay. In Lake Wingra, the loss of phosphorus from stands of *Myriophyllum* was estimated to be 0.266 x 10^{-3} lb/ft^2 (1.3 g/m^2). This represented 47 percent of the annual external phosphorus input to the lake.

Physical disruption of the bottom sediments by benthic invertebrates, motorboats, and wave action can cause phosphorus concentrations in the water column to increase. The effects of physical disruption of the sediments by benthic invertebrates on phosphorus exchange are unclear but are most likely small in comparison to overriding chemical-microbial processes (Wetzel, 1983, p. 268). Motorboats in shallow hypereutrophic systems have been found to resuspend the bottom sediments, which results in an increase of phosphorus concentrations in the water column (Wright and Wagner, 1991). Winds can also cause resuspension of the lake sediments and phosphorus in shallow hypereutrophic systems (Ryding and Forsberg, 1980).

Internal recycling and sedimentation of phosphorus to Whitewater and Rice Lakes was calculated by use of a mass-balance phosphorus budget described in the following equation:

Net internal recycling/sedimentation =
change of total-phosphorus (TP) mass in lake
+ outflow TP mass - inflow TP mass.

A positive value for net internal recycling/sedimentation indicates internal recycling dominates, whereas a negative value indicates sedimentation dominates. Internal recycling of phosphorus was calculated only for April 1-November 14, 1991. This equation ignores ground-water outflow and harvesting of macrophytes and fish. Thus, the internal recycling/sedimentation component is the minimum that occurs.

Internal recycling of total phosphorus was estimated to be at least 582 lb for Whitewater Lake and 295 lb for Rice Lake (tables 5 and 6). These amounts represent at least 51 percent of the combined internal and external total-phosphorus input of 1,140 lb for Whitewater Lake and 82 percent of the combined internal and external total-phosphorus input of 358 lb for Rice Lake. The internal recycling of phosphorus is probably greater than that shown because some phosphorus left the lakes in ground-water outflow.

For Whitewater Lake, the amount of phosphorus lost from the water column was at least 882 lb. For Rice Lake, the amount of phosphorus lost was at least 305 lb. It should be recalled that the weight of phosphorus removed through macrophytes harvesting is large compared to other parts of the phosphorus budget.

Internal recycling of phosphorus during summer seems to be the driving force in increasing phosphorus concentrations in Whitewater and Rice Lakes. The in-lake phosphorus mass and the cumulative external total-phosphorus inputs for Whitewater and Rice Lakes for April 1-November 14, 1991, are shown in figure 11. At Whitewater Lake, by late July, in-lake phosphorus mass had exceeded the external inputs by a factor of more than 3, and at Rice Lake, the in-lake phosphorus mass had exceeded the external inputs by a factor of more than 13.

SUMMARY

A comprehensive hydrologic and water-quality study of Whitewater and Rice Lakes in southeastern Wisconsin during November 15, 1990-November 14, 1991, showed that internal recycling of phosphorus from the lake sediments during summer caused most of the observed water-quality problems. The internal recycling of phosphorus was estimated for April 1-November 14, 1991, by use of a mass-balance approach. For Whitewater Lake, the internal load of 582 pounds was slightly greater than the annual external load of 558 pounds. For Rice Lake, the internal load of 295 pounds far exceeded the annual external load of 63 pounds. Vollenweider's model (1968), which uses external-phosphorus loading and mean lake depth to classify lakes, fairly accurately predicted the lakes' spring turnover concentration and showed that the external-phosphorus loads for Whitewater Lake would cause mesotrophic to eutrophic conditions, whereas the loads for Rice Lake would cause mesotrophic conditions. Dillon and Rigler's model further suggested additional phosphorus from internal recycling was required to result in the high chlorophyll-*a* concentrations experienced in both systems during summer. Both lakes are well into the eutrophic classification by summer, owing to the additional internal recycling of phosphorus from the lake sediments.

Because of the large amount of phosphorus recycled from the sediments during summer, the water quality rapidly deteriorated as summer progressed. In the upper 1.5 ft of Whitewater Lake, mean phosphorus concentrations increased from 21 µg/L in spring to 48 µg/L in July and August, and mean chlorophyll-*a* concentration increased from 7 µg/L to 35 µg/L, and mean water clarity decreased from 4.8 ft to 3.0 ft. In the upper 1.5 ft of Rice Lake, mean phosphorus concentrations increased from 22 µg/L in spring to 122 µg/L in July and August, and mean chlorophyll-*a* concentration increased from 6 µg/L to 108 µg/L, and mean water clarity decreased from 5.5 ft to 1.25 ft.

Although no phosphorus is lost from either lake through the lake outlets, more phosphorus is removed through a recently started macrophyte-control program in Whitewater Lake than from the combined external and internal phosphorus inputs. In 1991, macrophyte harvesting was estimated to have removed 1,670 pounds of phosphorus from Whitewater Lake and 14 pounds from Rice Lake. In 1990, macrophyte harvesting removed 2,500 pounds of phosphorus from Whitewater Lake and 60 pounds from Rice Lake.

Table 5. Summary of total phosphorus (TP) input, output, and changes in the water column, Whitewater Lake, April 1-November 14, 1991

[TP, total phosphorus. All data are in pounds.]

Period	External TP input						(2) Date (month/day)	(3) TP mass in water column	(4) Change in TP mass	(5) TP outlet mass	(6) Minimum internal recycling or sedimentation	
	Baseflow	Runoff	Precipitation	Ground-water inflow	Septic	(1) Total					Internal recycling	Sedimentation
							04/01	335		0		
4/1-4/3/91	0.5	2.1	0.10	0.40	0.5	3.60	04/03	348	13	0	9	0
4/4-5/9/91	9.4	48.0	13.70	4.30	8.0	83.40	05/09	471	123	0	40	0
5/10-5/22/91	3.4	2.9	2.80	1.60	5.2	15.90	05/22	421	-50	0	0	66
5/23-6/4/91	3.8	7.1	3.30	1.60	5.2	21.00	06/04	531	110	0	89	0
6/5-6/19/91	4.6	4.8	4.20	1.80	6.0	21.40	06/19	536	5	0	3	16
6/20-7/9/91	4.2	2.7	2.80	2.40	8.0	20.10	07/09	617	81	0	61	0
7/10-7/25/91	2.3	8.4	3.90	1.90	6.4	22.90	07/25	910	293	0	270	0
7/26-8/14/91	2.6	7.1	7.00	2.40	8.0	27.10	08/14	935	25	0	0	2
8/15-8/27/91	1.5	2.0	.30	1.60	5.2	10.60	08/27	954	19	0	8	0
8/28-9/11/91	1.3	1.7	2.10	1.80	6.0	12.90	09/11	689	-265	0	0	278
9/12-9/25/91	1.0	14.4	8.30	1.70	5.6	31.00	09/25	825	136	0	105	0
9/26-10/24/91	3.5	19.7	9.20	3.50	11.6	47.50	10/24	512	-313	0	0	361
10/25-11/14/91	3.2	38.5	14.80	2.50	8.4	67.40	11/14	420	-92	0	0	159
						385			85	0	582	882

Sum of internal recycling (Net gains) = 582

Sum of sedimentation (Net losses) = 882

Net deposition (Sedimentation - Internal recycling) = 300

Minimum internal recycling or sedimentation (6) = change in TP mass in lake (4) + outflow TP mass (5) - inflow TP mass (1)

Table 6. Summary of total phosphorus (TP) input, output, and changes in the water column, Rice Lake, April 1-November 14, 1991
[TP, total phosphorus. All data are in pounds.]

Period	External TP input					(3) TP mass in water column	(4) Change in TP mass	(5) TP outlet mass	(6) Minimum internal recycling or sedimentation	
	Runoff	Precipitation	Ground-water inflow	(1) Total	(2) Date (month/day)				Internal recycling	Sedimentation
					04/01	58.0		0		
4/1-4/3/91	0.3	0.000	0.020	0.32	04/03	58.5	0.5	0	0.2	0.0
4/4-5/9/91	7.6	3.440	.210	11.25	05/09	63.3	4.8	0	.0	6.5
5/10-5/22/91	.4	.698	.075	1.17	05/22	81.4	18.1	0	16.9	.0
5/23-6/4/91	1.1	.747	.075	1.92	06/04	67.3	-14.1	0	.0	16.0
6/5-6/19/91	.7	.916	.087	1.70	06/19	141.1	73.8	0	72.1	.0
6/20-7/9/91	.3	.660	.120	1.08	07/09	258.1	117.0	0	115.9	.0
7/10-7/25/91	1.4	1.700	.092	3.19	07/25	328.9	70.8	0	67.6	.0
7/26-8/14/91	1.1	1.540	.120	2.76	08/14	270.4	-58.5	0	.0	61.3
8/15-8/27/91	.3	.054	.075	.43	08/27	277.7	7.3	0	6.9	.0
8/28-9/11/91	.2	.470	.087	.76	09/11	293.6	15.9	0	15.1	.0
9/12-9/25/91	2.3	2.010	.081	4.39	09/25	272.3	-21.3	0	.0	25.7
9/26-10/24/91	3.0	2.180	.170	5.35	10/24	115.8	-156.5	0	.0	161.9
10/25-11/14/91	6.0	3.600	.120	9.72	11/14	92.0	-23.8	0	.0	33.5
				44.0			34.0	0	295	305

Sum of internal recycling (Net gains) = 295

Sum of sedimentation (Net losses) = 305

Net deposition (Sedimentation - Internal recycling) = 10.0

Minimum internal recycling or sedimentation (6) = change in TP mass in lake (4) + outflow TP mass (5) - inflow TP mass (1)

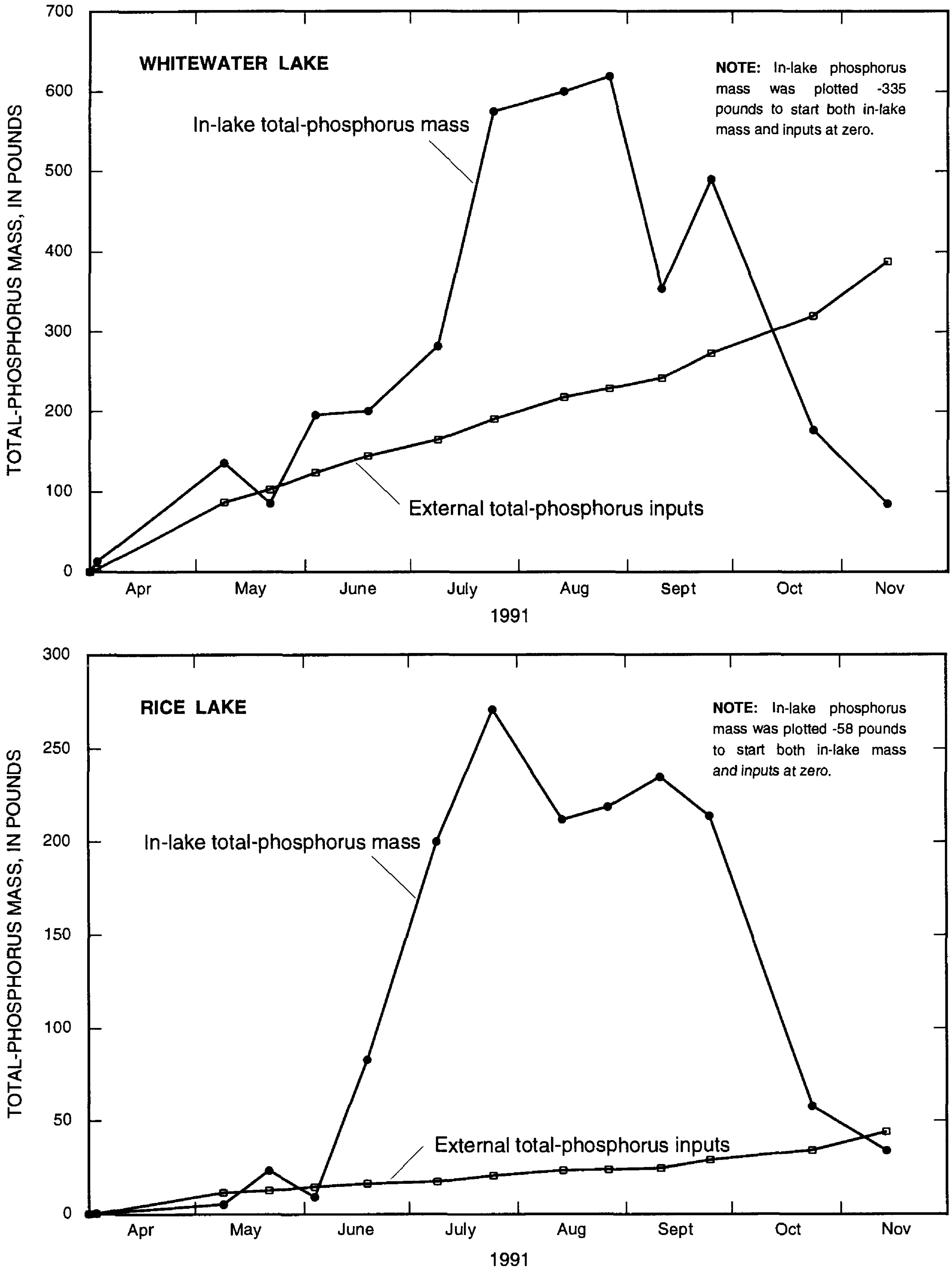


Figure 11. In-lake total-phosphorus mass and cumulative external total-phosphorus inputs for Whitewater and Rice Lakes.

Analysis of historical data of Whitewater Lake indicates possibly a slight improvement in lake-water quality since 1960. Concentration of phosphorus data show a weak trend in declining concentrations. The lake has shifted from an algal dominated system shortly after creation in 1947 to one now dominated by macrophytes.

According to the hydrologic budget for Whitewater Lake for November 15, 1990-November 14, 1991, 57 percent of the inflow budget was from ground water, 26 percent was from precipitation, 15 percent was from a spring-inlet base flow, and 2 percent was from near-lake drainage. Ground water accounted for 81 percent of the outflow and 19 percent was from evaporation.

The hydrologic budget for the study of Rice Lake showed that precipitation was the principal source of water to the lake at 88 percent of the inflow budget. The remainder of the inflow was ground water, 8 percent, and near-lake drainage, 4 percent. Evaporation accounted for 66 percent of the outflow, and ground water accounted for 34 percent.

Lake levels since Whitewater Lake was created in 1947 and Rice Lake was created in 1954 have been difficult to maintain at spillway elevations. Much of this difficulty is due to the large amount of ground water lost from both lakes through coarse, glacial soils consisting of sand, gravel, cobble, and boulders.

Lake levels at spillway elevations are correlated with high ground-water levels. The level of Whitewater Lake did not rise to its spillway until 1973. Water flowed intermittently from the outlet during 1973-1986. Lake levels at spillway elevations correlate with the high ground-water levels of a nearby well.

To help protect the water quality of Whitewater and Rice Lakes, it is suggested the following items be documented:

1. Lake stage, to determine if the lake sediments are sealing naturally and loss of water and phosphorus from both lakes.

2. The weight and the number of truckloads of macrophytes removed annually from each lake, to determine the effect of macrophyte-phosphorus removal on water quality of the lakes.

3. The water quality of both lakes, to determine water-quality trends.

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GLOSSARY

Acre-foot–Volume of water required to cover 1 acre to a depth of 1 foot, and equal to 43,560 ft^3. (Dion and others, 1976).

Alga, algae, algal–A group of simple primitive plants that live in wet or damp places, and generally are microscopic in size, containing chlorophyll and lacking roots, stems, and leaves. (Britton and others, 1975).

Algal bloom–A high concentration of a particular algal species, amounting to 1/2 million to 1 million cells per liter of water or more. (Britton and others, 1975).

Anoxic–Devoid of oxygen. (Britton and others, 1975).

Bedrock–A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material. (Bates and Jackson, 1980).

Benthic invertebrate–An animal without a backbone, living on or near the bottom of an aquatic environment. (Kuhn and others, 1983).

Biomass–The amount of living matter present in a unit area or volume, at any given time. (Dion and others, 1976).

Chlorophyll a–Chlorophyll *a* is a green photosynthetic pigment present in plant cells, including algae. The concentration of chlorophyll *a* in water is a commonly accepted indicator of algal biomass. (Dion and others, 1976).

Color–Color is one control of light transmission through water. High color values in many lakes result from the decomposition of vegetation, which gives the water a brown, tea-like color. Color is determined by a comparison of the water with standardized colored-glass discs and is reported in platinum-cobalt (Pt-Co) units. (Dion and others, 1976).

Discharge–In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the volume of the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean.

The data in the reports of the Geological Survey on surface water represent the total fluids measured. Thus, the terms discharge, streamflow, and runoff represent water with the solids dissolved in it and the sediment mixed with it. Of these terms, discharge is the most comprehensive. The discharge of drainage basins is distinguished as follows:

Yield–Total water runout or crop; includes runoff plus underflow.

Runoff–That part of water yield that appears in streams.

Streamflow–The actual flow in streams, whether or not subject to regulation, or underflow.

Each of these terms can be reported in total volumes (such as acre-feet) or time rates (such as cubic feet per second or acre-feet per year). The differentiation between runoff as a volume and streamflow as a rate is not accepted. (Langbein and Iseri, 1960).

Dolomite–A carbonate sedimentary rock of which more than 50 percent by weight or by areal percentages under the microscope consists of the mineral dolomite, or a variety of limestone or marble rich in magnesium carbonate. Dolomite occurs in crystalline and noncrystalline forms, is clearly associated and often interbedded with limestone, and usually represents a post depositional replacement of limestone. Pure dolomite (unless finely pulverized) will effervesce very slowly in cold hydrochloric acid. (Bates and Jackson, 1980).

Drainage area–The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide. (Langbein and Iseri, 1960).

Drainage basin–A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water. (Langbein and Iseri, 1960).

Epilimnion, epilimnetic–The upper, relatively warm, circulating zone of water in a thermally stratified lake. (Dion and others, 1976).

Eutrophication, eutrophic–The natural process of enrichment and aging of a body of water that may be accelerated by the activities of man. Pertains to water bodies in which primary production is high because of a large supply of available nutrients. (Dion and others, 1976).

Evaporation pan–An open tank used to contain water for measuring the amount of evaporation. The U.S. Weather Bureau class A pan is 4 feet in diameter, 10 inches deep, set up on a timber grillage so that the top rim is about 16 inches from the ground. The water level in the pan during the course of observation is maintained between 2 and 3 inches below the rim. (Langbein and Iseri, 1960).

Equal-width-increment (EWI) method–A cross-sectional water sample obtained by the EWI method requires a sample volume proportional to the amount of flow at each of several equally spaced verticals in the cross section. This equal spacing between the verticals (EWI) across the stream and sampling at an equal transit rate at all verticals yields a gross sample volume proportional to the total streamflow. (Edwards and Glysson, 1988).

Hardness–Water hardness is defined as the sum of the polyvalent cations expressed as the equivalent quantity of calcium carbonate ($CaCO_3$). As a general rule, hard-water lakes are more productive of plants and animals than soft-water lakes, but there are many exceptions. (Dion and others, 1976).

Hydrograph–A graph showing stage, flow, velocity, or other characteristics of water with respect to time. A stream hydrograph commonly shows rate of flow; a ground-water hydrograph, water level or head. (Bates and Jackson, 1980).

Hydrologic budget–An accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir; the relationship between evaporation, precipitation, runoff, and the change in water storage. (Bates and Jackson, 1980).

Hydrology–The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. (Langbein and Iseri, 1960).

Hypolimnion, hypolimnetic–The lower, relatively cold, noncirculating water zone in a thermally stratified lake. (Dion and others, 1976).

Internal recycling–The process by which phosphorus is recycled from the lake-bottom sediments under anaerobic or aerobic conditions by chemical exchange, turbulence, and the actions of aquatic organisms.

Load–The amount, by weight or volume, of a substance transported by a stream past a specific point during a specified length of time. (Kuhn and others, 1983).

Macrophyte–A megascopic plant, especially in an equatic environment. (Gary and others, 1972).

Maximum depth–The difference, in feet of elevation, between the bottom and the surface of the lake. (Dion and others, 1976).

Mean depth–The mean depth, in feet, for a specified lake stage, is obtained by dividing the volume of the lake by its area. (Dion and others, 1976).

Mesotrophic–Intermediate stage in lake classification between the oligotrophic and eutrophic stages, in which primary production occurs at a greater rate than in oligotrophic lakes, but at a lesser rate than in eutrophic lakes. This is due to a moderate supply of nutrients. (See also *Eutrophic* and *Oligotrophic*.) (Dion and others, 1976).

Metalimnion–The horizontal layer of a thermally stratified lake in which the temperature decreases rapidly with depth. The metalimnion lies between the *epilimnion* and the *hypolimnion*, and includes the thermocline. (Bates and Jackson, 1980).

Moraine–A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice, in a variety of topographic landforms that are independent of control by the surface on which the drift lies. (Bates and Jackson, 1980).

Nutrient–Any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes. (Dion and others, 1976).

Oligotrophic–Pertaining to waters in which primary production is low as a consequence of a small supply of available nutrients. (Britton and others, 1975).

pH–pH is the negative logarithm of the effective hydrogen-ion concentration, expressed as a number from 0 to 14. A pH of 7 is neutral, a pH of less than 7 is acidic, and a pH of greater than 7 is basic. (Dion and others, 1976).

Pitted outwash plain–A plain underlain by pitted outwash. Outwash with pits or kettles, produced by the partial or complete burial of glacial ice by outwash and the subsequent thaw of the ice and collapse of the surficial materials. (Bates and Jackson, 1980).

Plankton–The individual plant, animal, or bacterium in the plankton community. (Cole, 1979).

Quaternary–The second period of the Cenozoic era, following the Tertiary; also, the corresponding system of rocks. It began 2 to 3 million years ago and extends to the present. It consists of two grossly unequal epochs: the Pleistocene, up to about 8,000 years ago, and the Holocene since that time. The Quaternary was originally designated an era rather than a period, with the epochs considered to be periods, and it is still sometimes used as such in the geologic literature. The Quaternary may also be incorporated into the Neogene, when the Neogene is designated as a period of the Tertiary era. (Bates and Jackson, 1980).

Sediment–Fragmental material, both mineral and organic, that is in suspension or is being transported by the water mass or has been deposited on the bottom of the aquatic environment. (Dion and others, 1976).

Silurian–A period of the Paleozoic, thought to have covered the span of time between 440 and 400 million years ago; also, the corresponding system of rocks. The Silurian follows the Ordovician and precedes the Devonian; in the older literature, it was sometimes considered to include the Ordovician. (Bates and Jackson, 1980).

Species–The basic or final unit for the classification of organisms. (Dion and others, 1976).

Specific conductance–Specific conductance is a measure of the water's ability to conduct an electric current and is used as an approximation of the dissolved-solids concentration in the water. It is measured in units of microsiemens (formerly micromhos) per centimeter at 25° Celsius. (Dion and others, 1976).

Streamflow–The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation. (Langbein and Iseri, 1960).

Surface runoff–That part of the runoff that travels over the ground surface to the nearest stream without passing beneath the surface. (Bates and Jackson, 1980).

Surface water–Water on the surface of the earth. (Langbein and Iseri, 1960).

Thermal stratification (of a lake)–Vertical temperature stratification that shows the following: the upper layer of the lake, known as the epilimnion, in which water temperature is virtually uniform; a stratum next below, known as the thermocline, in which there is a marked drop in temperature per unit of depth; and the lowermost region or stratum, know as the hypolimnion, in which the temperature from its upper limit to the bottom is nearly uniform. (Langbein and Iseri, 1960).

Thermocline–The plane in a thermally stratified lake located at the depth where temperature decreases most rapidly with depth. (Bates and Jackson, 1980).

Trophic–Of or pertaining to nutrition. (Gary and others, 1972).

Water quality–That phase of hydrology that deals with the kinds and amounts of matter dissolved and suspended in natural water, the physical characteristics of the water, and the ecological relationships between aquatic organisms and their environment. (Dion and others, 1976).

Zooplankton, zooplanktonic–The animal part of the plankton. (Dion and others, 1976).