HYDROLOGY AND WATER QUALITY OF WIND LAKE IN SOUTHEASTERN WISCONSIN

By Stephen J. Field

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4107

Prepared in cooperation with the
WIND LAKE MANAGEMENT DISTRICT

Madison, Wisconsin
1993

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

CONTENTS

Page

CONTENTS--Continued

ILLUSTRATIONS

TABLES

Page

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter
inch (in.)	0.0254	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	kilograms per square kilometer
	Other Conversions	
micrograms per liter (µg/L)	0.001	milligrams 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.

HYDROLOGY AND WATER QUALITY OF WIND LAKE IN SOUTHEASTERN WISCONSIN

By Stephen J. Field

ABSTRACT

The hydrology and water quality of Wind Lake--a recreational lake in a densely populated area of southeastern Wisconsin was studied from October 1, 1987 through September 30, 1989.

A drought in 1988 affected the hydrologic budget of Wind Lake in water years 1988-89. Precipitation was 5.9 inches less than normal in water year 1988 but was 2.3 inches greater than normal in water year 1989. Streamflows were near normal in water year 1988 and 25 percent less than normal in water year 1989 as indicated by data from a nearby streamflow-gaging station. Surface runoff was the dominant source of water to the lake in water year 1988 and 75 percent of the inflow was from Big Muskego Lake.

The water level in Big Muskego Lake was 1.1 feet below the dam crest at the start of the 1989 water year because of the 1988 drought. About 2,510 acre-feet of water had to fill Big Muskego Lake before water could discharge to Wind Lake. In water year 1989, surface runoff was still the dominant source of water to the lake, but Big Muskego Lake only contributed 52 percent of the water inflow.

Streamflow dominated the outflow budget for both years. In water year 1988, 88 percent of the outflow budget left by way of Wind Lake outlet and 12 percent evaporated from the lake surface. In water year 1989, 81 percent of the outflow budget left by way of Wind Lake outlet and 19 percent evaporated from the lake surface. On the basis of outflow from Wind Lake for water year 1988, the hydraulic residence time was 0.46 year; in water year 1989 it was 1.05 years.

The total phosphorus input to Wind Lake from external sources was the same for both years, 3,160 pounds. The largest percentage of the phosphorus load came from Big Muskego Lake--70 percent in water year 1988 and 65 percent in water year 1989. Analysis of data by use of Vollenweider's model indicates that the phosphorus loadings for each year would cause eutrophic conditions. Data from a nearby gaging station indicate that phosphorus loading to Wind Lake was less than normal. Phosphorus retention in the lake is small and averages 14 percent of the incoming load for both years.

Oxygen depletion occurs in the bottom waters during winter and summer months. A maximum anoxic zone was reached on July 18, 1988, when depths greater than 15 feet (about 21 percent of the lake bottom area) were anoxic.

Total phosphorus concentrations at the lake surface for both years ranged from 11 to 78 micrograms per liter. Mean total phosphorus concentrations in June, July, and August that had averaged 49 micrograms per liter in 1985 through 1987 declined to 20 micrograms per liter in water year 1988 and 22 micrograms per liter in water year 1989. This reduction was related to the drought and reduced phosphorus loadings.

Phosphorus concentrations 1.5 feet above the lake bottom increase during summer anoxic periods. The phosphorus concentration increased at a rate of 5.2 and 4.8 micrograms per liter per day for total and dissolved orthophosphate phosphorus. A maximum concentration of 760 micrograms per liter of total phosphorus and 650 micrograms per liter of dissolved orthophosphate phosphorus occurred on September 21, 1988, just before autumn turnover. Internal loading of phosphorus for the period October 15, 1987 through October 14, 1988, was estimated to be 2,890 pounds. This represents 48 percent of the combined internal and external total-phosphorus input of 5,960 pounds.

Algal populations in water year 1988 ranged from 28,200 to 1,610,000 cells per milliliter. A total of 143 species were identified. Blue-green algae dominated the algal population and ranged from 56 percent (February 16, 1988) to 99 percent (five other sampling dates). *Aphanocapsa delicatissima* caused the largest algal bloom, which reached a maximum concentration of 934,000 cells per milliliter (September 7, 1988).

Zooplankton populations in water year 1988 ranged from 52.5 to 686 organisms per liter. Eigh-

teen species were identified. The cladoceran, *Daphnia*, dominated 12 of the 18 samples.

INTRODUCTION

Wind Lake is in Racine County in southeastern Wisconsin (fig. 1). It is close to large cities (Milwaukee immediately to the northeast, and Chicago, Ill., 75 mi (miles) to the southeast), and it is used extensively for recreation--swimming, fishing, and boating. Draining to Wind Lake from upstream is Big Muskego (Muskego) Lake, a shallow, **eutrophic**[1] lake with a surface area of 3.2 mi^2 (square miles) and a volume of 1,164 **acre-feet** at a water elevation of 771.5 ft (feet) above sea level (Wisconsin Department of Natural Resources, 1971). During 1965-78, recurring blooms of **blue-green algae** in Big Muskego Lake degraded water quality and resulted in fish kills. Kohler (1982) reported that mean concentrations of total phosphorus and dissolved orthophosphorus at sampling sites in Big Muskego Lake were 242 and 50 µg/l (micrograms per liter) in 1980.

Analyses of samples collected from Wind Lake periodically from February 1985 through August 1987 indicated that the water was unsuitable for most uses and that the lake could be classified as eutrophic. Depth profiles of dissolved oxygen, water temperature, **pH**, and **specific conductance** were measured in late February, April, June, July, and August. During periods of open water, water clarity and concentrations of phosphorus and **chlorophyll *a*** also were determined. The data from these samplings were used in the design of a subsequent investigation by the USGS, in cooperation with the Wind Lake Management District, to describe the **hydrology** and **water quality** of Wind Lake and its **drainage basin** and to determine the cause of the lake's poor quality.

The primary objectives of the study were to determine the phosphorus inputs to the lake from **surface water**, ground water, and precipitation. For the lake itself objectives were: (1) determine phosphorus loads from internal recycling (**water year** (WY) 1988 only), (2) to determine the chemical and physical characteristics of the lake water, (3) to identify the **phytoplankton** and **zooplankton** present, and (4) to determine the phosphorus discharges from the lake from surface and ground water. Determination of the hydrologic and phosphorus-input budgets required separation of the Wind Lake basin into five parts: Big Muskego Lake basin, Muskego Canal tributary basin, intervening area, shoreline drainage to Wind Lake, and the Wind Lake surface area (fig. 2).

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

Purpose and Scope

This report summarizes the results of the intensive data-collection program at Wind Lake and in its drainage basin from October 1, 1987 through September 30, 1989, and provides an evaluation and interpretation of the data. Phosphorus was the major constituent of interest in this study because previously collected (1985-87) in-lake water-quality data indicated that phosphorus was the **nutrient** limiting algal growth. Specifically, the report describes (1) the phosphorus inputs to the lake from surface water, ground water, and precipitation, (2) the phosphorus loads from internal recycling, (3) the chemical and physical characteristics of the lake water, (4) the phytoplankton and zooplankton present, and (5) the phosphorus **loads** associated with the surface-water and ground-water discharge.

Acknowledgments

Thanks are extended to the following people who contributed to the Wind Lake project: Mr. Neal O'Reilly, Wisconsin Department of Natural Resources, who helped in the design of the monitoring program; Ms. Kathy Aron, President of the Wind Lake Management District, who read the evaporation pan and rain gage and supervised field observer activities; and Mr. Edward Palmer and Ms. Jackie Bayer, who read rain gages.

PHYSICAL SETTING

The characteristics of Wind Lake and its drainage basin are listed in table 1.

LAKE CHARACTERISTICS

Wind Lake has an irregular shape with a shoreline of 9.3 mi and a surface area of 936 acres (Wisconsin Department of Natural Resources, 1969). A central island of 2.6 acres is covered with emergent vegetation. Another island of

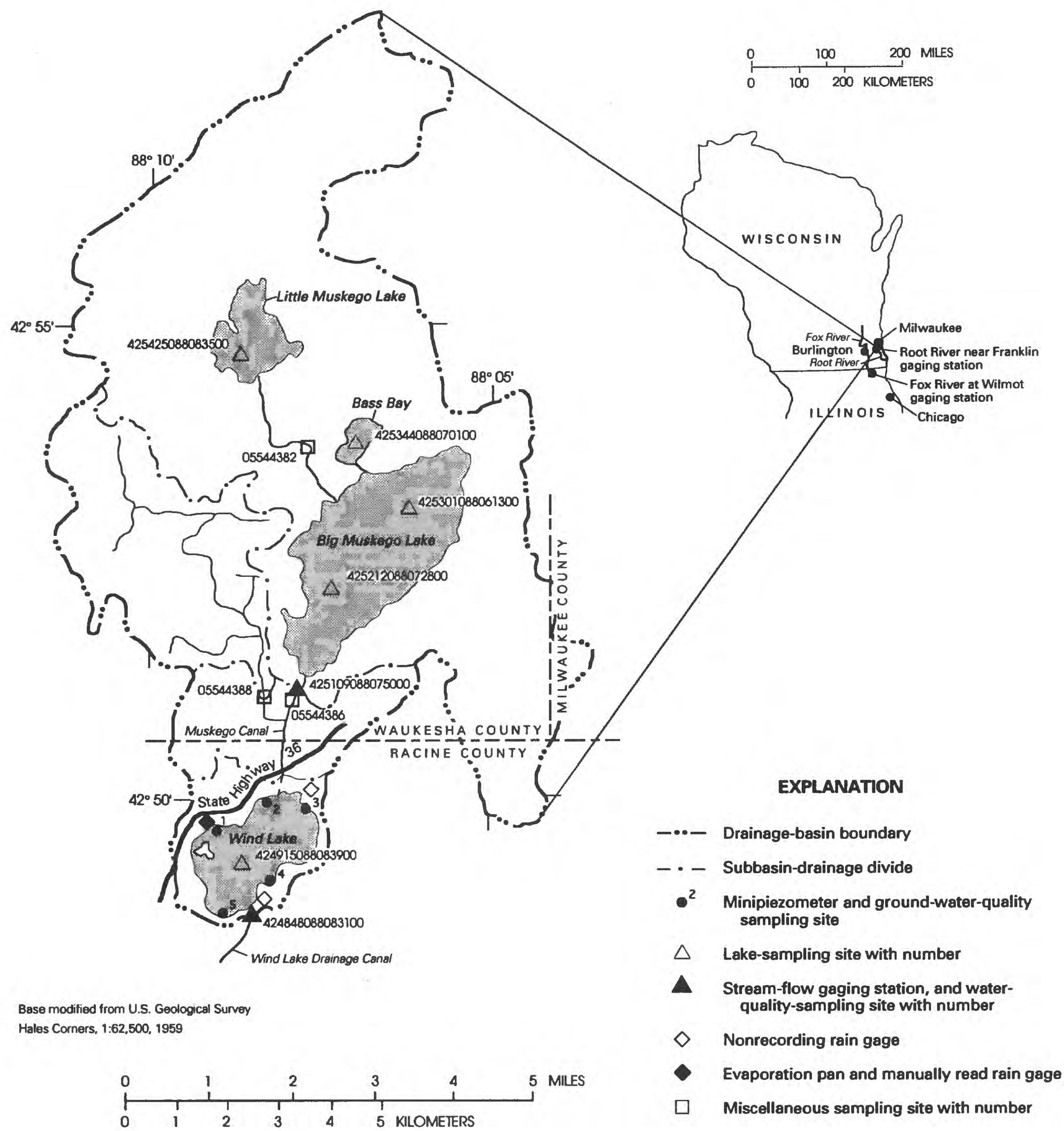


Figure 1. Wind Lake drainage basin and data-collection sites.

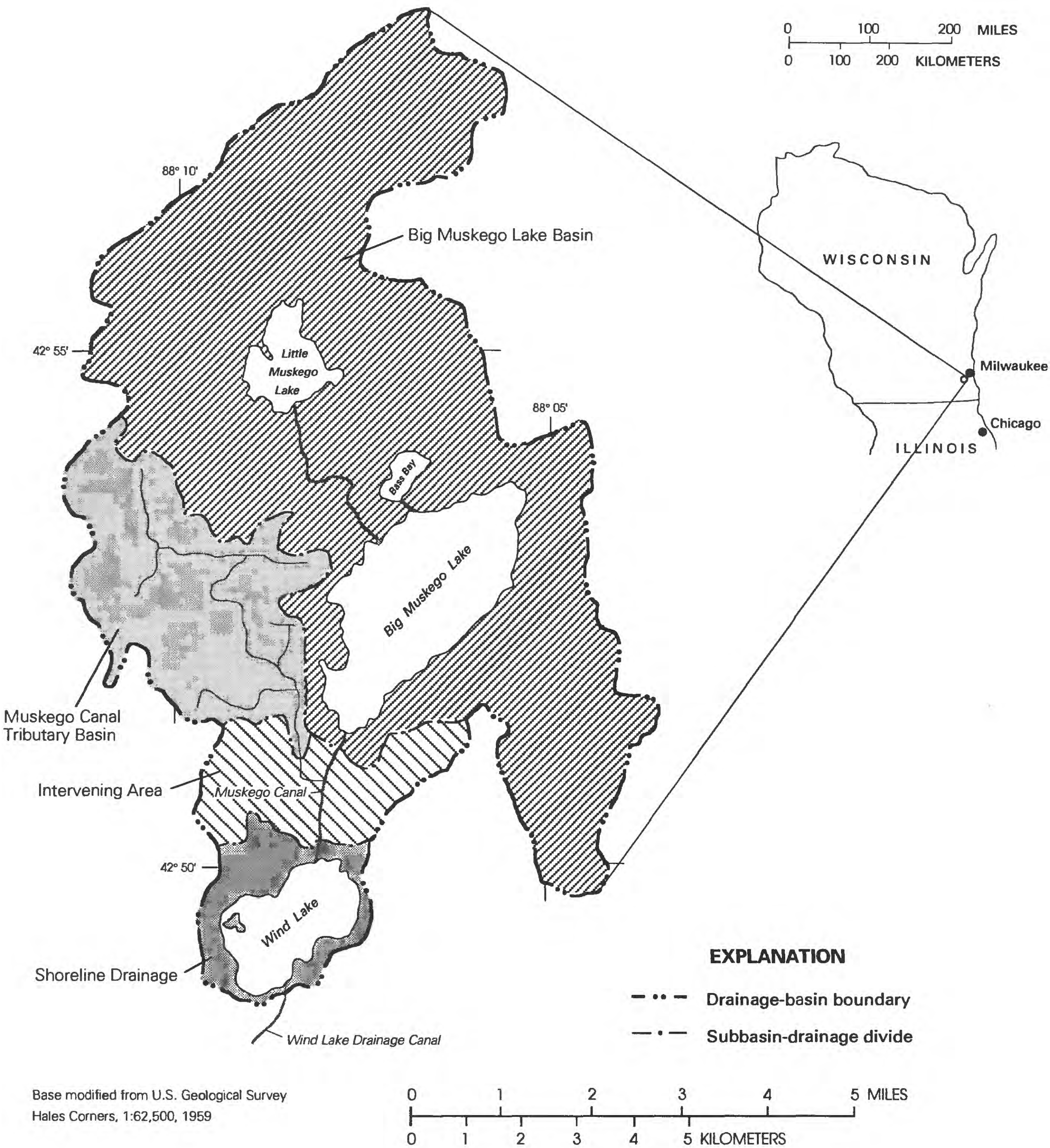


Figure 2. Wind Lake subbasins.

Table 1. Characteristics of Wind Lake and its drainage basin

Characteristic	Value
Drainage areas (square miles)	
Big Muskego Lake outlet	28.3
Tributary to Muskego Canal	5.7
Intervening area	2.7
Lake shoreline drainage	1.4
Lake surface area	1.5
Wind Lake outlet	39.6
Shape of lake (miles)	
Maximum length	1.9
Maximum width	1.1
Length of shoreline (miles)	9.3
Depth (feet)	
Maximum	52
Mean	9.5
Volume (acre-feet at lake stage of 768.61 feet above sea level)	8,995
Hydraulic residence time (years)	
1987 water year	0.46
1988 water year	1.05

16.5 acres borders the west shore and is partly wooded. Nearly one-third of the lake area is less than 3 ft deep, (fig. 3) and only one-eighth of the lake area is more than 20 ft deep. **Mean depth** is 9.5 ft and maximum depth is 52 ft.

Water level at the outlet of Wind Lake is controlled by a 30-foot-wide broad-crested concrete dam. During periods of high runoff, two 10-foot-wide tainter gates are manually raised to prevent the water level from rising too much.

Shoreline Characteristics

Soft **sediments** predominate along 53 percent of the shoreline, sand covers 25 percent, and rubble covers the remaining 22 percent (Wisconsin Department of Natural Resources, 1969). Sand and gravel usually dominate along wave-washed shores, where water turbulence suspends fine sediments. Fine sediments are deposited in areas at depths greater than 3 ft or where wave action has little effect. The lakebed consists of muck in shallow protected bays and at the eastern, shallow end of the lake, where vegetation is abundant. The shoreline of Wind Lake is densely developed. About 370 homes are within 300 ft of the shoreline (Kathy Aron, Wind Lake Management District, oral commun., 1990). The homes were sewered in 1978 and 1979 (Neal O'Reilly, Wisconsin Department of Natural Resources, written commun., 1988).

Drainage-Basin Characteristics

The Wind Lake drainage basin is characterized by moderate relief and gently undulating plains. The headwaters of the Wind Lake basin drain to Little Muskego Lake (fig. 1). Little Muskego Lake has a dam at the outlet, at which the water level of the lake is controlled. During winter months, the water level is drawn down about 1 ft from summer level. The lake has a surface area of 506 acres, a **maximum depth** of 65 ft, a mean depth of 14 ft, and a **drainage area** of 11.6 mi^2 at the outlet (Wisconsin Department of Natural Resources, 1969).

Little Muskego Lake drains into Big Muskego Lake. Streamflows downstream of Little Muskego Lake approach zero at times; a minimum flow of 0.05 ft^3/s was estimated on July 18, 1988 (U.S. Geological Survey, 1989).

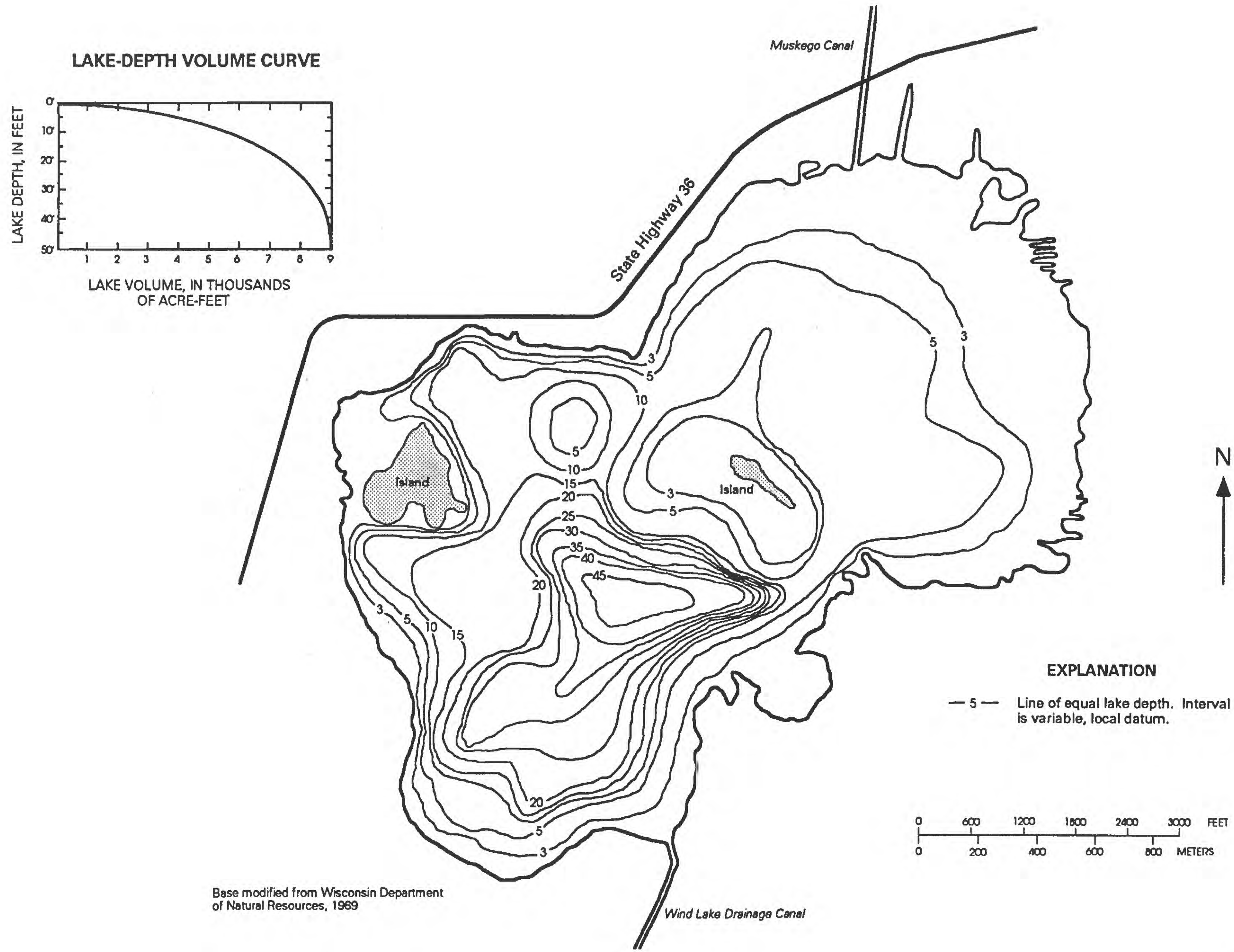


Figure 3. Lake-bottom contour (June 1969) and relation of depth to volume in Wind Lake.

Big Muskego Lake has a surface area of 2,070 acres, a maximum depth of 4 ft, a mean depth of 2.6 ft (Wisconsin Department of Natural Resources, 1971), and a drainage area at the outlet of 28.3 mi^2. The water level at the outlet of Big Muskego Lake is controlled by a 58-foot-wide broad-crested concrete dam. During periods of high runoff, a vertical-lift gate (5 ft wide, bottom withdrawal) is manually raised to prevent the water level from rising too much. During drought periods, the water level in the lake drops below the crest of the dam resulting in no flow from the lake.

Big Muskego Lake drains to Wind Lake through a dredged channel, Muskego Canal. Downstream from Big Muskego Lake, a fairly large unnamed tributary (drainage area, 5.7 mi^2) enters Muskego Canal from the west. Water drains from Wind Lake through another dredged channel, Wind Lake Drainage Canal to the Fox River (Illinois).

Water level at the outlet of Wind Lake is controlled by a broad-crested concrete dam and two 10-foot-wide tainter gates. These gates are manually adjusted when the water level in the lake becomes undesirably high. During winter, the water level is lowered from 0.75 to 1.0 ft below summer level to prevent ice damage to shoreline structures (Kathy Aron, Wind Lake Management District, oral commun., 1990).

Wind Lake was formed as ice of the Lake Michigan glacier receded from the area about 15,000 years ago during the late Wisconsin stage of glaciation (Alden, 1918). **Unconsolidated** glacial deposits, mainly of silty clay **till**, overlie **Silurian dolomite** throughout the basin (Green and Hutchinson 1965; Hutchinson, 1970). The till is overlain by **organic** deposits, formed during and after glaciation, in many of the low-lying parts of the basin around Wind and Big Muskego Lakes. Wind and Big Muskego Lakes occupy part of a large marsh, which was the site of a former body of water that became overgrown with peat-forming vegetation, the marsh subsequently was drained (Alden, 1918).

METHODS OF DATA COLLECTION AND ANALYSIS

All basic data except phytoplankton and zooplankton were published in the U.S. Geological Survey annual water data report for Wisconsin (U.S. Geological Survey, 1986, 1987, 1988, 1989, 1990).

Water-quality samples from Wind Lake and its tributaries were analyzed by the Wisconsin State Laboratory of Hygiene according to standard analytical methods (Wisconsin State Laboratory of Hygiene, 1980). Analyses for dissolved constituents were done on samples that were filtered in the field through a 0.45-μm (micrometer) filter. Chlorophyll *a* analyses are uncorrected for pheophytin--a natural degradation product of chlorophyll. Analyses for total or total recoverable constituents were done on raw water samples. Preservation and shipment of samples followed standard protocols established by the laboratory.

Streams

Water inflow to and outflow from the lake was computed from continuous record of stage and **discharge** measured at Big Muskego Lake outlet and Wind Lake outlet according to procedures outlined by Rantz and others (1982). Miscellaneous streamflow measurements were made at about 6-week intervals at other inflow sites (fig. 1). The stage record at Big Muskego and Wind Lake outlets served as a lake-stage record for the lakes.

Water samples for analysis of total phosphorus were collected at Big Muskego outlet by U.S. Geological Survey personnel on a 6-week interval and by a local observer during storms. Total-phosphorus samples from the Wind Lake surface collected above the deep hole (fig. 1) were assumed to represent the phosphorus concentration in water leaving Wind Lake by way of the outlet and were used to supplement samples collected at the outlet. Concentrations in samples collected concurrently from the outlet and from the surface at the center of the lake were similar. Flow-integrated samples were collected at the streamflow sites according to the equal-width-increment method described by Edwards and Glysson (1988). Phosphorus loads at each continuous-record station were computed according to the integration method described by Porterfield (1972).

Ground Water

Five small-diameter wells (0.5-in.-outside diameter) were installed about 10 ft from the shoreline (fig. 1). Well-water levels were measured monthly from May through September to determine whether ground water was discharging to or being recharged by the lake. Water-quality samples were collected in November 1987 from four wells to determine the phosphorus concentration of the ground water. The wells were similar to those described by Lee and Cherry (1978). The wells were driven into the lakebed to just beneath the organic sediment.

Precipitation and Evaporation

Rainfall quantity data were collected at three gages (fig. 1) during nonfreezing weather. Records from the National Weather Service station at Burlington (U.S. Department of Commerce, 1987, 1988, and 1989), 12 mi to the southwest, were used when these gages were not operating. No measurements of the phosphorus content of the precipitation were made. Instead, phosphorus concentrations were estimated on the basis of 1984-85 bulk-precipitation data collected at Delavan Lake, 30 mi southwest of Wind Lake (Field and Duerk, 1988).

Evaporation from the lake's surface was estimated from daily readings (during nonfreezing periods) of an **evaporation pan** at the northwestern edge of the lake (fig. 1). Pan data were not available for parts of April, October, and November (freezing periods). Evaporation values for these months include estimates based on interpolation for periods in the spring from ice-out to beginning of pan measurement, and in the fall from last pan measurement to lake freezeup. Evaporation during ice cover was assumed to be zero.

Lake Sampling

One site was sampled in the center of the lake at a depth of about 50 ft (fig. 1). The lake water column was sampled for chemical and physical characteristics and **plankton** population. The bottom sediment also was sampled.

Chemical and Physical Characteristics

Water-quality samples from the water column were collected with an Alpha Type or Kemmerer sampler. In WY 1988, samples were collected once a month in November through April and twice a month in October and May through September. In WY 1989, samples were collected once a month in October and March through September. Discrete samples were collected 1.5 ft below the water surface and 1.5 ft above the lakebed. Two to three additional samples were collected from above the lower but below the upper sampling points during **anoxic** periods.

Depth profiles of water temperature, dissolved-oxygen concentration, specific conductance, and pH were determined at the sampling frequency described above by use of a Hydrolab 4000 meter[2]. Before sampling, the meter was calibrated with reference to standard solutions for pH and specific conductance and to a Winkler titration for dissolved-oxygen concentration.

Plankton

Samples for phytoplankton and zooplankton were collected once a month in November through April and twice a month in October and May through September in WY 1988; samples were collected monthly in June, July, and August in WY 1989. Samples for phytoplankton were collected from the upper 3 ft of the lake with a Kemmerer sampler and were preserved with a 5 percent formalin solution. Samples for zooplankton were collected by vertically towing a Wisconsin Plankton net, mesh size 153 μm, through the oxygenated zone; only a single haul per site was used. These samples were preserved with an equal volume of 70 percent ethanol solution. Phytoplankton and zooplankton samples were analyzed by a private laboratory.

Bottom Sediments

A bottom-sediment core was collected at the deep hole (52 ft deep) during winter by use of a freeze corer similar to one described by Walkotten (1976). The freeze corer is an aluminum tube about 5 ft long and 2 in. in diameter with a

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

pointed lead plug at one end. The corer was weighted with lead and then filled with pelletized dry ice and ethanol. The corer was plugged at the top with a rubber stopper and dropped into the sediments. The corer remained in the sediment for about 5 minutes to allow the dry ice to freeze the sediment around the corer. The corer was raised to the surface, and the frozen sediment around the outside of the corer was removed by emptying the dry ice from the tube and filling the tube with lake water. The water thawed the sediment around the tube until the sediment could slide over the end of the corer. The frozen sediment was wrapped in aluminum foil, labeled, and preserved with dry ice. The core was then sliced with a steel-bladed bandsaw into individual segments for analysis.

HYDROLOGY

Determining the hydrology of Wind Lake involved measurement of precipitation and evaporation, monitoring lake-water levels, and determining the amount of streamflow and ground water entering and leaving the lake.

Precipitation

Precipitation totalled 27.6 in. in WY 1988 and was 35.8 in. in WY 1989. The monthly totals are shown below. The precipitation for the WY 1988 was 5.88 in. less than the long-term average of 33.48 in. at Burlington, Wis., 12 mi southwest of Wind Lake (fig. 1). In WY 1989, it was 2.33 in. greater than the long-term average (U.S. Dept. of Commerce, 1987, 1988, 1989).

The precipitation of 27.6 in. on the lake's surface in WY 1988 amounted to 2,180 acre-ft of water. In WY 1989, the precipitation of 35.81 in. on the lake's surface amounted to 2,830 acre-ft of water.

Evaporation

Evaporation from the lake's surface was calculated as 33.9 in. for the WY 1988 and 25.3 in. for WY 1989 on the basis of evaporation-pan data (table 2). An annual pan coefficient of 0.77 was used to determine the evaporation from the lake surface (U.S. Dept. of Commerce, 1982). The coefficient of 0.77 was determined by the National Oceanic and Atmospheric Administration for May through October. This coefficient was also applied to the April data for Wind Lake. The estimated evaporation from Wind Lake's surface area of 1.48 mi^2 was 2,680 acre-ft of water in WY 1988 and 2,000 acre-ft of water in WY 1989.

Lake Levels

Water-level fluctuations for Big Muskego and Wind Lakes are shown in figure 4 (as hydrographs of lake stage above an arbitrary datum). The water level of Big Muskego Lake fluctuated 2.24 ft in WY 1988, ranging from 10.03 ft on September 20 to 12.27 ft on February 2. In WY 1989, the water level fluctuated 1.55 ft, ranging from 10.48 ft on October 1 to 12.03 ft on March 29. At Wind Lake, the water level fluctuated 2.93 ft in WY 1988 ranging from 5.57 ft on February 26 to 8.5 ft during May 2-5. In WY 1989, the water level fluctuated 1.63 ft ranging from 6.90 ft on October 14, 16, 20, and 31 to 8.53 ft on September 1.

Annual net changes in water level at Wind Lake differed considerably between the two water years. In WY 1988, the water level dropped 1.39 ft from October 1 through September 30 for a net loss in volume of 1,320 acre-ft of water. In WY 1989, the water level increased 1.1 ft from October 1 through September 30 for a net gain in volume of 1,050 acre-ft of water.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Water Year 1988													
Precipitation	0.96	2.10	3.69	2.18	0.79	1.12	4.13	0.59	0.98	1.15	4.04	5.87	27.60
Water Year 1989													
Precipitation	3.15	4.70	1.52	0.68	0.48	2.69	1.15	1.32	1.64	7.70	2.96	7.82	35.81

Table 2. Evaporation data for Wind Lake, water years 1988-89

[All data are in inches except for pan coefficient, which is dimensionless]

Type of data	Water year 1988	Water year 1989
Evaporation-pan data:		
October	[1]1.95	[1]2.94
November	[2]1.0	[2]1.5
December	[2].3	.5
January	[2]0	[2]0
February	[2]0	[2]0
March	[2]0	[2]0
April	4.57	[2]3.0
May	7.16	5.18
June	8.83	5.15
July	8.38	7.04
August	6.96	4.08
September	4.85	3.43
Total	44.0	32.82
Pan coefficient	x0.77	x0.77
Evaporation	33.88	25.27

[1] Based on partial-month readings.
[2] Estimated.

Streamflow

Summaries of the **streamflow** characteristics for **streamflow-gaging station** in the Wind Lake basin and on the Fox and Root Rivers are listed in table 3[3]. Hydrographs of daily discharge for Big Muskego and Wind Lake outlets are shown in figure 5.

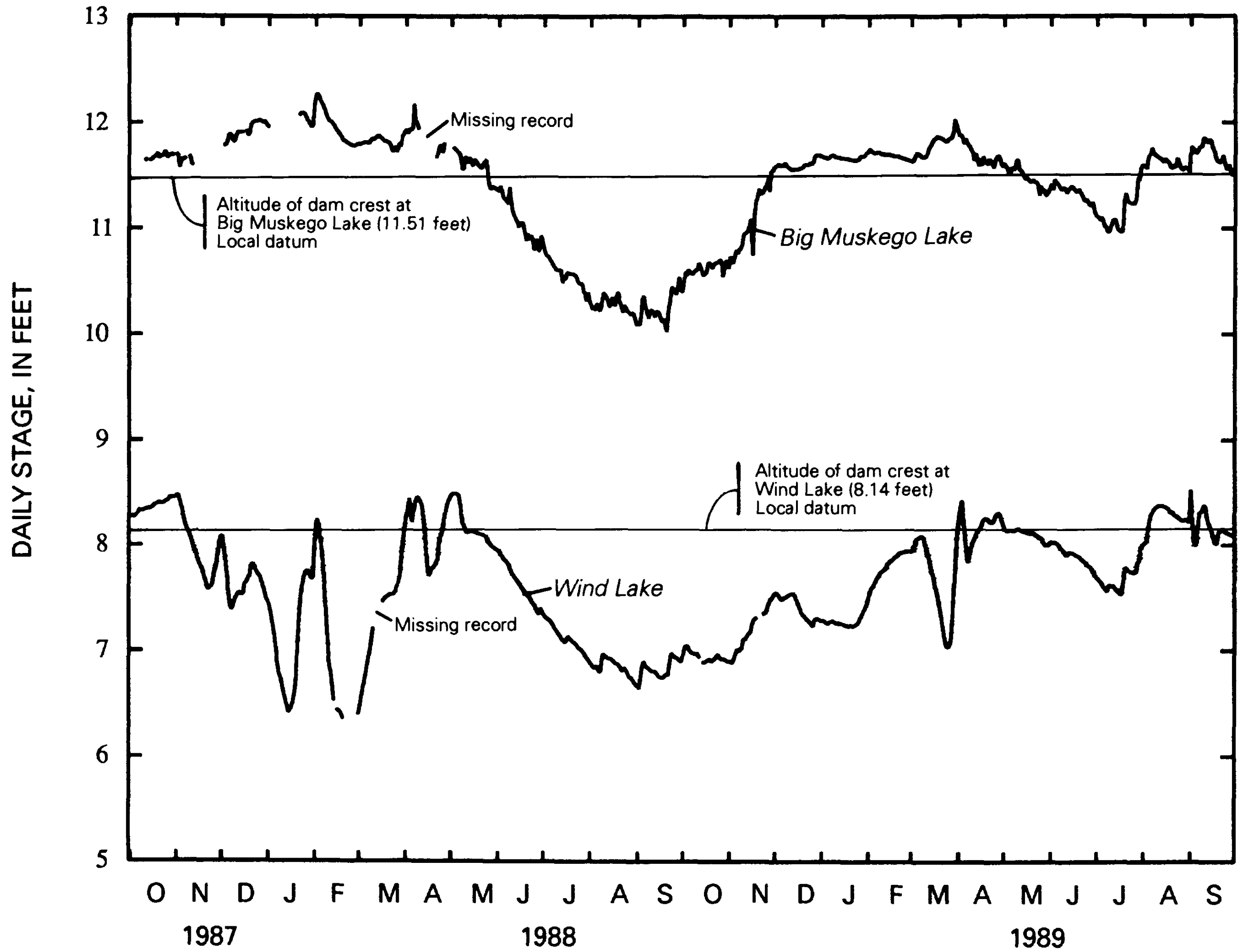
Fifty-one years of streamflow records for the Fox River at Wilmot (table 3) were used to evaluate the streamflow characteristics of Muskego and Wind Lake outlets. On the basis of these long-term data, the recorded streamflow for the Fox River was about normal for WY 1988 and 25 percent less than normal in WY 1989.

If maximum streamflows at nearby long-term gaging stations are assumed to be representative of the maximum streamflows at Big Muskego and Wind Lake outlets, then maximum flows at the outlets were not unusually high. The maximum instantaneous flows for the Root River near Franklin and Fox River at Wilmot for WY 1988 and 1989 were less than their mean annual floods computed from streamflow data through 1988 (William Krug, U.S. Geological Survey, written commun., 1990).

Although total precipitation in the Wind Lake basin was 8.2 in. greater in WY 1989 than in WY 1988, runoff conveyed by Big Muskego and Wind Lake outlets was less in WY 1989 than in WY 1988 (table 3). This reduced runoff was due to low water levels in Big Muskego and Wind Lakes at the end of WY 1988 and low ground-water levels.

The level of Big Muskego Lake on September 30, 1988, was 1.11 ft below the dam crest. On the basis of a lake-surface area of 2,260 acres (Wisconsin Department of Natural Resources, 1981), 2,510 acre-ft of water would have been required to fill the lake before water would discharge over the dam crest. There was zero or near zero flow [less than 0.05 ft^3/s (**cubic feet per second**)] over the dam crest from May 25 through Novem-

[3]The streamflow-gaging stations on Fox River at Wilmot and Root River near Franklin (fig. 1) are near the Wind Lake basin. The drainage area from the Fox River is very large (868 mi^2). Because the Root River adjoins the Wind Lake basin and is a smaller basin, the data from the Root River gaging station (drainage area, 49.2 mi^2) also are shown.



425109088075000 Muskego Lake outlet near Wind Lake, Wisconsin, mean daily discharge, in feet

424848088083100 Wind Lake outlet at Wind Lake, Wisconsin, mean daily discharge, in feet

Figure 4. Relation of lake stages to dam-crest altitudes of Big Muskego and Wind Lakes, water years 1988-89.

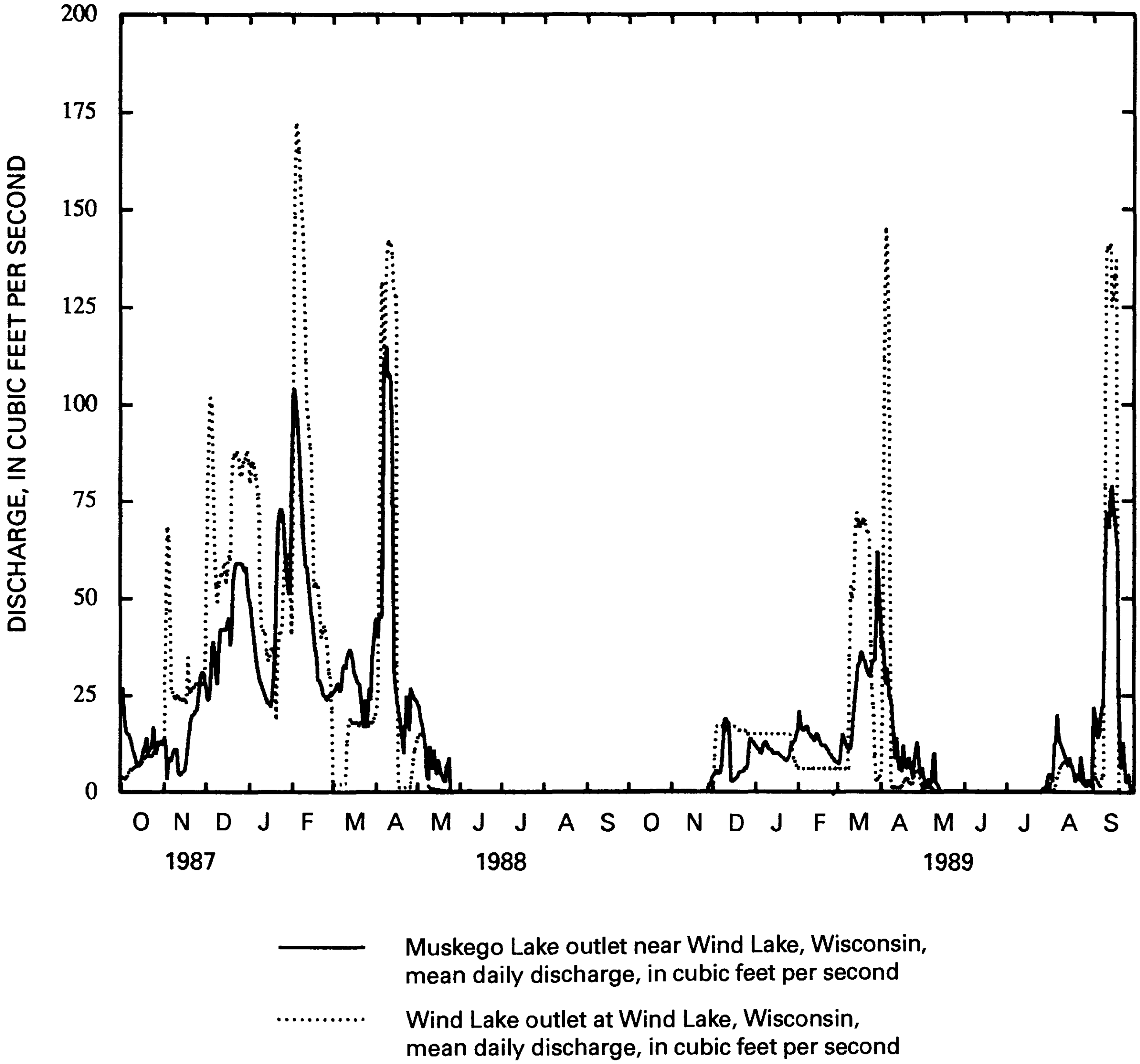


Figure 5. Streamflow at Big Muskego and Wind Lake outlets, water years 1988-89.

Table 3. Summary of streamflow characteristics and drainage area for Big Muskego Lake outlet, Unnamed Tributary to Muskego Canal, Wind Lake outlet, Fox River at Wilmot, and Root River near Franklin

[ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; --, not applicable]

Station name	Water year	Drainage area	Total discharge[1] (acre-feet)	Average discharge (ft^3/s)	Maximum instantaneous discharge (ft^3/s)	Minimum daily discharge (ft^3/s)	Average discharge per square mile [$(ft^3/s)/mi^2$]	Runoff (inches)
Short term								
Big Muskego Lake outlet	1988	28.3	15,000	20.7	115	0	0.73	9.95
	1989		6,820	9.4	79	0	.33	4.52
Unnamed Tributary to Muskego Canal	1988	5.7	1,580	2.2	12	0	.38	5.16
	1989		2,050	2.8	28	0	.49	6.72
Wind Lake outlet	1988	39.6	19,500	26.9	172	.20	.68	9.24
	1989		8,490	11.7	145	0	.30	4.02
Fox River at Wilmot	1988	868	391,000	539	2,390	65	.62	8.45
	1989		294,000	407	1,850	56	.47	6.36
Root River near Franklin	1988	49.2	25,700	35.4	470	1.6	.72	9.79
	1989		22,800	31.3	393	1.6	.64	8.64
Long term								
Fox River at Wilmot	1939-1989	868	--	546	7,520	35	--	8.54
Root River near Franklin	1964-1989	49.2	--	44.0	3,700	.38	--	12.14

[1]Total discharge is the sum of the daily discharges for the water year.

ber 27, 1988, from May 14 through July 26, 1989, and July 28 and 29, 1988.

The water level of Wind Lake on September 30, 1988, was 1.24 ft below the dam crest. Before water could flow over the dam, 1,160 acre-ft of water was required to fill the lake. Other than minor leakage through the tainter gates, water did not flow continuously from the lake until December 2, 1988. Zero or near zero flow [less than 0.5 ft^3/s] occurred from May 20 through December 1, 1988, from May 10 through August 4, 1989, and September 19 through September 30, 1989.

Ground-water levels in WY 1989 were lower than in WY 1988. At a water-table well 15 mi south of Big Muskego Lake, for example, the water level averaged 3.3 ft lower in WY 1989 than in WY 1988. Ground-water contributions to **base flow** reflect these lower ground-water levels. Base flow can be a large percentage of the total discharge for the year. A hydrographic separation of base flow and **surface runoff** was done for the Root River near Franklin by use of a technique described by Linsley, Kohler, and Paulhus (1975). The separation showed that WY 1988 base flow was 10,100 acre-ft or 39 percent of the annual total discharge. In WY 1989, base flow declined to 6,370 acre-ft or 28 percent of the annual total discharge.

The annual discharge from the unnamed tributary to Muskego Canal (fig. 2) was based on monthly discharge measurements (U.S. Geological Survey, 1989, 1990) and hydrographic comparison with the discharge at Big Muskego Lake outlet. The estimated annual runoff from this unnamed tributary for WY 1988 was 5.16 in., equivalent to 1,580 acre-ft or a **yield** of 276 acre-ft/mi^2. For WY 1989, the estimated annual runoff was 6.72 in., equivalent to 2,050 acre-ft or a yield of 358 acre-ft/mi^2. These runoff values were used to estimate runoff from the intervening area (fig. 2, table 3).

Runoff from the Wind Lake shoreline drainage (fig. 2) was estimated from the surface runoff at the Root River at Franklin gaging station which also partly drains an urban area. The hydrograph separation mentioned previously indicates that surface runoff--runoff that flows overland and enters the stream--was 5.93 in. (equivalent to 15,600 acre-ft of water or a yield of

316 acre-ft/mi^2) in WY 1988 and 6.21 in. (equivalent to 16,300 acre-ft of water or a yield of 331 acre-ft/mi^2) in WY 1989. If the above yields represent yields from shoreline drainage, then the surface runoff from the shoreline drainage from Wind Lake was 442 acre-ft of water in WY 1988 and 463 acre-ft of water in WY 1989.

Ground Water

Shallow ground water is present in unconsolidated glacial deposits and Silurian dolomite underlying the Wind Lake basin (Foley and others, 1953; Green and Hutchinson, 1965; Hutchinson, 1970). The regional flow of ground water is from the northwest to the southeast.

Five **piezometers** installed in the lake bed (fig. 1) were used to determine the direction of local ground-water flow near the lake from May through October 1988. The relation between the altitudes of the water levels in these wells and the lake surface for WY 1988 is shown in figure 6.

The hydraulic gradient between the lake bed and well screen for all wells except well 3, indicate ground-water recharge from the lake for the entire period of record. The gradient for well 3 indicates flow away from the lake during May and September and toward the lake during June and July. No gradient was apparent at the August reading.

Ground-water discharge from the lake was calculated by using the equation for Darcy's Law:

$$Q = K(dH/dL)A.$$

Values for the various parameters were determined as follows:

$$dH = H2-H1,$$

where

- H2 is the water-surface elevation of the lake, in feet;
- H1 is the ground-water hydraulic head at the screened interval of the piezometer, in feet;
- dL is the distance between the lake bottom and the midpoint of the piezometer screen, in feet;
- K is **hydraulic conductivity** in ft/d. The lake bed material underlying organic sediment is calcareous clay. Hydraulic conductivity ranges from 1 x 10^{-7} to 1 x 10^{-4} ft/d (Freeze and Cherry (1979), p.29).
- A is area in square feet. The area of the lake was divided into five sectors, each represented by a piezometer.

The water levels in the five piezometers and the lake stage were measured on May 25, June 21, July 18, August 23, and September 20.

Discharge from the lake was calculated for all sectors and measurement dates. Discharge values for each day between measurement dates were prorated between the calculated values. Daily values for each sector were summed to get total discharge. The total discharge volume for each sector based on lowest and highest possible hydraulic conductivity of the lakebed, from May 25 through September 30, is as follows:

Sector	Discharge volume for hydraulic conductivity: Highest [K = 1 x 10^{-7} ft/d] (acre-ft)	Lowest [K = 1 x 10^{-4} ft/d] (acre-ft)
1	8.34 x 10^{-4}	8.34 x 10^{-1}
2	6.67 x 10^{-4}	6.67 x 10^{-1}
3	1.05 x 10^{-4}	1.05 x 10^{-1}
4	1.26 x 10^{-4}	1.26 x 10^{-1}
5	2.89 x 10^{-4}	2.89 x 10^{-1}

The total calculated discharge volume from the lake to ground water for May 25 through September 30 was estimated to range from 0.002 to 2.02 acre-ft. A value of 1 acre-ft, which was about midway in the range, was arbitrarily chosen as the discharge volume for the period from May 25 through September 30. The total estimated ground-water discharge volume from the lake for the entire water year, 3 acre-ft, was determined, based on the assumption that discharge for the May 25 through September 30 period was the same as that for the entire water year. Measurement of water levels in the piezometers was discontinued in WY 1989 because the discharge from the lake to ground water was insignificant in comparison to the water leaving the lake through the Wind Lake outlet and by evaporation.

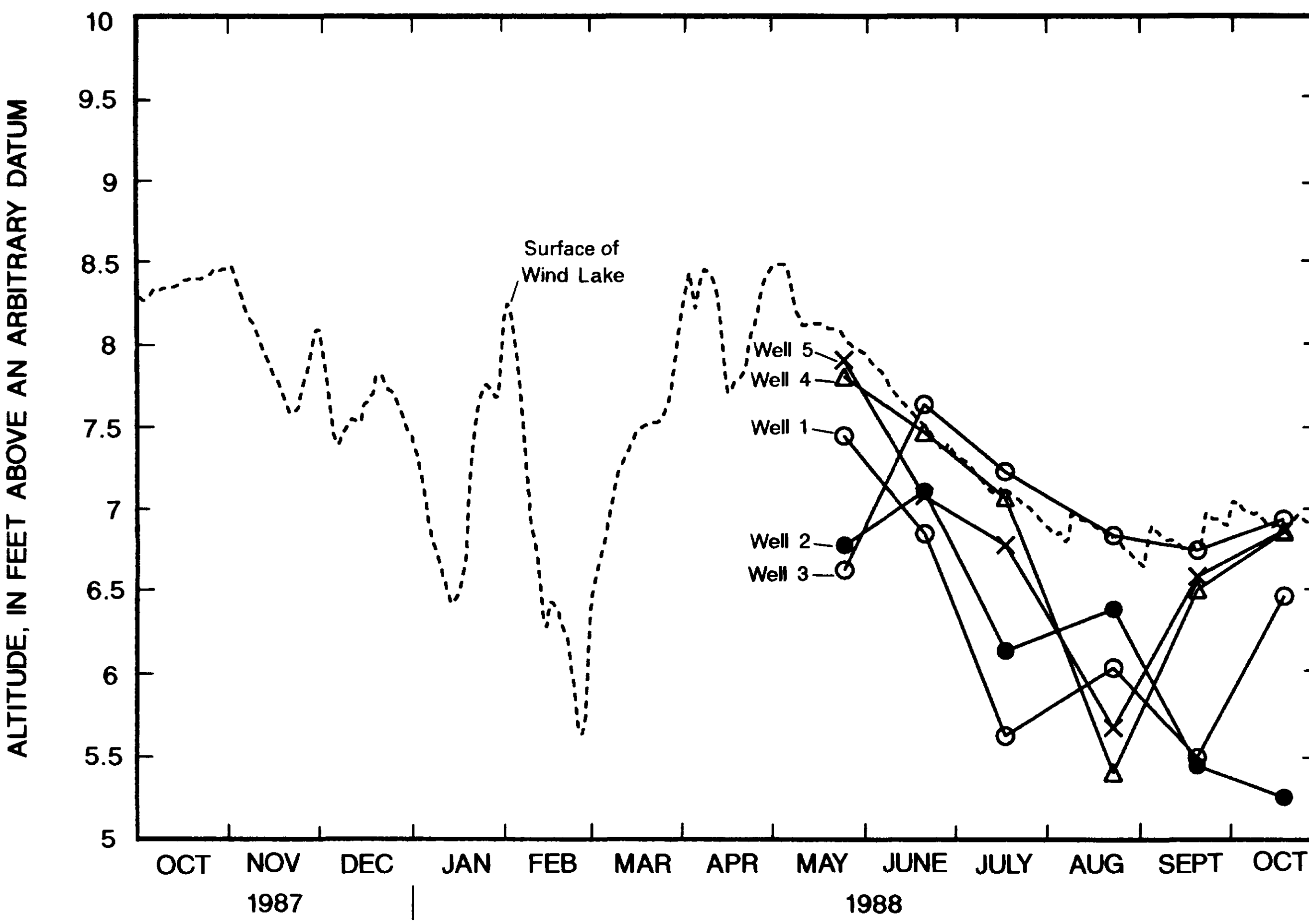


Figure 6. Relation between water level in wells within 10 feet of Wind Lake's shoreline and the lake's water surface.

Hydrologic Budget

The annual hydrologic budget for Wind Lake is conceptualized as follows:

Change in storage = inflow - outflow.

The budget can be rewritten as

Change in storage - inflow + outflow = 0.

The various terms considered are--

Change in storage = ΔS
Inflow = P + Qi
Outflow = Qo + E + 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, and

Go is ground-water outflow.

Therefore, the hydrologic budget for Wind Lake is written as

$$\Delta S - P - Qi + Qo + E + Go = 0.$$

A water budget (table 4) was calculated for WY 1988 and 1989 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 are associated with each term in the hydrologic-budget equation. To aid in evaluating these errors, the hydrologic budget can be written as

$$r = \Delta S - (P + Qi) + (Qo + E + Go).$$

where r is a net residual term.

The net residuals associated with WY 1988 and 1989 were 5 and 12 percent of the total inflow to the lake. Errors associated with 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.

The hydrologic budgets for WY 1988 and 1989 show that streamflow dominates inflow and outflow. Most of the inflow comes from Big Muskego Lake outlet (75 percent of the total inflow in WY 1988 and 52 percent in WY 1989). Most of the outflow comes from Wind Lake outlet (88 percent of the total outflow in WY 1988 and 81 percent of the total outflow in WY 1989).

Hydraulic Residence Time

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

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

The calculated hydraulic residence time for WY 1988, based on an outflow of 19,500 acre-ft, was 0.46 year. The hydraulic residence time for WY 1989, based on an outflow of 8,490 acre-ft, was 1.05 years. In contrast, Fowler Lake in Waukesha County, which has a small volume and a large stream inflow, had a mean hydraulic residence time of 7 days in 1984 (P.E. Hughes, U.S. Geological Survey, written commun., 1990).

WATER QUALITY

The water quality of Wind Lake is dependent on many variables. Most important are the water and nutrient changes that occur. The conditions during the study allowed for the formation of a stratified environment that controls the chemical and biological properties of the lake.

Phosphorus Budget

Phosphorus is the nutrient generally recognized as causing most algal problems in lakes. Phosphorus is therefore the single most important nutrient to quantify for inputs to and outputs from the lake.

Table 4. Hydrologic budget for Wind Lake, water years 1988-89

[--, not applicable or no data available]

	Water year 1988			Water year 1989	
	Percentage of total	Drainage area (square miles)	Volume (acre-feet)	Percentage of total	Volume (acre-feet)
Inflow					
Big Muskego Lake outlet	28.3	15,000	75	6,820	52
Muskego Canal tributary	5.7	1,580	8	2,050	16
Intervening area	2.7	745	4	972	7
Shoreline drainage	1.4	442	2	463	3
Precipitation on lake surface	1.5	2,180	11	2,830	22
Total inflow	39.6	19,947	100	13,135	100
Outflow					
Wind Lake outlet	39.6	19,500	88	8,490	81
Evaporation	--	2,680	12	2,000	19
Ground water	--	3	0	--	--
Total outflow	39.6	22,183	100	10,490	100
Change in storage--					
lake-volume decrease				-1,320	
lake-volume increase		+1,050			
Residual net:		r = 916 acre-feet		r = -1595 acre-feet	

Inputs

Wind Lake receives total phosphorus external inputs from streams, overland runoff, and precipitation. Ground water does not contribute phosphorus to Wind Lake.

Big Muskego Lake outlet

Phosphorus loads from Big Muskego Lake outlet (table 5) were calculated using the continuous discharge record from the station and the discrete samples collected. Phosphorus loads in WY 1988 and WY 1989 were 2,230 lb and 2,050 lb, respectively. These phosphorus loadings are low when compared to the loadings for Delavan Lake inlet (table 6). Delavan Lake is 25 mi southwest of Wind Lake; data for Delavan Lake are the only long-term phosphorus data available nearby.

On the basis of data for Delavan Lake inlet, phosphorus loadings to Big Muskego Lake in WY 1988 and 1989 were probably less than the long-term (WY 1984-89) annual average. At Muskego Lake outlet, loads in WY 1989 were less than in WY 1988 because of water (and phosphorus mass) that went into storage to refill Big Muskego Lake at the start of WY 1989.

Muskego Canal tributary

Phosphorus loads from Muskego Canal tributary (table 5) were based on phosphorus concentration from samples collected and streamflow measurements made by the USGS and a local observer. The phosphorus loads were estimated as 390 and 478 lb in WY 1988 and 1989.

Intervening area

Phosphorus loads from the intervening area (table 5) were based on yields from the Muskego Canal tributary of 68.4 and 83.9 lb/mi^2 (pounds per square mile) for WY 1988 and 1989. These yields amount to a phosphorus load from this area of 185 and 226 lb in WY 1988 and 1989.

Shoreline drainage

Surface runoff and phosphorus loads from the shoreline area (fig. 2) surrounding Wind Lake

Table 5. Phosphorus loads and yields in the Wind Lake basin

[--, not applicable; mi^2, square miles; lbs, pounds; lbs/mi^2, pounds per square mile]

		Total phosphorus			
		Water Year 1988		Water Year 1989	
Source	Drainage area (mi^2)	Load (lbs)	Yield (lbs/mi^2)	Load (lbs)	Yield (lbs/mi^2)
Big Muskego Lake outlet	28.3	2,230	78.8	2,050	72.4
Muskego Canal tributary	5.7	390	68.4	478	83.9
Intervening area[1]	2.7	185	68.4	226	83.9
Shoreline drainage	1.4	241	172	251	179
Precipitation[2]	1.5	119	--	154	--
Total	39.6	3,165	--	3,159	--
Wind Lake outlet	39.6	2,376	60.0	1,322	33.4

[1] Based on yield from Muskego Canal tributary.
[2] On surface of Wind Lake.

Table 6. Phosphorus loads and yields at Big Muskego Lake outlet and Delavan Lake inlet

[--, no data]

	Muskego Lake outlet			Delavan Lake inlet		
Water year	Phosphorus loads (pounds)	Phosphorus yield (pounds per square mile)	Precipitation (inches)	Phosphorus loads (pounds)	Phosphorus yield (pounds per square mile)	Precipitation (inches)
1984	--	--	--	7,040	323	32.0
1985	--	--	--	6,730	309	38.9
1986	--	--	--	15,100	693	51.2
1987	--	--	--	4,510	207	31.0
1988	2,230	78.8	27.6	1,400	64	29.1
1989	2,050	72.4	35.8	3,140	144	35.0

were not measured; therefore, the phosphorus load was estimated (table 5). Bannerman and others (1983) found a geometric mean total phosphorus concentration of 0.22 mg/L in runoff sampled in urban, medium-density, residential areas in Milwaukee, 10 mi northeast of Wind Lake, from June 1, 1980 through June 30, 1982.

On the basis of these data, a mean total phosphorus concentration of 0.2 mg/L was selected to represent that for the shoreline drainage. From this concentration and total water volumes of 442 and 463 acre-ft, respectively, for WY 1988 and 1989, total phosphorus loads of 240 and 250 lb were calculated. These loads represent yields of 170 and 180 lb/mi^2 in WY 1988 and 1989.

Precipitation

Total phosphorus concentrations in precipitation were not measured. The volume-weighted mean total phosphorus concentration of precipitation (0.02 mg/L) measured in Field and Duerk's (1988) study of the Delavan Lake basin for the WY 1984 and 1985 was used to estimate this concentration. Total phosphorus loading to Wind Lake from precipitation was 120 and 150 lb for WY 1988 and 1989.

Ground water

No ground water entered Wind Lake and, therefore, no phosphorus load was contributed by ground water.

Outputs

Phosphorus loads from Wind Lake outlet were calculated using the continous discharge record at the station and the surface samples collected in the lake. The total phosphorus loads leaving the lake through the outlet were 2,380 and 1,320 lb in WY 1988 and 1989. Insignificant phosphorus left by way of ground water because recharge to ground water from the lake was insignificant. The difference between the total input phosphorus load and the total phosphorus load from the outlet was incorporated into the sediments through sedimentation, 789 lb in WY 1988 and 1,830 lb in WY 1989.

Summary

Phosphorus budgets for both water years are shown in table 7. The budget for WY 1988 showed that 70 percent of the total phosphorus input of 3,165 lb came from Big Muskego Lake outlet. Big Muskego Lake outlet was also the principal contributor of phosphorus (65 percent of total input) in WY 1989. Phosphorus retention in the lake averaged 42 percent of the incoming load for both years. In WY 1988, 25 percent of the incoming total phosphorus load was retained in the lake; in WY 1989, 58 percent of the incoming total phosphorus load was retained.

Chemical, Physical and Biological Characteristics of the Water Column

Spring-turnover water-quality data for Wind Lake in April 1985-87 are shown in table 8. A pie diagram for water samples from April 18, 1986 (fig. 7), shows the proportions of major anions and cations. No spring-turnover analyses were done during the study period. Wind Lake water is hard, having an average **hardness** of 240 mg/L (as calcium carbonate). Principal dissolved constituents are calcium, magnesium, and bicarbonate (alkalinity), which collectively are 67 percent of the total dissolved constituents. Sodium, chloride, and sulfate comprise about equal parts of the balance; potassium accounts for only about 1 percent of the total.

Wind Lake stratifies in winter and summer (fig. 8). Stratification affects the chemical and biological properties of the lake. Temperature stratification, in particular, can affect life processes, chemical reactions, and the **solubility** of chemical constituents in water.

Water temperature and dissolved oxygen in Wind Lake will be discussed in detail, and pH and specific conductance will be discussed briefly; the depth profiles of these physical and chemical characteristics are shown in figure 8. Water-quality analyses for Wind Lake also are shown in this figure.

Water Temperature

Seasonal climatic factors affect the vertical distribution of temperatures in Wind Lake. Complete mixing of the lake is restricted by **thermal stratification** in the summer and by ice cover in the winter. Thermal stratification of

Table 7. Phosphorus budgets for Wind Lake, water years 1988-89

[--, not applicable]

	Drainage area (square miles)	Water year 1988		Water year 1989	
		Phosphorus (pounds)	Percentage of total	Phosphorus (pounds)	Percentage of total
Input					
Big Muskego Lake outlet	28.3	2,230	70	2,050	65
Muskego Canal tributary	5.7	390	12	478	15
Intervening area	2.7	185	6	226	7
Shoreline drainage	1.4	240	8	250	8
Precipitation on lake surface	1.5	120	4	150	5
Total inputs	39.6	3,165	100	3,154	100
Output					
Wind Lake outlet	39.6	2,376	75	1,322	42
Evaporation	--	0	--	--	--
Sedimentation	--	789	25	1,832	58
Total outputs	--	3,165	100	3,154	100

lake water is a result of differential heating, temperature-dependent variations in density, and wind-driven mixing. Water is unique among liquids because it reaches its maximum density (weight per unit volume) at about 4°C (degrees Celsius).

As summer begins, the lake surface absorbs the sun's energy and the upper layer of water is heated. Wind action and, to some extent, internal heat transfer transmit this energy to underlying water. A density "barrier" begins to form between the warmed water at the surface and the underlying denser, colder water. This barrier is marked by a sharp temperature gradient known as the thermocline. The zone where the thermocline develops, called the **metalimnion**, separates the **epilimnion**--the upper zone of warm water from the **hypolimnion**--the lower zone of colder, denser. Once stratification begins, the temperature of the hypolimnetic water changes little throughout the stratification period.

Wind Lake is strongly thermally stratified throughout the summer (fig. 8). The epilimnion is shallowest in late July when it extends from the water surface to a depth of about 13 ft; the metalimnion extends from 13 to about 30 ft and the hypolimnion extends from 30 ft to the lake bottom. The metalimnion is not a barrier to fish migration, but it inhibits the exchange of water between the hypolimnion and epilimnion and has a great effect on the chemical characteristics of, and biological activity in, the lake. The development of the thermocline begins in early summer, reaches its maximum in late summer, and disappears in the fall when air temperatures cool water at the lake surface and wind action results in the erosion of the thermocline (fig. 8).

As the lake surface cools, the water increases in density, sinks and mixes (because of wind action) until the entire column of water is a uniform temperature. This mixing, which follows summer stratification, is known as **autumn turnover**. When the water temperature drops below 4°C, the density of water again decreases and the water rises to the surface. Eventually the surface of the water is cooled until, at 0°C, ice forms, covers the surface of the lake, isolates the underlying water from the atmosphere, and prevents wind-driven mixing for 3 to 4 months. During the study period, ice cover lasted from December 17, 1987 through March 17, 1988, and

Table 8. Water-quality data for Wind Lake spring turnover, April 1985, 1986, and 1987

[concentrations in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; Pt-Co, platinum cobalt; NTU, Nephelometric units; µg/L, micrograms per liter; <, less than; --, no data]

	April 12, 1985		April 18, 1986		April 8, 1987	
Depth of sample (feet)	3	51	3	51.5	3	51
Lake stage (feet)	8.19		7.82		7.84	
Specific conductance	529	533	570	580	550	561
pH	8.6	8.5	9.2	8.6	8.3	8.5
Water temperature (degrees Celsius)	6.5	5.5	9.7	8.0	6.3	6.1
Color (Pt-Co. scale)	5	400	40	40	35	37
Turbidity (NTU)	1.5	1.1	5.6	12	3.2	3.2
Secchi-depth (meters)	1.2		.6		.7	
Dissolved oxygen	13.8	12.0	11.7	9.2	12.2	11.9
Hardness, as calcium carbonate	230	220	230	230	250	250
Calcium, dissolved	46	45	48	49	54	54
Magnesium, dissolved	27	26	27	27	29	29
Sodium, dissolved	25	25	23	24	22	22
Potassium, dissolved	2.3	2.2	2.7	2.7	3.3	3.3
Alkalinity, as calcium carbonate	159	158	161	161	191	191
Sulfate, dissolved	50	50	70	70	46	45
Fluoride, dissolved	.3	.3	.2	.2	.2	.2
Chloride, dissolved	49	49	48	48	41	40
Silica, dissolved	<.01	.02	.06	.08	.22	.22
Solids, dissolved, at 180 degrees Celsius	335	331	346	340	334	334
Nitrogen, nitrate, total (as N)	.39	.39	.38	.38	.09	.09
Nitrogen, nitrite, total (as N)	.01	.01	.02	.02	<.01	<.01
Nitrogen, nitrite + nitrate, total (as N)	.40	.40	.40	.40	.10	.10
Nitrogen, ammonia, total (as N)	.21	.21	.10	.13	.10	.09
Nitrogen, organic, total (as N)	.99	.59	1.4	1.4	1.6	1.6
Nitrogen, ammonic + organic, total (as N)	1.20	0.80	1.50	1.50	1.70	1.70
Nitrogen, total (as N)	1.6	1.2	1.9	1.9	1.8	1.8
Phosphorus, total (as P)	.037	.047	.067	.073	.087	.084
Phosphorus, ortho, dissolved (as P)	<.001	.003	.003	.003	.003	<.001
Iron, dissolved µg/L	14	14	24	9	11	12
Manganese, dissolved µg/L	2	3	11	4	2	2
Chlorophyll *a*, phytoplankton (µg/L)	1.8	--	58	--	35	--

WATER-QUALITY DATA, APRIL 1985, 1986, 1987

Concentrations in milligrams per liter unless otherwise indicated; ms/cm, microsiemens per centimeter; pt-co, platinum cobalt; NTU, Nephelometric units; diss., dissolved; mg/L, micrograms per liter

STATION: 424915088083900

	April 12, 1985		April 18, 1986		April 8, 1987	
Depth of sample (ft)	3.0	51	3.0	52	3.0	51
Lake stage (ft)	8.19		7.82		7.84	
Specific conductance (S/cm)	529	533	570	580	550	561
pH (units)	8.6	8.5	9.2	8.6	8.3	8.5
Water temperature (°C)	6.5	5.5	9.5	8.0	6.5	6.0
Color (Pt-Co. scale)	5	400	40	40	35	37
Turbidity (NTU)	1.5	1.1	5.6	12	3.2	3.2
Secchi-depth (meters)	1.2		0.6		0.7	
Dissolved oxygen	13.8	12.0	11.7	9.2	12.2	11.9
Hardness, as $CaCO_3$	230	220	230	230	250	250
Calcium, dissolved (Ca)	46	45	48	49	54	54
Magnesium, dissolved (Mg)	27	26	27	27	29	29
Sodium, dissolved (Na)	25	25	23	24	22	22
Potassium, dissolved (K)	2	2	3	3	3	3
Alkalinity, as $CaCO_3$	160	160	160	160	190	190
Sulfate, dissolved (SO_4)	50	50	70	70	46	45
Chloride, dissolved (Cl)	49	49	48	48	41	40
Fluoride, dissolved (F)	0.3	0.3	0.2	0.2	0.2	0.2
Silica, dissolved (SiO_2)	<0.0	0.0	0.1	0.1	0.2	0.2
Solids, dissolved, at 180°C	335	331	346	340	334	334
Nitrogen, nitrate, total (as N)	0.39	0.39	0.38	0.38	---	---
Nitrogen, nitrite, total (as N)	0.01	0.01	0.02	0.02	<0.01	<0.01
Nitrogen, NO_2 + NO_3, total (as N)	0.40	0.40	0.40	0.40	0.10	0.10
Nitrogen, ammonia, total (as N)	0.21	0.21	0.10	0.13	0.10	0.09
Nitrogen, organic, total (as N)	0.99	0.59	1.4	1.4	1.6	1.6
Nitrogen, amm. + org., total (as N)	1.2	0.80	1.5	1.5	1.7	1.7
Nitrogen, total (as N)	1.6	1.2	1.9	1.9	1.8	1.8
Phosphorus, total (as P)	0.037	0.047	0.067	0.073	0.087	0.084
Phosphorus, ortho, dissolved (as P)	<0.001	0.003	0.003	0.003	0.003	<0.001
Iron, dissolved (Fe) g/L	14	14	24	9	11	12
Manganese, dissolved (Mn) g/L	2	3	11	4	2	2
Chlorophyll a, phytoplankton (g/L)	1.8	---	58	---	35	---

Composition of lake water, April 18, 1986

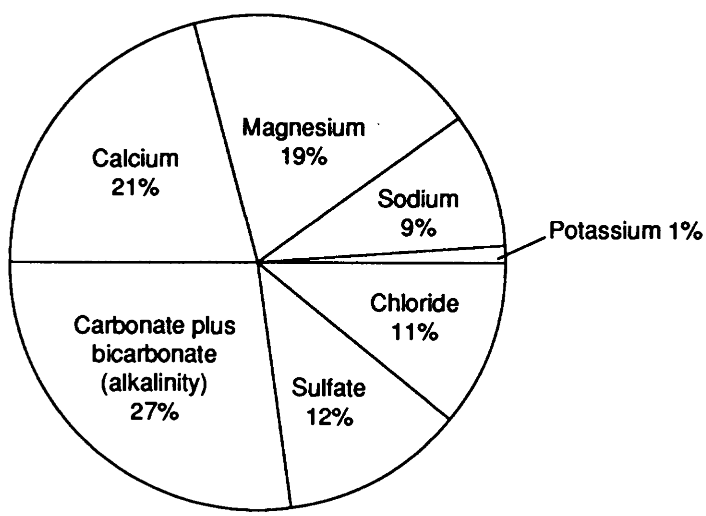


Figure 7. Composition of Wind Lake water, April 18, 1986, and water-quality data for spring turnover, April 1985, 1986, and 1987.

WATER QUALITY DATA, WATER YEAR OCTOBER 1987 TO SEPTEMBER 1988

(Concentration in milligrams per kilogram (mg/kg) unless otherwise indicated; µg/g, micrograms per gram)

DATE	TIME	DEPTH TO TOP OF SAMPLE INTER-VAL (IN FEET)	DEPTH TO BOT-TOM OF SAMPLE INTER-VAL(IN FEET)	MOIS-TURE CONTENT DRY WT. (% OF TOTAL (00495)	NITRO-GEN, NO2+NO3 TOT. IN BOT MAT (MG/KG AS N) (00633)	NITRO-GEN,NH4 TOTAL IN BOT. MAT. (MG/KG AS N) (00611)	NITRO-GEN,NH4 + ORG. TOT. IN BOT MAT (MG/KG AS N) (00626)	PHOS-PHOROUS TOTAL IN BOT. MAT. (MG/KG AS P) (00668)	IRON, RECOV. FM BOT-TOM MA-TERIAL (UG/G AS FE) (01170)	MANGA-NESE, RECOV. FM BOT-TOM MA-TERIAL (UG/G) (01053)
JAN 1988										
28...	1200	0.0	0.33	85	<10	910	11000	1100	14000	990
28...	1201	0.33	0.83	84	--	--	--	1000	14000	990
28...	1202	0.83	1.33	83	--	--	--	940	15000	990
28...	1203	1.33	1.83	79	--	--	--	860	15000	1100

WATER-QUALITY DATA, OCTOBER 15 TO DECEMBER 10, 1987

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	Oct. 15		Oct. 29		Nov. 17		Dec. 10		
Depth of sample (ft)	1.5	51	1.5	51	1.5	51	1.5	51	54
Lake stage (ft)	8.36		8.46		7.79		7.50		
Specific conductance (µS/cm)	540	594	545	636	538	539	541	547	546
pH (units)	8.0	6.6	8.6	6.8	8.4	8.4	8.3	8.3	8.3
Water temperature (°C)	11.0	10.5	8.0	7.5	7.0	7.0	2.5	2.5	2.5
Secchi-depth (meters)	1.1		1.4		1.0		1.4		
Dissolved oxygen	8.7	0.6	10.0	4.7	10.7	10.4	11.7	11.6	2.5
Phosphorus, total (as P)	0.045	0.054	0.037	0.032	---	0.038	0.031	0.030	0.034
Phosphorus, ortho, dissolved (as P)	---	0.016	---	0.007	---	---	---	---	<0.004
Chlorophyll a, phytoplankton (µg/L)	9.0	---	9.0	---	23	---	12	---	---

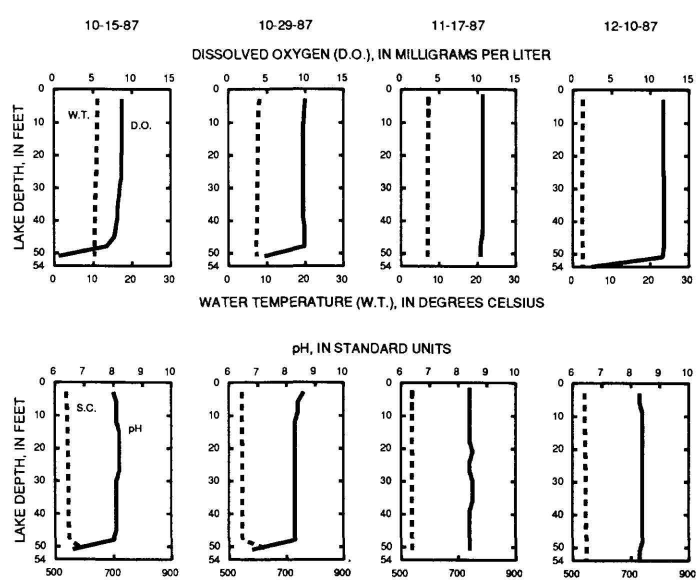


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89.

WATER-QUALITY DATA, JANUARY 28 TO APRIL 8, 1988

(Concentration in milligrams per liter unless otherwise indicated; μS/cm, microsiemens per centimeter; μg/L, micrograms per liter; °C, degrees Celsius)

	Jan. 28			Feb. 16			Apr. 08	
Depth of sample (ft)	1.5	42	48	1.5	44	48	1.5	48
Lake stage (ft)		7.72			6.43		8.46	
Specific conductance (μS/cm)	603	735	736	590	743	749	564	569
pH (units)	7.4	7.4	7.4	7.5	7.3	7.1	8.3	8.1
Water temperature (°C)	2.0	2.0	2.0	2.0	2.5	2.5	10.0	8.5
Secchi-depth (meters)		0.6			0.6		0.9	
Dissolved oxygen	10.4	7.2	2.7	14.4	0.0	0.0	11.0	9.6
Nitrogen, NO2 + NO3, diss. (as N)	---	---	---	---	---	---	0.27	0.26
Nitrogen, ammonia, dissolved (as N)	---	---	---	---	---	---	0.15	0.21
Nitrogen, amm. + org., total (as N)	---	---	---	---	---	---	1.6	1.5
Phosphorus, total (as P)	0.038	0.096	0.410	0.077	0.118	0.600	0.056	0.042
Phosphorus, ortho, dissolved (as P)	---	---	0.109	---	---	0.384	<0.001	<0.001
Chlorophyll _a_, phytoplankton (μg/L)	64	---	---	65	---	---	25	---

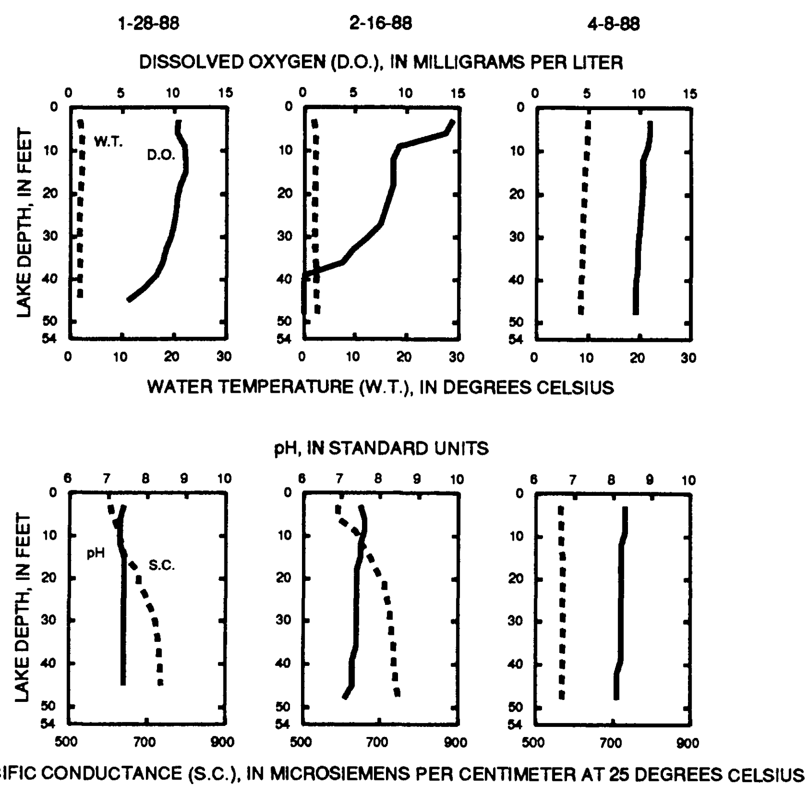


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

WATER-QUALITY DATA, MAY 2 TO MAY 25, 1988

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	May 02			May 11				May 25			
Depth of sample (ft)	1.5	44	48	1.5	21	42	48	1.5	27	42	50
Lake stage (ft)	8.49			8.12				8.05			
Specific conductance (µS/cm)	553	556	556	563	566	562	563	556	563	570	570
pH (units)	8.4	8.0	8.0	8.3	8.1	7.6	7.6	8.7	8.4	7.6	7.6
Water temperature (°C)	15.5	9.5	9.5	15.0	14.0	9.5	9.5	17.0	14.0	10.0	10.0
Secchi-depth (meters)	0.9			1.1				1.0			
Dissolved oxygen	11.2	7.6	7.5	8.1	6.0	3.1	2.5	9.0	1.9	0.1	0.1
Phosphorus, total (as P)	0.044	0.015	0.015	0.024	0.022	0.046	0.044	0.014	0.049	0.113	0.097
Phosphorus, ortho, dissolved (as P)	---	---	0.004	---	---	---	0.022	---	---	---	0.101
Chlorophyll _a_, phytoplankton (µg/L)	9.0	---	---	8.0	---	---	---	7.0	---	---	---

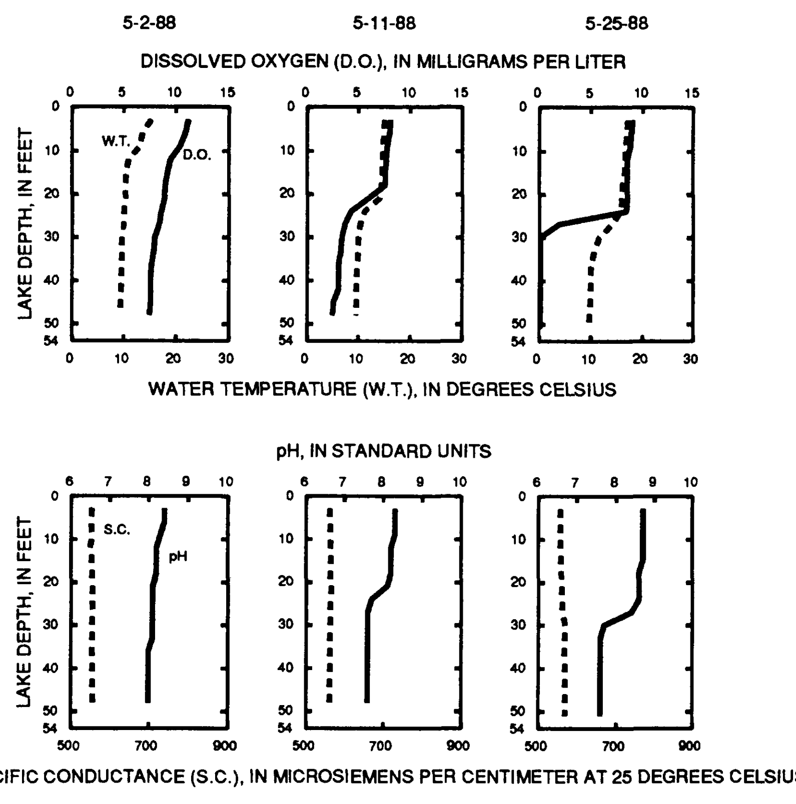


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

WATER-QUALITY DATA, JUNE 7 TO JULY 18, 1988

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	June 07				June 22				
Depth of sample (ft)	1.5	18	39	47	1.5	15	33	44	49
Lake stage (ft)	7.83				7.50				
Specific conductance (µS/cm)	536	558	569	574	542	560	590	591	594
pH (units)	8.8	8.3	7.5	7.4	8.7	8.3	7.4	7.3	7.3
Water temperature (°C)	23.0	19.0	10.5	10.0	25.0	22.5	11.5	10.5	10.5
Secchi-depth (meters)	0.9				0.9				
Dissolved oxygen	11.2	4.5	0.2	0.2	7.8	3.9	0.2	0.2	0.2
Phosphorus, total (as P)	0.011	0.050	0.170	0.180	0.028	0.016	0.113	0.198	0.300
Phosphorus, ortho, dissolved (as P)	---	---	---	0.137	---	---	---	---	0.248
Chlorophyll a, phytoplankton (µg/L)	8.0	---	---	---	14	---	---	---	---

	July 06					July 18			
Depth of sample (ft)	1.5	24	33	46	50	1.5	15	39	48
Lake stage (ft)	7.28					7.12			
Specific conductance (µS/cm)	539	564	590	596	600	537	556	596	598
pH (units)	8.7	7.6	7.1	7.0	7.0	8.5	7.7	7.1	7.1
Water temperature (°C)	27.5	19.0	12.0	11.0	11.0	26.5	23.5	11.5	11.0
Secchi-depth (meters)	1.1					1.1			
Dissolved oxygen	10.8	0.0	0.0	0.0	0.0	8.5	0.2	0.4	0.4
Phosphorus, total (as P)	0.015	0.026	0.142	0.330	0.380	0.012	0.040	0.360	0.440
Phosphorus, ortho, dissolved (as P)	---	---	---	---	0.310	---	---	---	0.340
Chlorophyll a, phytoplankton (µg/L)	8.0	---	---	---	---	12	---	---	---

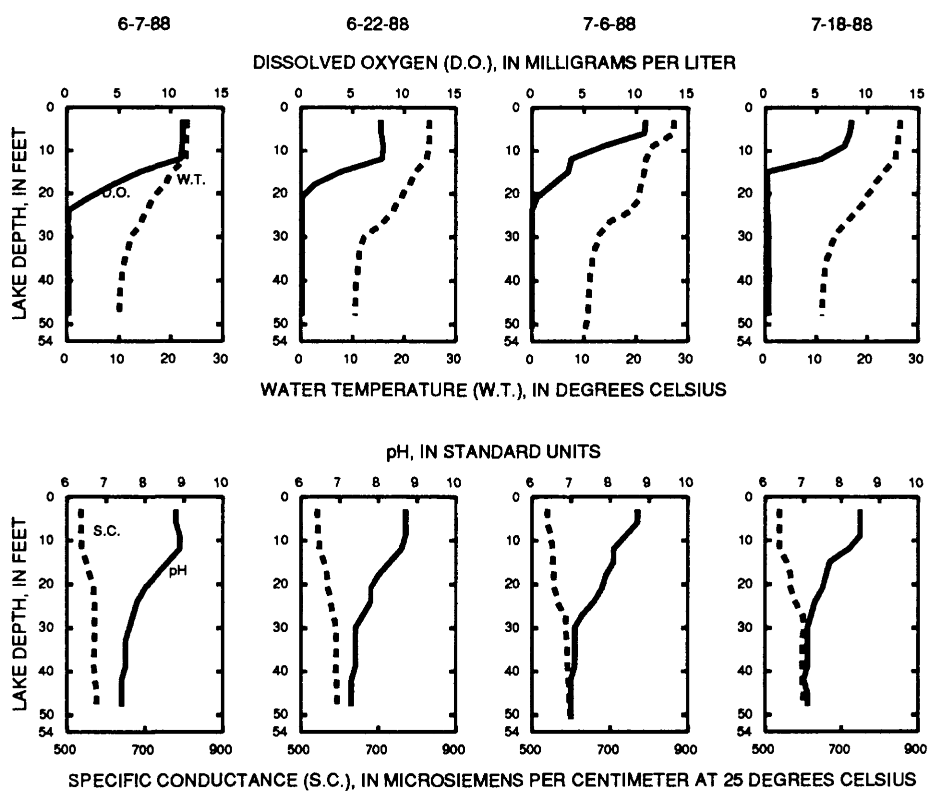


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

WATER-QUALITY DATA, AUGUST 10 TO SEPTEMBER 21, 1988

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	Aug. 10					Aug. 23				
Depth of sample (ft)	1.5	15	33	42	47	1.5	18	30	44	48
Lake stage (ft)	6.96					6.84				
Specific conductance (µS/cm)	525	542	607	612	615	522	530	604	619	621
pH (units)	8.5	8.0	7.0	7.0	6.9	8.5	8.1	7.0	6.9	6.9
Water temperature (°C)	26.5	25.5	13.0	11.5	11.5	24.0	23.5	13.5	11.5	11.5
Secchi-depth (meters)	1.1					0.8				
Dissolved oxygen	8.1	1.2	0.0	0.0	0.0	6.8	3.3	0.0	0.0	0.0
Phosphorus, total (as P)	0.029	0.029	---	0.500	0.530	0.023	0.030	0.340	0.560	0.600
Phosphorus, ortho, dissolved (as P)	0.005	0.006	0.310	0.470	0.510	0.004	0.004	0.310	0.470	0.540
Chlorophyll *a*, phytoplankton (µg/L)	17	---	---	---	---	14	---	---	---	---

	Sep. 07				Sep. 21			
Depth of sample (ft)	1.5	27	36	46	1.5	39	45	48
Lake stage (ft)	6.85				6.77			
Specific conductance (µS/cm)	538	545	631	648	531	569	633	637
pH (units)	8.4	8.1	7.0	6.9	8.2	7.1	6.9	6.9
Water temperature (°C)	19.0	18.0	12.5	11.5	18.0	16.0	12.0	12.0
Secchi-depth (meters)	1.0				1.1			
Dissolved oxygen	8.9	6.3	0.4	0.3	7.2	0.3	0.3	0.3
Phosphorus, total (as P)	0.027	0.048	0.470	0.640	0.078	0.260	0.690	0.760
Phosphorus, ortho, dissolved (as P)	0.004	0.006	0.440	0.630	---	---	---	0.650
Chlorophyll *a*, phytoplankton (µg/L)	14	---	---	---	13	---	---	---

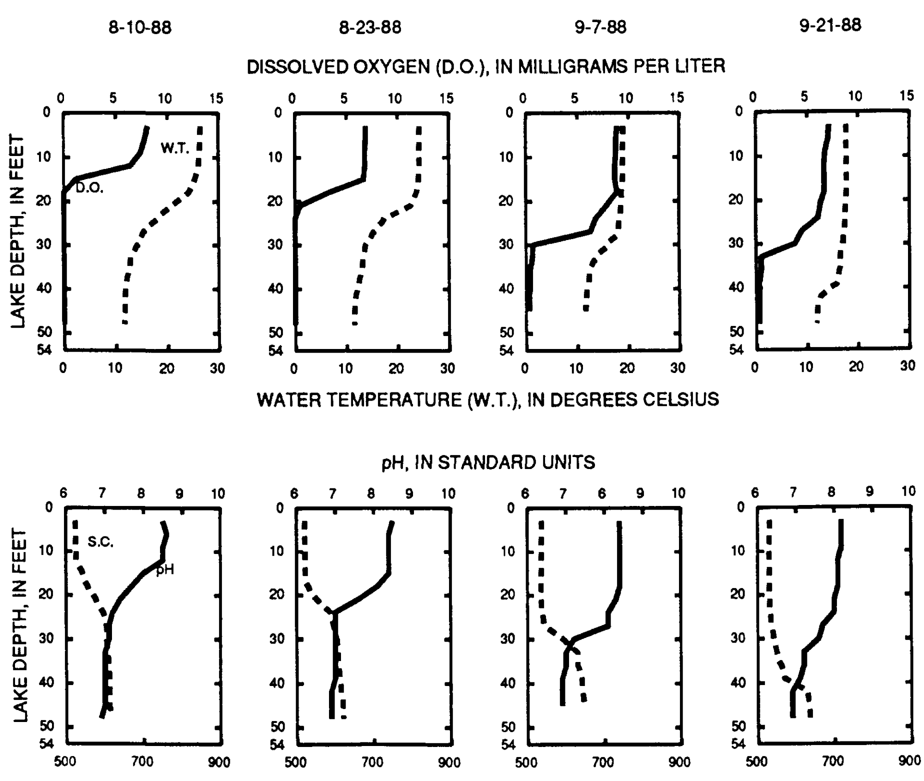


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

WATER-QUALITY DATA, OCTOBER 18 TO MAY 8, 1989

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	Oct. 18			Mar. 01		Apr. 11		May 08		
Depth of sample (ft)	1.5	44	50	1.5	49	1.5	50	1.5	45	50
Lake stage (ft)		6.92		7.95		8.05			8.14	
Specific conductance (µS/cm)	528	528	527	606	698	591	586	594	593	595
pH (units)	8.4	8.4	8.4	6.6	7.1	7.2	8.1	8.3	8.0	7.9
Water temperature (°C)	12.5	12.0	11.5	2.0	3.0	5.5	4.5	13.0	11.0	10.5
Color (Pt-Co. scale)	---	---	---	---	---	30	30	---	---	---
Turbidity (NTU)	---	---	---	---	---	3.0	3.2	---	---	---
Secchi-depth (meters)		1.2		1.4		1.2			2.7	
Dissolved oxygen	10.6	10.3	10.3	17.7	7.5	12.9	13.1	11.3	9.0	7.0
Hardness, as CaCO3	---	---	---	---	---	250	250	---	---	---
Calcium, dissolved (Ca)	---	---	---	---	---	48	49	---	---	---
Magnesium, dissolved (Mg)	---	---	---	---	---	32	32	---	---	---
Sodium, dissolved (Na)	---	---	---	---	---	26	27	---	---	---
Potassium, dissolved (K)	---	---	---	---	---	3	3	---	---	---
Alkalinity, as CaCO3	---	---	---	---	---	170	170	---	---	---
Sulfate, dissolved (SO4)	---	---	---	---	---	62	62	---	---	---
Chloride, dissolved (Cl)	---	---	---	---	---	49	49	---	---	---
Fluoride, dissolved (F)	---	---	---	---	---	0.2	0.2	---	---	---
Silica, dissolved (SiO2)	---	---	---	---	---	0.3	0.3	---	---	---
Solids, dissolved, at 180°C	---	---	---	---	---	360	356	---	---	---
Nitrogen, NO2 + NO3, diss. (as N)	---	---	---	0.34	0.24	0.40	0.41	<0.02	---	---
Nitrogen, ammonia, dissolved (as N)	---	---	---	0.30	0.73	0.14	0.13	---	---	---
Nitrogen, amm. + org., total (as N)	---	---	---	---	---	1.5	1.5	---	---	---
Phosphorus, total (as P)	0.032	0.024	0.025	0.047	0.080	0.056	0.051	0.060	0.070	0.060
Phosphorus, ortho, dissolved (as P)	---	---	0.006	---	0.045	0.005	0.005	0.014	---	0.027
Iron, dissolved (Fe) µg/L	---	---	---	---	---	< 50	< 50	---	---	---
Manganese, dissolved (Mn) µg/L	---	---	---	---	---	< 40	< 40	---	---	---
Chlorophyll a, phytoplankton (µg/L)	29	---	---	35	---	25	---	4.0	---	---

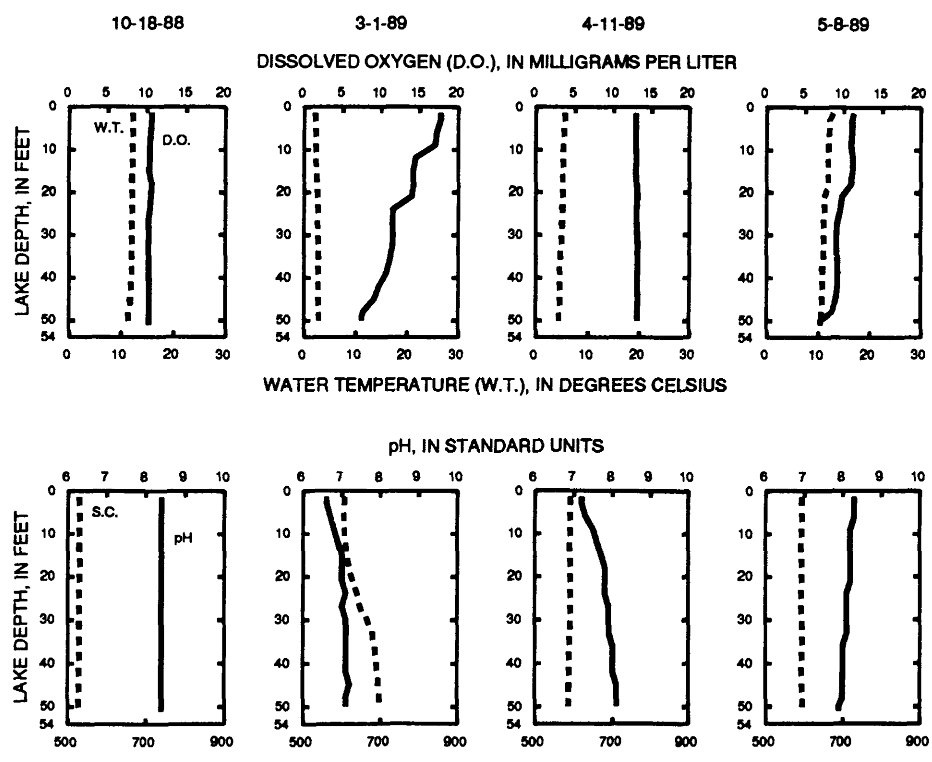


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

WATER-QUALITY DATA, JUNE 7 TO SEPTEMBER 27, 1989

(Concentration in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; °C, degrees Celsius)

	June 07				July 11			
Depth of sample (ft)	1.5	12	27	50	1.5	12	30	48
Lake stage (ft)	7.98				7.61			
Specific conductance (µS/cm)	577	587	614	631	565	569	622	633
pH (units)	8.7	8.6	7.5	7.2	8.6	8.4	7.2	7.1
Water temperature (°C)	22.0	21.0	14.0	12.0	26.5	25.5	14.0	12.5
Secchi-depth (meters)	1.3				1.5			
Dissolved oxygen	9.9	9.1	0.0	0.0	8.0	5.5	0.0	0.0
Phosphorus, total (as P)	0.016	0.016	0.131	0.390	0.025	0.026	0.290	---
Phosphorus, ortho, dissolved (as P)	0.003	0.004	0.091	0.310	0.003	---	---	---
Chlorophyll a, phytoplankton (µg/L)	15	---	---	---	14	---	---	---

	Aug. 08				Sep. 27		
Depth of sample (ft)	1.5	24	42	50	1.5	45	48
Lake stage (ft)	8.35				8.10		
Specific conductance (µS/cm)	559	594	643	647	578	623	676
pH (units)	8.3	7.3	7.0	7.0	7.6	7.1	6.9
Water temperature (°C)	23.5	19.5	13.0	13.0	16.0	14.5	13.0
Secchi-depth (meters)	1.6				0.9		
Dissolved oxygen	7.3	0.1	0.0	0.0	5.7	0.0	0.0
Phosphorus, total (as P)	0.026	0.052	0.500	0.530	0.061	0.080	0.550
Phosphorus, ortho, dissolved (as P)	0.003	---	---	0.490	0.005	---	0.500
Chlorophyll a, phytoplankton (µg/L)	14	---	---	---	26	---	---

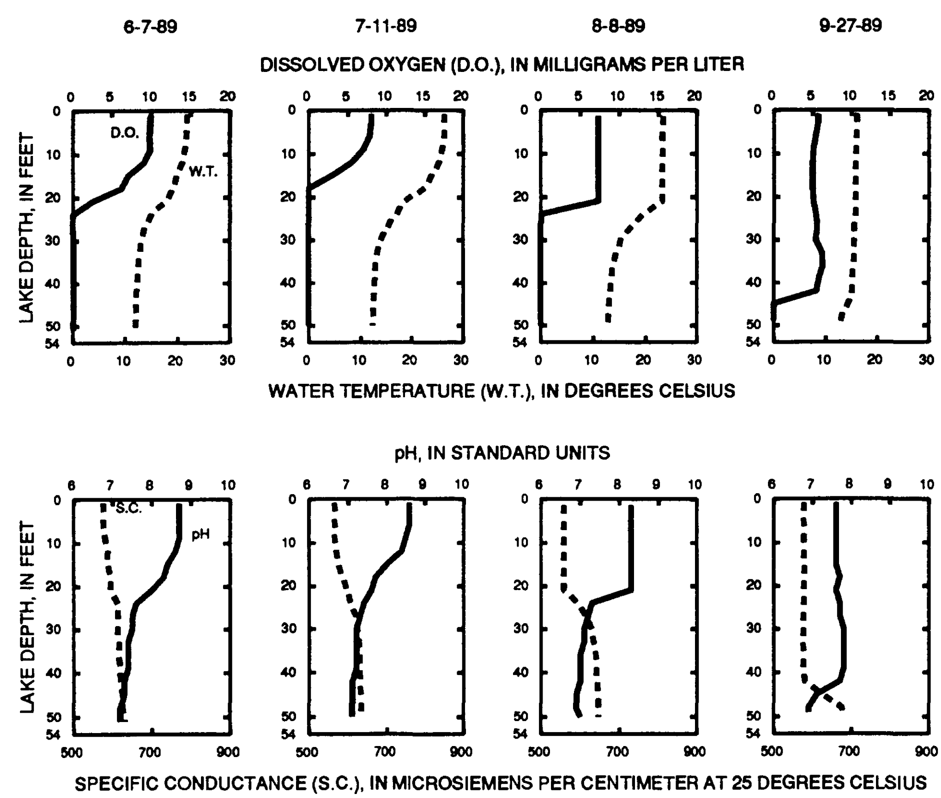


Figure 8. Water-quality data and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance for Wind Lake, water years 1988-89--Continued.

from December 11, 1988 through March 28, 1989 (Kathy Aron, Wind Lake Management District, oral commun., 1990).

Winter stratification occurs as the cold (less than 4°C) water and ice remain at the surface, again separated from the relatively warmer, denser water (near 4°C) near the bottom of the lake. Spring brings a reversal to the process. As the ice thaws and the upper layer of water warms, it increases in density and begins to approach the temperature of the deeper water until the entire water column reaches the same temperature and permits wind-driven mixing. This mixing, which follows winter stratification, is referred to as spring turnover and usually occurs within weeks after the ice melts. The summer stratification follows spring turnover.

Dissolved Oxygen

Dissolved oxygen is one of the most critical constituents in a lake **ecosystem**, and it is essential to most aquatic organisms. Dissolved-oxygen depth profiles at the center of the lake are shown in figure 8. Maximum solubility of oxygen in water is inversely related to temperature--that is, oxygen solubility decreases as water temperature increases. This relation is significant because as temperatures increase, the metabolic rate of organisms increases but the amount of oxygen available for metabolism decreases.

In early summer, as the thermocline develops, the epilimnion cuts off the surface supply of dissolved oxygen to the hypolimnion. The hypolimnion thus becomes isolated from the atmosphere. Large populations of **algae** (phytoplankton) are produced because the waters of Wind Lake are nutrient rich. These organisms die, fall to the bottom of the lake, and decompose. The oxygen demand from these decaying organisms depletes the oxygen content of the water, beginning at the lake bottom. Oxygen depletion then progresses upward but stays confined to the hypolimnion. Depletion can progress until all of the oxygen is consumed (anoxia).

In WY 1988, oxygen depletion in the bottom water during summer stratification began about May 18 and lasted 130 days, until about September 25. The anoxic zone reached a maximum thickness around July 18, when depths greater than 15 ft were devoid of oxygen; this represents about 21 percent of the lake-bottom area. Anoxia was last noted on September 21. Autumn turnover likely occurred shortly after September 21 because the thermocline was almost eroded. Anoxia in the bottom waters also occurs at the end of winter under ice cover. Anoxia in the bottom waters was documented on February 16, 1988 (fig. 8), February 23, 1987 (U.S. Geological Survey, 1988), and March 4, 1986 (U.S. Geological Survey, 1987). Anoxia was not observed on March 1, 1989, or on February 28, 1985 (U.S. Geological Survey, 1986).

Anoxia is common in eutrophic lakes and, in varying degrees, in all of the thermally stratified eutrophic lakes in southeastern Wisconsin. Anoxia can release phosphorus from the bottom sediments if phosphorus is present in large enough quantities in the sediments.

pH

Hydrogen-ion concentration in water, expressed as pH, affects the solubility of many chemical constituents and is influenced by biological activity. The photosynthetic and respiratory processes of algae can have a considerable effect on the pH of water. These organisms produce oxygen and consume carbon dioxide as they photosynthesize during daytime; they consume oxygen and produce carbon dioxide as they respire at night. When carbon dioxide concentrations decrease, pH increases; when carbon dioxide concentrations increase, pH decreases. The algae in Wind Lake metabolize much of the available carbon dioxide as they photosynthesize during the daytime and thereby raise the pH of water in the epilimnion; however, no photosynthesis occurs near the lake bottom, carbon dioxide is not metabolized, and the pH of the hypolimnion is lowered (fig. 8).

Specific Conductance

Specific conductance is an indicator of the concentration of dissolved solids in the water; as the dissolved-solids concentration increases, specific conductance increases. Measured differences in specific-conductance profiles help distinguish differences in water quality (dissolved-solids concentration) with depth.

The profile measurements after spring turnover on April 8, 1988, and April 11, 1989, as illustrated in figure 8, show that specific conductance was almost uniform for both years and ranged from 564 to 591 μS/cm (microsiemens per centimeter at 25°C). Specific conductance increases at the lake bottom during winter and summer thermal stratification because of the accumulation of dissolved constituents either from dissolution of precipitates, settling of materials from the epilimnion, or from release of dissolved materials (such as iron and manganese) from the bottom sediments during anoxic periods.

Phosphorus

Phosphorus generally is the nutrient that limits biological productivity in bodies of water (Wetzel, 1983). Nitrogen, however, commonly becomes the nutrient limiting algal growth when there is an excess of phosphorus. When both phosphorus and nitrogen are in excess, algal growth continues until availability of other nutrients or light limits growth.

Water-quality data for Wind Lake before WY 1988 are limited. On April 14, 1966, a dissolved **orthophosphate** concentration of 131 μg/L was observed at 3-ft depth (Wisconsin Department of Natural Resources, 1969). In water samples from 3-ft depth during spring turnover in 1974 and 1975, total phosphorus concentrations were 60 and 80 μg/L, dissolved orthophosphate phosphorus concentrations were 18 and 31 μg/L, and **Secchi depths** were 1.2 and 1.5 m (meters), respectively (Richard Lillie, Wisconsin Department of Natural Resources, written commun., 1990).

Wind Lake receives 70 to 75 percent of its phosphorus input from Big Muskego Lake; therefore, the water quality of Big Muskego Lake affects Wind Lake's water quality. Total phosphorus concentrations 1.5 ft below the lake surface of Little Muskego, Big Muskego, and Wind Lakes are shown in figure 9 (U.S. Geological Survey, 1987, 1988, 1989). At Big Muskego Lake, phosphorus concentrations increase dramatically as water temperatures increase. This increase is probably the result of increased activity of a large carp population.

Many carp were observed in shallow, Big Muskego Lake by field people during the summer 1988 sampling. Carp are bottom feeders and become increasingly active during summer months as water warms. When foraging for food or spawning, they resuspend the bottom sediments that contain phosphorus and phosphorus concentrations in the water column increase. As water temperatures cool, the carp reduce their activity and phosphorus concentrations decrease.

Total phosphorus concentrations in Big Muskego Lake declined dramatically during the summer of 1989 (fig. 9). Fewer carp were observed by field people during sampling in open water in 1989 than in 1988 (D.L. Olson, U.S. Geological Survey, oral commun., 1990).

During the February and March 1989 sampling under ice cover, oxygen concentrations were 16 and 24 mg/L, respectively, and were adequate to support carp populations. During the January and March 1990 sampling under ice cover in Big Muskego Lake and Bass Bay--a small bay off Big Muskego Lake--oxygen concentrations were also adequate to support carp populations. However, the USGS field person who did the sampling talked to a local fisherman, who commented that there were many dead fish in Bass Bay under the ice in December 1988 (D.L. Olson, U.S. Geological Survey, oral commun., 1990). In past years when oxygen depletions occurred in Big Muskego Lake, carp migrated to Bass Bay, where many fish died (Neal O'Reilly, Wisconsin Department of Natural Resources, oral commun., 1990).

It is therefore possible that oxygen depletions occurred during the winter of 1988-1989, and that carp populations were reduced, and that phosphorus concentrations in the summer of 1989 were thereby reduced from those in the summers of 1987 and 1988.

Total phosphorus concentrations at the surface of Wind Lake in WY 1988 ranged from 11 μg/L on June 7 to 78 μg/L on September 21. In WY 1989, total phosphorus concentrations ranged from 16 μg/L on June 7 to 61 μg/L on September 27 (fig. 10). Total phosphorus concentrations during spring turnover on April 8, 1988, and April 11, 1989, were both 56 μg/L and were indicative of eutrophic conditions (G.C. Gerloff, University of Wisconsin, written commun., 1984; Wisconsin Department of Natural Resources, 1981 and 1983) and poor water quality (Lillie and Mason, 1983).

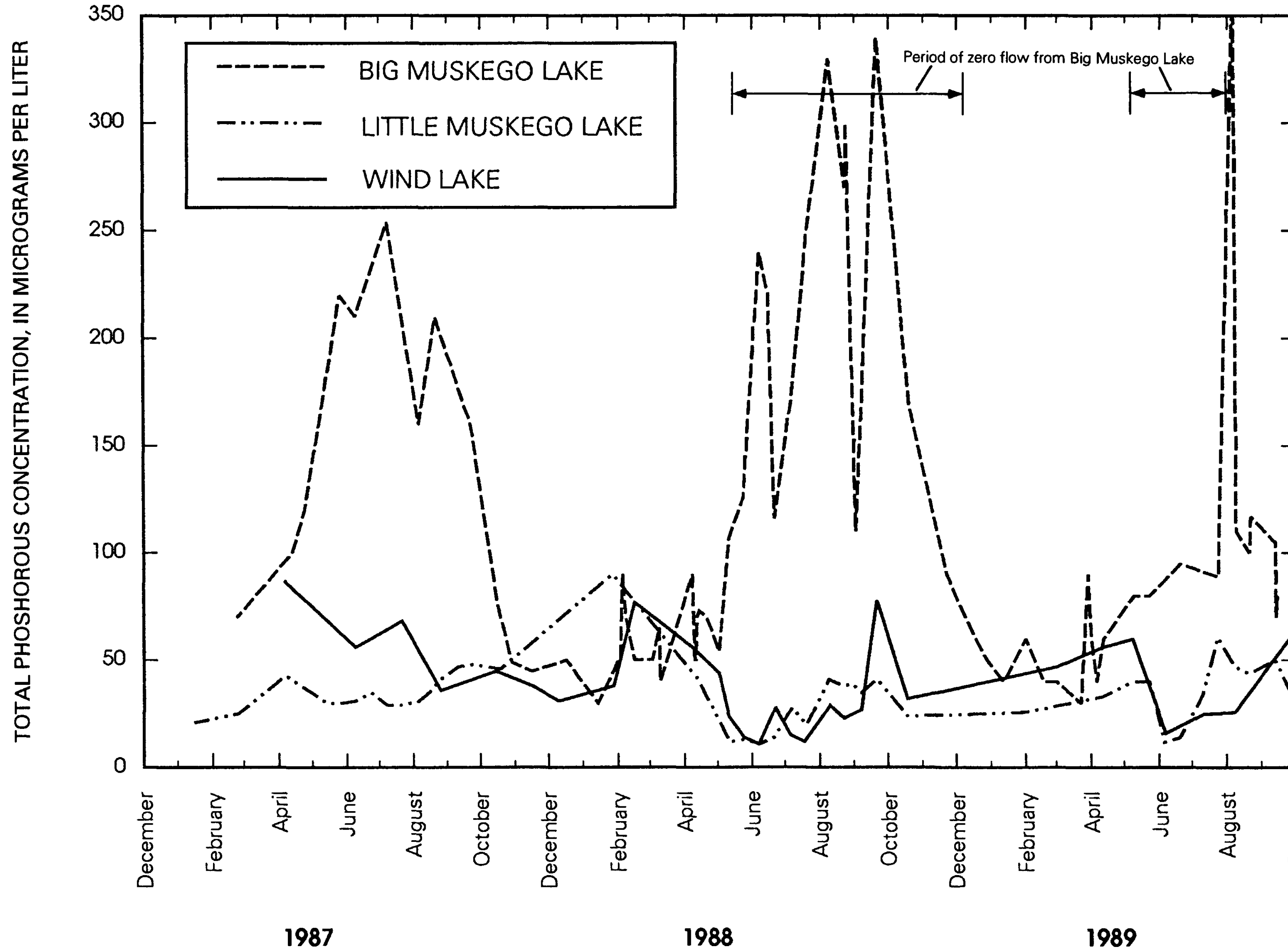


Figure 9. Total phosphorus concentrations 1.5 feet below lake surface at Wind, Big Muskego, and Little Muskego Lakes, 1987-89.

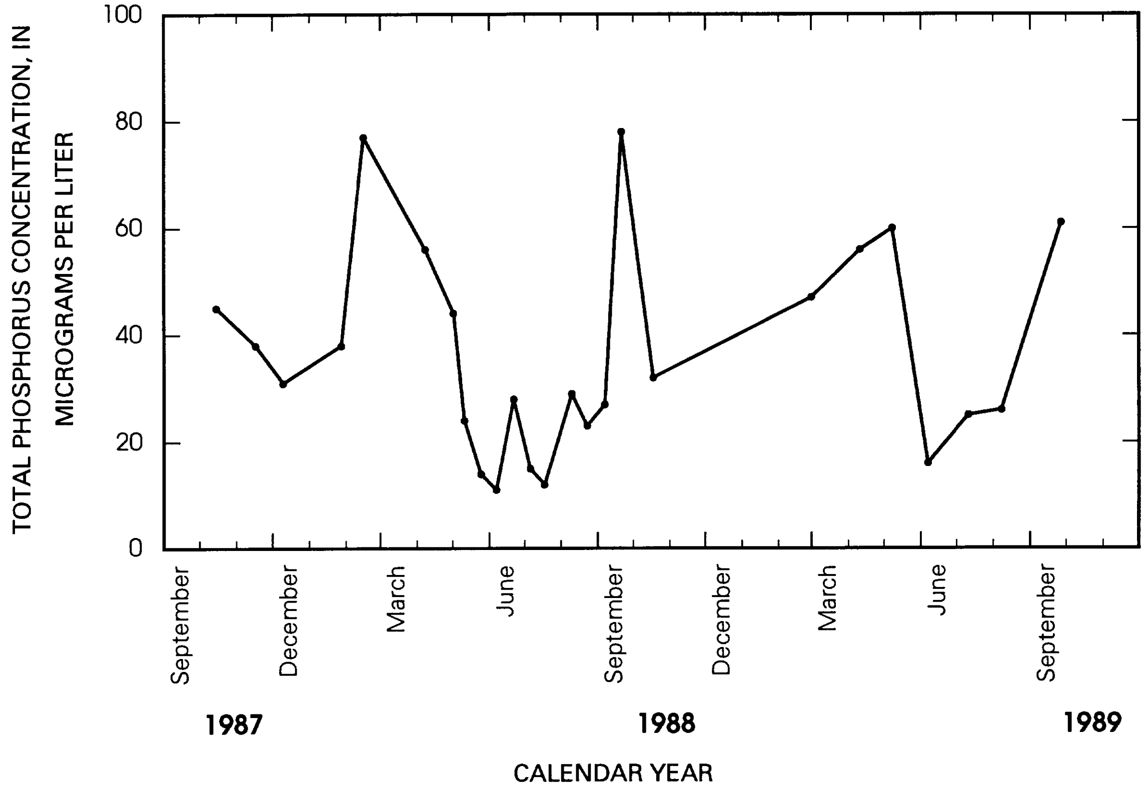


Figure 10. Total phosphorus concentrations 1.5 feet below lake surface at Wind Lake, water years 1987-89.

Total phosphorus concentration 1.5 ft below the surface of Wind Lake in June, July, and August in WY 1988 and 1989 were about two and one-half times lower than in WY 1985-1987 (fig. 11). This was due, in part, to extended periods of zero flow from Big Muskego Lake during WY 1988 and 1989. Total phosphorus concentrations in June, July, and August that averaged 49 µg/L during 1985-87 declined to 20 µg/L in WY 1988; in WY 1989, the concentrations averaged 22 µg/L. Data in figure 11 are from the months April, June, July, and August, 1985-89 (U.S. Geological Survey, 1986-90), which are the only months having data available in every year from WY 1985-89.

Dissolved orthophosphate phosphorus is extracted from water by algae and incorporated in their cell walls as they grow. Algae are short-lived organisms. When they die they settle to the lake bottom and carry with them the phosphorus extracted during their growth. Therefore, this growth and death of the algal cells in the top layer of water causes some of the change in the total phosphorus and dissolved orthophosphate concentrations. In Wind Lake dissolved orthophosphate phosphorus that has been released from the bottom sediments during summer anoxic periods is generally confined to the hypolimnion because of strong thermal stratification. However, increases in the phosphorus concentrations in the epilimnion were observed in the summer of 1988 when there was little external loading. It appears that phosphorus, principally dissolved orthophosphate, migrated from the hypolimnion through the metalimnion into the epilimnion. Cold fronts accompanied by high winds may be the cause of this vertical migration as suggested by Stauffer (1974) in his study of Delavan Lake.

Fluctuations of total phosphorus and dissolved orthophosphate phosphorus concentrations at the bottom of Wind Lake are shown in figure 12. The large increase in concentration at the bottom of the lake is primarily due to the large amount of phosphorus that is released during anoxic periods from bottom sediments.

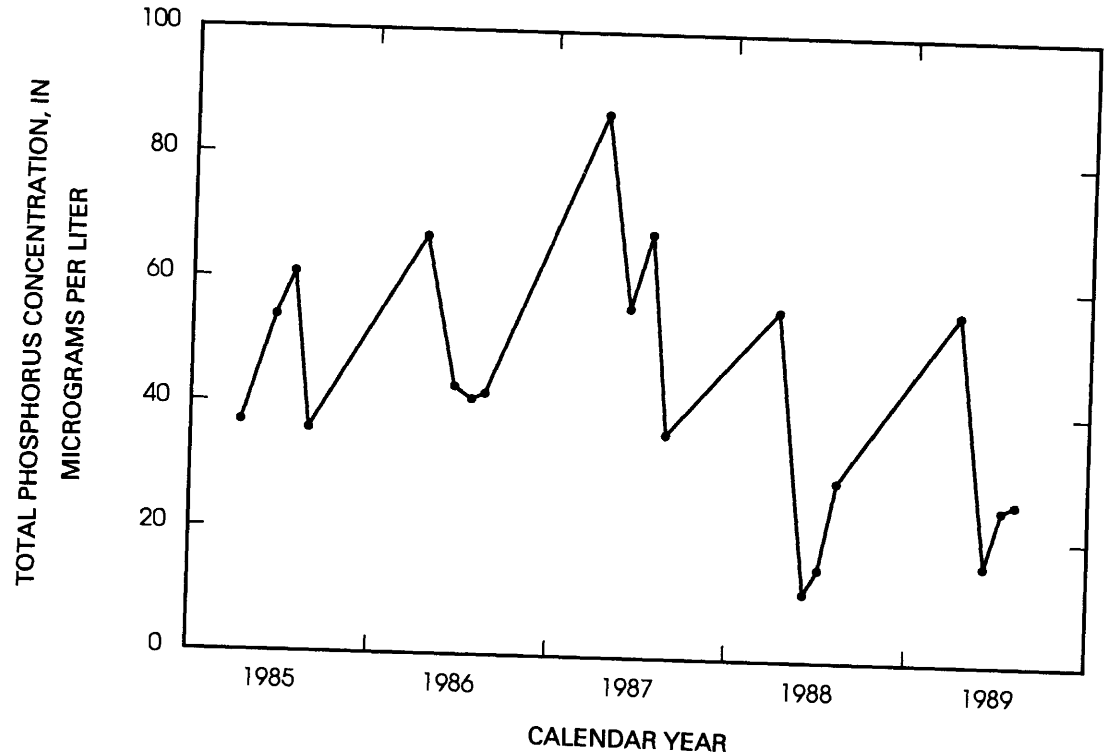


Figure 11. Total phosphorus concentrations 1.5 feet below lake surface at Wind Lake, April, June, July, and August 1985-89.

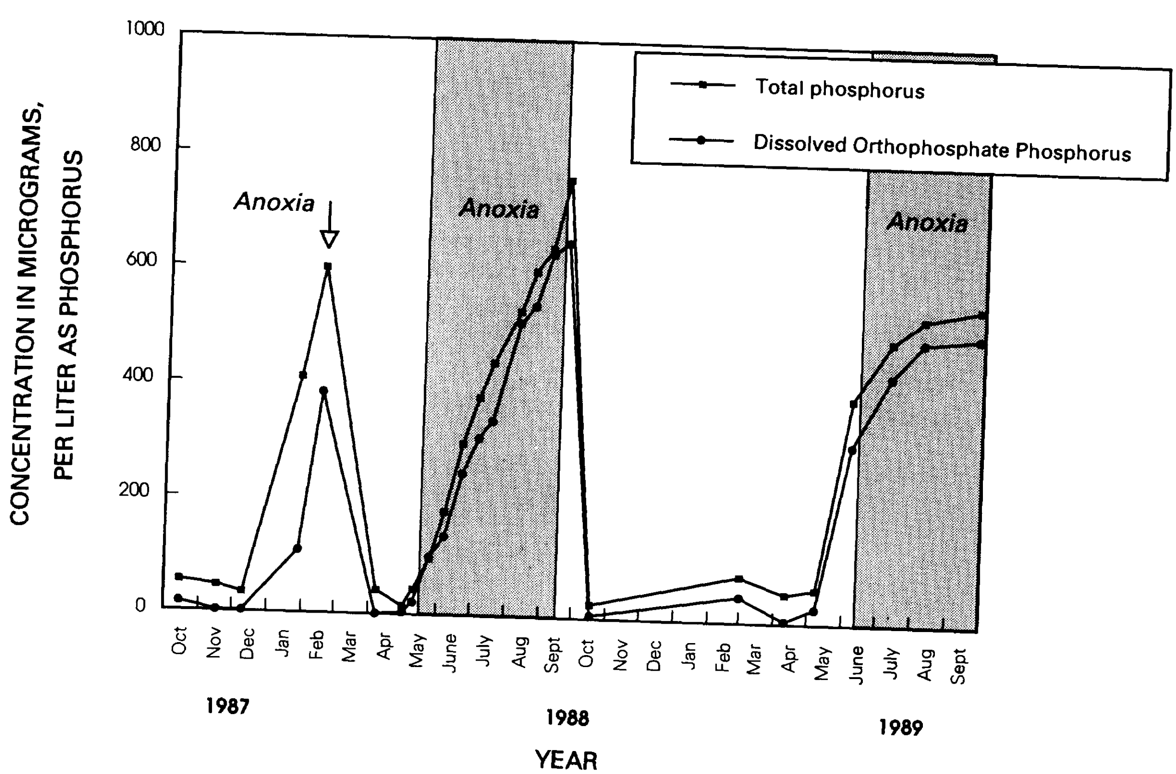


Figure 12. Phosphorus concentrations 1.5 feet above lake bottom at Wind Lake, water years 1987-89.

Phosphorus concentrations in Wind Lake's sediments are very high (1,100 mg/kg (milligrams per kilogram)) as indicated by analyses of a sediment core from near the center (deep area) of the lake (site 424915088083900, fig. 1) are listed in table 9. According to a classification of the Great Lakes harbor sediments (U.S. Environmental Protection Agency, 1977), phosphorus concentrations greater than 650 mg/kg are indicative of "heavily polluted" water. Numerous laboratory studies have shown that phosphorus can be released from lake sediments when the overlying water is anoxic (Mortimer, 1941, 1942; Theis and McCabe, 1978; Holdren and Armstrong, 1980).

Phosphorus is released from the sediments in the dissolved form. The dissolved orthophosphate phosphorus and total phosphorus concentrations were similar during WY 1988. The concentration of phosphorus from May 2 through September 21, 1988, increased at a rate of 5.2 and 4.8 (μg/L)/d (micrograms per liter per day), respectively. It is likely that the dissolved orthophosphate phosphorus accumulation in the water column was released from sediments, rather than from decomposing algal cells. Gachter and Mares (1985) found that, in a phosphorus-limited lake (Lake Lucerne in Switzerland), dead algal cells settling to the lake bottom accumulated dissolved orthophosphate phosphorus by sorption.

The phosphorus-accumulation rates above the lake bottom in the hypolimnion in Wind Lake are higher than those found in eutrophic Lake Mendota in Madison, Wis., by Sonzogni (1974). Total phosphorus concentration in samples from Lake Mendota during spring turnover (April) averaged 153 μg/L in 1972 and 1973. Sonzogni found the accumulation rates above the lake bottom for total phosphorus and dissolved reactive phosphorus were the same, but different for 1971 and 1972, 3.9 and 3.1 (μg/L)/d, respectively[4]. In contrast, the phosphorus-accumulation rates above the lake bottom of Wind Lake are less than those found in eutrophic Delavan Lake near Lake Lawn, Wis. (Field and Duerk, 1988). Water samples collected from Delavan Lake during spring turnover (April) and analyzed for total phosphorus in 1984 and 1985 averaged 150 μg/L. Accumulation rates of total and dissolved orthophosphate phosphorus above the lake bottom were 6.4 and 6.7 (μg/L)/d.

[4]The analyses for dissolved reactive phosphorus and dissolved orthophosphate phosphorus are considered comparable because analytical procedures are identical.

Nitrogen

Nitrogen, like phosphorus, can cause **algal blooms** when in abundant supply. All nitrogen sources cannot be controlled; certain **species** of blue-green algae have heterocysts in their cell walls (Wetzel, 1983) that enable them to fix nitrogen from the atmosphere. Samples from Wind Lake were collected for nitrogen analysis only during spring turnover. Lakes with a total nitrogen:total phosphorus ratio larger than 15:1 are considered phosphorus limited, lakes with a ratio from 10:1 to 15:1 could be limited by either nutrient, and lakes with a ratio smaller than 10:1 are considered nitrogen limited (Lillie and Mason, 1983). Total nitrogen:total phosphorus ratios in samples collected after spring turnover (April) in Wind Lake during 1985-89 were all greater than 15:1. This indicates that phosphorus is the limiting factor for algal production in Wind Lake at spring turnover.

Water Clarity

The range of depths within which photosynthetic activity occurs depends largely on light penetration, which is influenced by water clarity. Secchi-disc measurements, known as Secchi depths, provide a measurement of water clarity. A Secchi disc is an 8-inch-diameter black-and-white patterned disc that is lowered to a depth at which it is no longer visible from the water surface. Factors that reduce water clarity are concentrations and types of algae and zooplankton, water, **color**, and turbidity. Presence of algae is the most dominant factor affecting water clarity in Wind Lake; therefore, Secchi depths correlate with the algal populations. Secchi depth generally is at its minimum during summer when algal populations are largest; however, the minimum Secchi depth of 0.6 m (meter) (2 ft) was measured on January 28 and February 16, 1988, and the maximum Secchi depth of 2.7 m (8.8 ft) was measured on May 8, 1989 in Wind Lake.

Chlorophyll *a*

Chlorophyll *a* is the primary photosynthetic pigment of all oxygen-evolving photosynthetic

Table 9. Sediment-core analyses for sampling site 424915088083900 (fig. 1) in Wind Lake

[Concentration in milligrams per kilogram (mg/kg) unless otherwise indicated; µg/g, micrograms per gram; N, nitrogen; P, phosphorus, <, less than; --, no data]

Depth from lake bottom to top of sample interval (feet)	Depth from lake bottom to bottom of sample interval (feet)	Moisture content, dry weight (percent of total)	Nitrogen, nitrite plus nitrate, total, in bottom material (mg/kg as N)	Nitrogen, ammonia, total, in bottom material (mg/kg as N)	Nitrogen, ammonia plus organic, total, in bottom material (mg/kg as N)	Phosphorus, total, in bottom material (mg/kg as P)	Iron, total, recoverable, from bottom material (µg/g)	Manganese, total, recoverable, from bottom material (µg/g)
0.0	0.33	85	<10	910	11,000	1,100	14,000	990
.33	.83	84	--	--	--	1,000	14,000	990
.83	1.33	83	--	--	--	940	15,000	990
1.33	1.83	79	--	--	--	860	15,000	1,100

organisms, and it is present in all algae (Wetzel, 1983). Its concentration is, therefore, an indicator of algal biomass. Chlorophyll *a* concentrations are generally lowest when algal populations are lowest, usually during winter, and highest when algal populations are highest, usually during summer. The data for the study period at Wind Lake are an exception to these generalizations. Chlorophyll *a* concentrations reached a maximum of 65 µg/L on February 16, 1988, and indicate an algal bloom under ice cover; the maximum open-water concentration of 29 µg/L was recorded on October 18, 1988. The minimum concentration of chlorophyll *a*, 4 µg/L, was recorded on May 8, 1989. The highest and lowest chlorophyll *a* concentrations coincide with the minimum and maximum Secchi depths, respectively.

Plankton

Plankton are a mixed group of tiny plants and animals and are divided into two groups. The plant community compose the phytoplankton (algae) and are primary producers that form the base of the aquatic food chain. The animal community compose the zooplankton that inhabit the same environments as the phytoplankton. Zooplankton are an important link in the aquatic food chain, in that they feed on phytoplankton and, in turn, are a food source for fish.

Phytoplankton

Phytoplankton populations in Wind Lake are listed in Appendixes I and II. Algal groupings are listed in table 10, and are shown in figure 13. Total populations in WY 1988 ranged from 28,200 cells/mL (cells per milliliter) on February 16 to 1,610,000 cells per milliliter on July 7; in WY 1989 the range was from 16,200 cells/mL on June 7 to 156,000 cells/mL on October 18. In WY 1988, 143 species were found. Blue-green algae (Cyanophyta) numerically dominated the algal population and ranged from 56 percent of the total population on February 16, 1988 to 99 percent on October 15, 1987, July 7, August 10, 23, and September 7, 1988. *Anacystis elachista* numerically dominated the samplings of October 15, 1987 through May 2, 1988; *A. aerusinosa* numerically dominated the samplings of May 11 through June 22, 1988, and *A. delicatissima* numerically dominated the samplings of July 7 through October 18, 1988. In WY 1989, different genera were numerically dominant: *Aphanizomenon* on June 7, 1989, and *Coccochloris* in July and August 1989 samplings. The colonies of *Coccochloris* often develop on lake bottoms, become loosened, float to the surface, and then are washed ashore, sometimes forming a "soupy" mass (Prescott, 1970).

Blue-green algae are not ordinarily used as food by zooplankton or fish, and they can become overabundant and out of balance in the lake ecosystem. Population explosions (blooms) of blue-green algae can occur when lake water is nitrogen limited (that is, nitrogen-phosphorus ratios are low), sunlight and temperature are optimum, and competition from other algal species is lacking.

The total cell counts for the summer months show large algal blooms. A common definition of an algal bloom is when the population of a particular algal species exceeds 500,000 cells per liter (Britton and others, 1975). Many species exceeded this concentration on many dates. *A. delicatissima* caused the largest algal bloom (934,000 cells/mL on September 7, 1988) in the study period.

Certain genera of blue-green algae including *Anacystis*, *Anabaena*, *Aphanizomenon*, *Gloeotrichia*, *Oscillatoria*, and *Lyngbya* are capable of producing toxins when conditions are right during algal blooms. Incidents of domestic animal deaths and positive laboratory tests for toxins have been reported in Wisconsin (Repavich and others, 1987). All of these genera except *Gloeotrichia* were found in Wind Lake in at least one or more lake samples. It is important to note, however, that even if one of these genera is present it does not mean toxins will be produced. In Delavan Lake, for example, the algal-related toxins were found before 1986 but not during a study in 1986 (Rapavich and others, 1987).

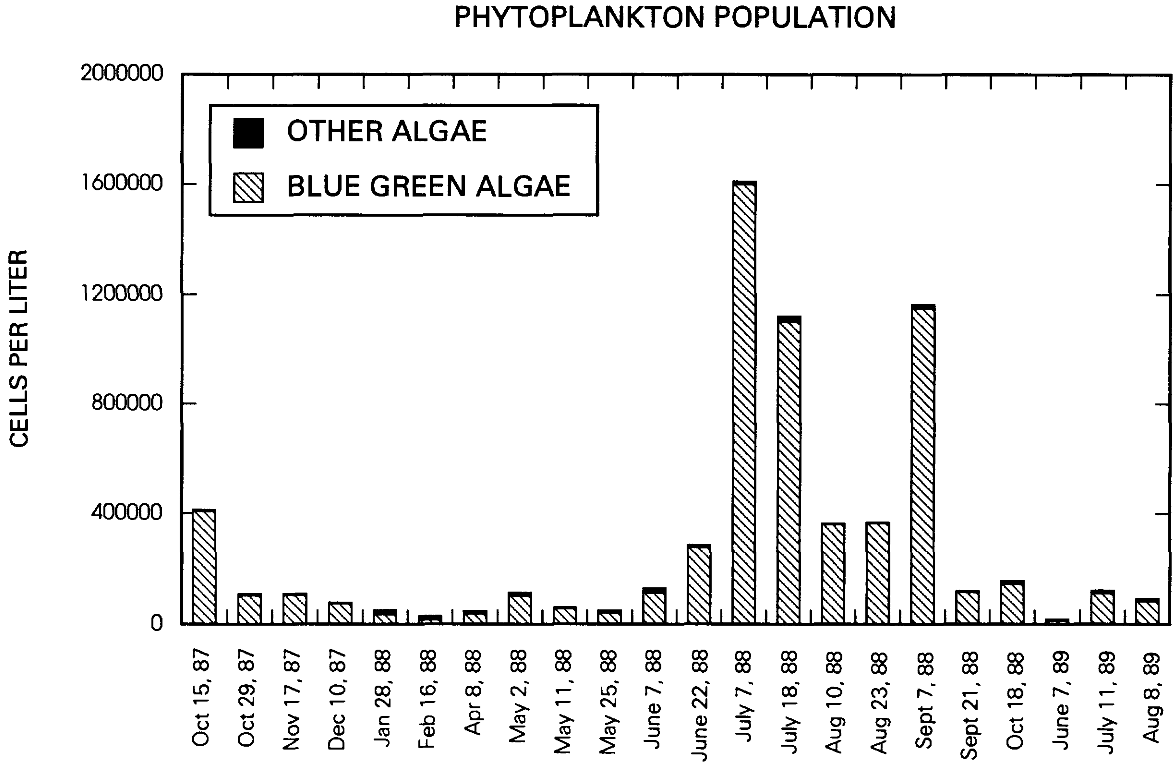
Zooplankton

Zooplankton populations for Wind Lake are listed in Appendixes III and IV and are illustrated in figure 13. There is a seasonal succession in Wind Lake from cladocerans to copepods as summer progresses. Zooplankton populations in WY 1988 ranged from 52.5 organisms/L (organisms per liter) on February 16 to 686 organisms/L on May 2; in WY 1989, they ranged from 61.6 organisms/L on August 8 to

Table 10. Types and densities of phytoplankton in Wind Lake, water years 1988-89

[a, population, in cells per milliliter; b, percentage of total population; <, less than; --, none present]

Date	Total population (cells per milliliter)	Diatoms		Green algae		Golden-brown algae		Blue-green algae		Cryptomonads		Dinoflagellates		Euglenoids	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b
10-15-87	413,000	596	<1	3,890	1	28	0	408,000	99	397	<1	--	--	--	--
10-29-87	110,000	596	<1	4,740	4	0	0	104,000	95	426	<1	--	--	--	--
11-17-87	110,000	223	<1	3,260	3	113	<1	106,000	96	338	<1	--	--	--	--
12-10-87	77,700	340	<1	2,365	3	788	1	73,900	95	225	<1	--	--	--	--
1-28-88	51,400	451	<1	2,140	4	11,900	23	36,000	70	901	2	--	--	--	--
2-16-88	28,200	80	<1	993	4	11,200	40	15,900	56	115	<1	--	--	--	--
4-08-88	47,700	5,890	12	4,450	9	744	2	36,400	76	185	<1	--	--	--	--
5-02-88	115,000	179	<1	9,780	8	263	<1	104,000	91	133	<1	--	--	--	--
5-11-88	60,400	65	<1	3,960	7	--	--	56,400	93	--	--	--	--	--	--
5-25-88	49,500	19	<1	9,180	19	--	--	40,300	81	--	--	--	--	--	--
6-07-88	130,000	17	<1	16,100	12	--	--	114,000	88	435	<1	53	<1	--	--
6-22-88	284,000	105	<1	7,140	2	--	--	277,000	98	--	--	--	--	--	--
7-07-88	1,610,000	--	--	6,660	<1	657	<1	1,600,000	99	1,689	<1	94	<1	--	--
7-18-88	1,120,000	--	--	18,100	2	612	<1	1,100,000	98	1,121	<1	102	<1	--	--
8-10-88	365,000	40	<1	3,440	1	--	--	361,000	99	40	<1	40	<1	--	--
8-23-88	367,000	263	<1	1,810	1	--	--	365,000	99	--	--	--	--	38	<1
9-07-88	1,160,000	--	--	11,700	1	309	<1	1,150,000	99	721	<1	206	<1	--	--
9-21-88	121,000	389	<1	2,900	2	--	--	117,000	97	168	<1	--	--	--	--
10-18-88	156,000	3,250	2	7,330	4	--	--	146,000	94	134	<1	--	--	--	--
6-07-89	16,200	108	<1	981	6	1,850	11	12,100	74	1,040	6	272	2	109	<1
7-11-89	123,000	544	<1	4,080	3	4,080	3	112,000	91	1,400	1	272	<1	--	--
8-08-89	92,500	1,090	1	4,080	4	2,720	3	82,100	89	2,450	3	--	--	--	--



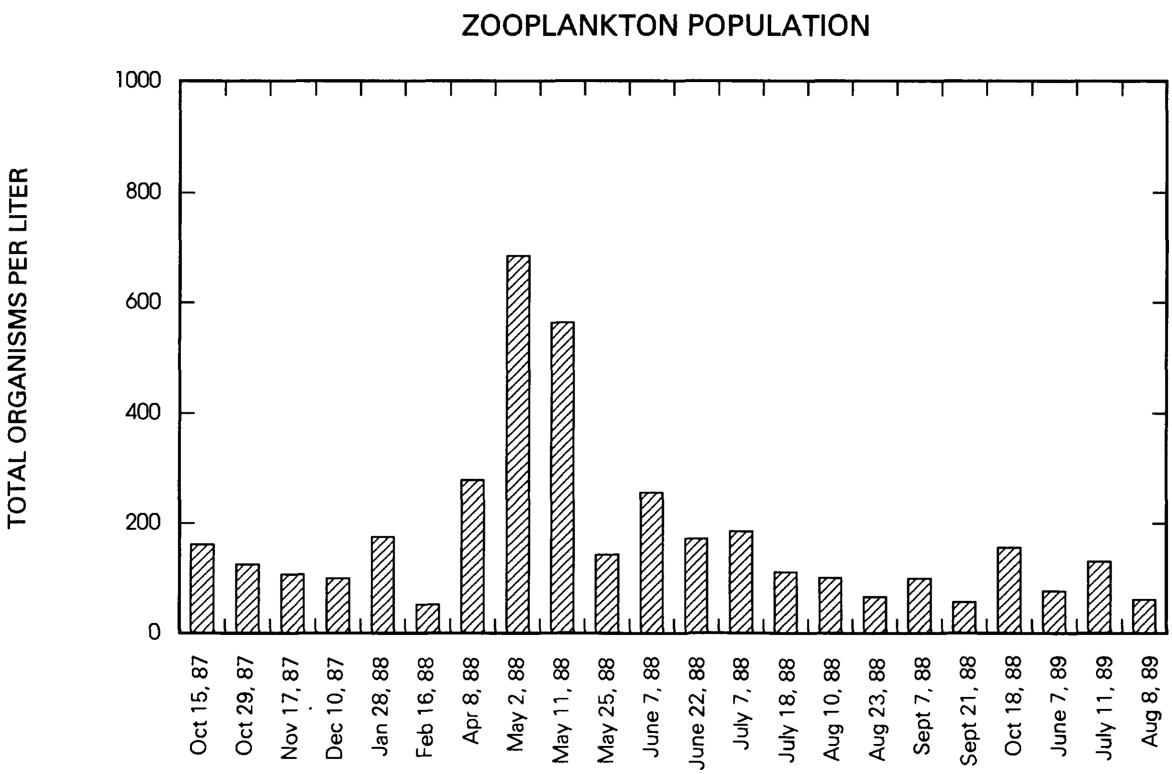


Figure 13. Phytoplankton and zooplankton populations in Wind Lake, water years 1988-89.

131 organisms/L on July 11. Twenty species of zooplankton were found in differing degrees of abundance; two protozoans, six rotifers, nine cladocerans, and three copepods were present. The cladoceran, *Daphnia*, was dominate in 12 of 18 samples. Little is know about the population dynamics and productivity of protozoans; however, several protozoans have been shown to feed actively on phytoplankton (Wetzel, 1983). Most rotifers are nonpredatory and feed on bacteria, small phytoplankton, and particulate organic matter. Cladocerans and copepods feed on phytoplankton and other zooplankton.

Trophic State

The trophic state of Wind Lake was evaluated by the application of two commonly used methods: Carlson's Trophic-State Index (TSI) and the Vollenweider model. Carlson's TSI can be used to evaluate the in-lake conditions and Vollenweider's model can be used to evaluate the phosphorus loading to a lake.

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 depths for lake ice-free periods. The TSI equation for Secchi depth was developed by Carlson (1977) whereas those for chlorophyll *a* and total phosphorus were developed by the DNR (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 DNR has adopted three TSI ranges to classify Wisconsin lakes: TSI's of less than 40 define oligotrophy, TSI's from 40 to 50 define mesotrophy, and TSI's greater than 50 define eutrophy (Wisconsin Department of Natural Resources, 1981 and 1983). G.C. Gerloff (University of Wisconsin, written commun., 1984) also uses these ranges. These ranges are used in this report for consistency with trophic-state evaluations of Wisconsin lakes done by the DNR.

These three classifications encompass a wide range of lake-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, and moderate algal blooms and occasional oxygen depletions occur. 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 can result at times if oxygen is severely depleted.

The following equations were used to calculate the TSI values for Wind Lake:

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

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

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

The three trophic levels and the different boundaries are shown below.

Trophic level	Trophic State Index	Total phosphorus concentration (micrograms per liter)	Secchi 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 Wind Lake (fig. 14) are generally in the range for eutrophic lakes. Only the lake's ice-free periods are plotted. An improvement in water quality in 1988 and 1989 is apparent because of the reduced phosphorus loading in these years.

Vollenweider's Model

External total-phosphorus loads to Wind Lake can be evaluated by use of Vollenweider's 1975 model. This model can be used to predict critical levels of external total-phosphorus loading to lakes. The external total-phosphorus loading to Wind Lake for WY 1988-89 according to Vollenweider's model is shown in figure 15.

Vollenweider classifies as "dangerous" the rate at which the receiving waters would become eutrophic (nutrient rich) or remain eutrophic. Vollenweider's model for evaluating external total-phosphorus loading to a lake is based on the ratio of mean lake depth to hydraulic residence time and phosphorus loading per unit of lake-surface area. On the basis of the WY 1988 ratio of the mean lake depth of 9.5 ft (2.9 m) to the hydraulic residence time of 0.46 year, a total phosphorus input of 3,160 lb (1.433×10^6 g) and a lake surface area of 4.077×10^7 ft^2 (3.788×10^6 m^2), the calculated phosphorus loading rate of 0.775×10^{-4} lb/ft^2 (.0378 g/m^2)/yr is "dangerous" and would be expected to cause eutrophic conditions. On the basis of the WY 1989 ratio of the mean lake depth of 9.5 ft (2.9 m) to the hydraulic residence time of 1.05 years, a total phosphorus input of 3,160 lb (1.433×10^6 g) and a lake surface area of 4.077×10^7 ft^2 (3.788×10^6 m^2), the calculated phosphorus loading rate of 0.775×10^{-4} lb/ft^2 (0.378 g/m^2)/yr is also "dangerous" and would be expected to cause eutrophic conditions. External loading of total phosphorus for both water years is classified as "dangerous." Vollenweider's classification does not consider internal loading. Internal loading or recycling of phosphorus from the lake sediments during anoxic periods is composed of predominately dissolved phosphorus.

Internal Loading

Phosphorus released from the sediments can contribute up to 91 percent of total phosphorus input (external and internal load) to a lake (Bengtsson, 1978). Nurnberg and Peters (1984) found that, for 23 stratified lakes with anoxic hypolimnia, the internal supply contributed an average of 39 percent to the total phosphorus load. The phosphorus release from sediments in Wind Lake during anoxic periods was discussed previously in the "Phosphorus" section of this report.

Internal loading and sedimentation of phosphorus to Wind Lake was calculated by use of a mass-balance phosphorus budget according to the following equation:

Internal loading or sedimentation =
change of total phosphorus (TP) mass in lake
+
outflow TP mass - inflow TP mass.

A positive value indicates internal phosphorus loading, whereas a negative value indicates sedimentation. A summary of the external input, output, changes in the water column and internal loading/sedimentation are shown in table 11. Internal loading of phosphorus was calculated only for the period October 15, 1987 through October 14, 1988.

Internal loading of total phosphorus, as shown for the time periods in table 11, were estimated as 2,890 lb. This represents 48 percent of the combined internal and external total phosphorus input of 5,960 lb. Sixty-three percent of the internal loading occurred during 32 percent of the days, from May 25 through September 20. Internal recycling of phosphorus into the water column is especially evident for this period; external phosphorus inputs were minimal (122 lb) because of the drought, yet the in-lake phosphorus mass increased dramatically (fig. 16).

The amount of phosphorus removed to bottom sediments by sedimentation was 3,850 lb. The total deposition (sedimentation - internal loading) was 957 lb.

SUMMARY AND CONCLUSIONS

A comprehensive study of Wind Lake during WY (water years) 1988-89 showed that total external loading of about 3,160 lb of total phosphorus for each year was excessive and would cause eutrophic conditions. The external loading of phosphorus was assessed by use of Vollenweider's model and the calculated hydraulic residence time of 0.46 year and 1.05 years for WY 1988 and 1989, respectively. Large amounts

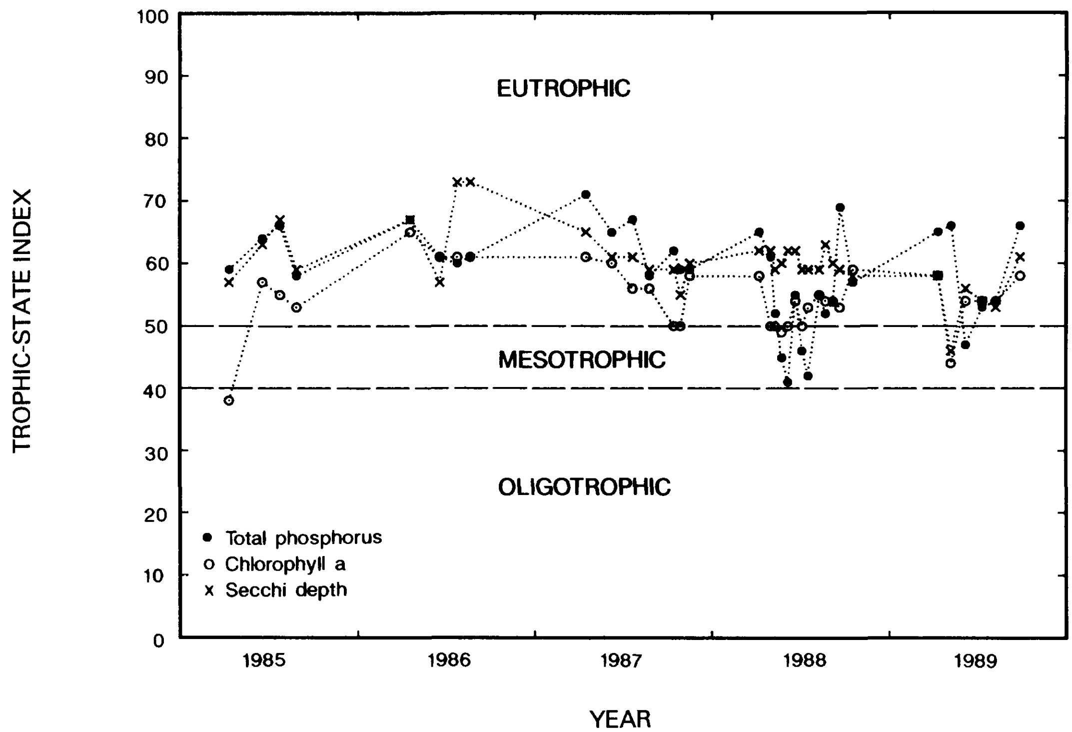


Figure 14. Trophic-State Indices for Wind Lake, water years 1985-89.

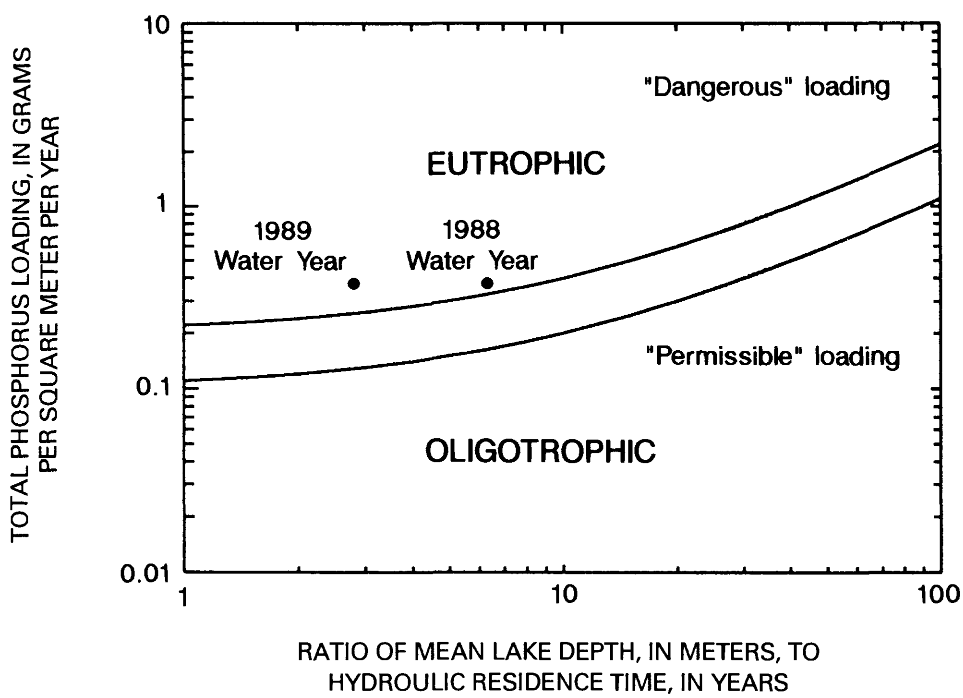


Figure 15. Phosphorus-loading classification for Wind Lake (Vollenweider model).

Table 11. Summary of total phosphorus input, output, and changes in the water column, Wind Lake, October 15, 1987 through October 14, 1988

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

Period	(1) External TP input (all sources)	(2) Date at start of period	(3) TP mass in water column	(4) Change in TP mass	(5) TP output mass	(6) Internal loading or sedimentation	
						Internal loading	Sedimentation
			1987				
	--	Oct. 15	1,246		--		
Oct.15 - Oct. 28	77	Oct. 29	857	-389	30	--	436
Oct. 29 - Nov. 16	54	Nov. 17	988	131	106	183	--
Nov. 17 - Dec. 9	244	Dec. 10	708	-280	186	--	338
Dec. 10, 1987 - Jan. 27, 1988	754	Jan. 28	1,111	403	558	207	--
			1988				
Jan. 28 - Feb. 15	485	Feb. 16	1,589	478	682	675	--
Feb. 16 - Apr. 7	721	Apr. 8	1,235	-354	450	--	625
Apr. 8 - May 1	430	May 2	748	-487	343	--	574
May 2 - 10	53	May 11	597	-151	20	--	184
May 11 - 24	67	May 25	479	-118	1	--	184
May 25 - June 6	1	June 7	793	314	0	313	--
June 7 - 21	1	June 22	819	26	0	25	--
June 22 - July 5	11	July 6	639	-180	0	--	191
July 6 - 17	11	July 18	1,220	581	0	570	--
July 18 - Aug. 9	36	Aug. 10	1,541	321	0	285	--
Aug. 10 - 22	11	Aug. 23	1,530	-11	0	--	22
Aug. 11 - Sep. 6	40	Sep. 7	1,157	-373	0	--	413
Sep. 7 - 20	11	Sep. 21	1,802	645	1	635	--
Sep. 21 - Oct. 14	55	Oct. 14	973	-829	1	--	883
Oct. 15, 1987 - Oct. 14, 1988	3,062			-273	2,378	2,893	3,850

Sum of internal loading (Oct. 15, 1987 - Oct. 14, 1988) = 2,893

Sum of sedimentation (Oct. 15, 1987 - Oct. 14, 1988) = 3,850

Net deposition (Sedimentation - Internal loading) = 957

Internal loading or sedimentation (6) = change in TP mass in lake (4) + outflow TP mass (5) - inflow TP mass (1)

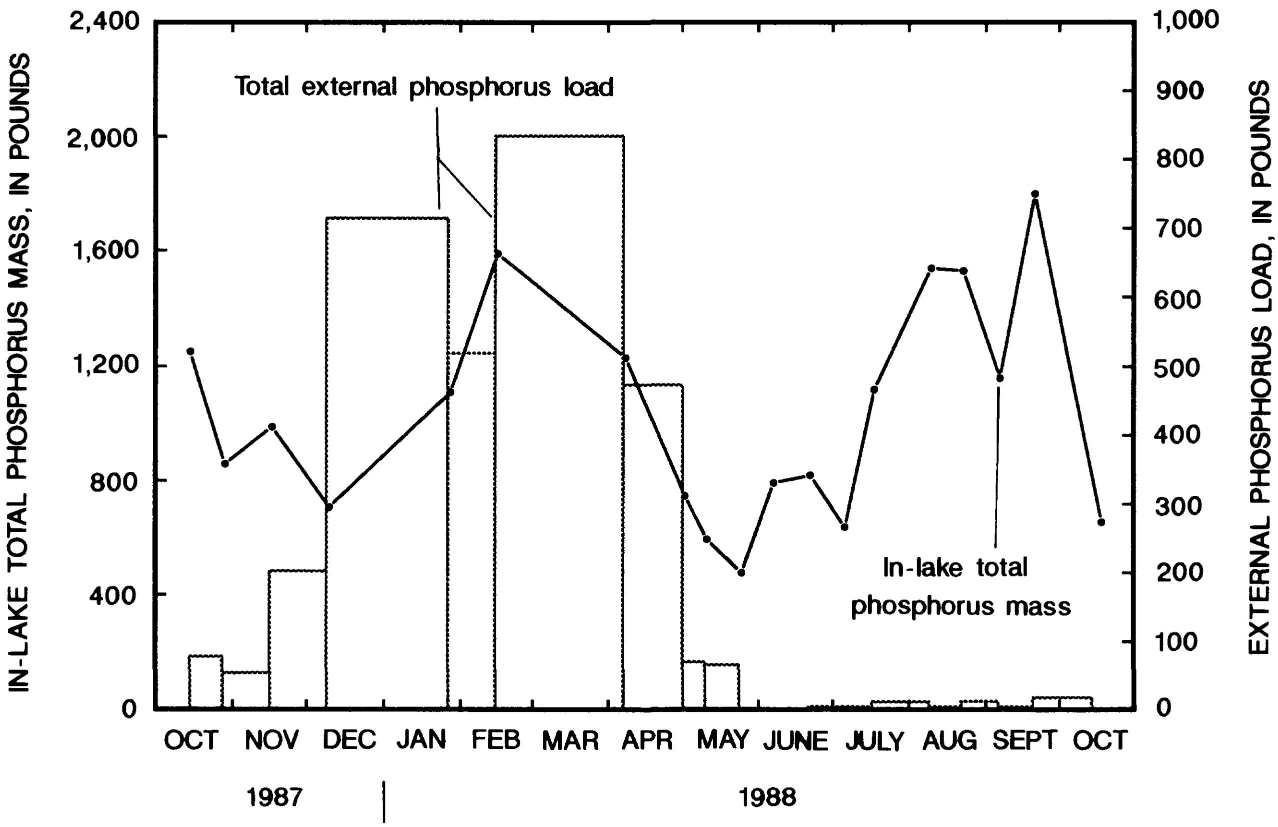


Figure 16. External total phosphorus load and in-lake total phosphorus mass for Wind Lake, mid-October 1987 through mid-October 1988.

of phosphorus in the lake's bottom sediments were released, mostly during summer, when the hypolimnion becomes anoxic; internal phosphorus loading in WY 1988 was nearly as great as the external loading. Phosphorus retention in the lake averaged 14 percent of the incoming load for both water years. In WY 1988, 7 percent more phosphorus left the lake than entered it; in WY 1989, 36 percent of the incoming load was retained.

A drought during WY 1988 affected the hydrologic and phosphorus budgets for both water years. Although streamflows in WY 1988 were about normal and in WY 1989 were 25 percent less than normal, phosphorus loadings were less than normal. Precipitation in WY 1988 was 5.9 in. less than the normal of 33.5 in.; in WY 1989, precipitation was 2.3 in. greater than normal.

Continuous streamflow and total phosphorus monitoring at Big Muskego Lake outlet, the major tributary to Wind Lake, showed that it contributed most of the water and phosphorus loading to the lake. In WY 1988, 19,900 acre-ft of water and 3,160 lb of phosphorus were delivered to the lake. Big Muskego Lake contributed 75 percent of the water input and 70 percent of the phosphorus input.

Although precipitation was 8.2 in. greater during 1989 water year than in 1988 water year, less water was delivered to Wind Lake. The total water input to Wind Lake in WY 1989 was 13,100 acre-ft, but phosphorus input was the same as in WY 1988--about 3,160 lb. Big Muskego Lake contributed 52 percent of the water input and 65 percent of the phosphorus input. Less water was delivered to Wind Lake in WY 1989 than in WY 1988 because lower groundwater levels caused base flow of the streams to be reduced and because water was not released from Muskego Lake for an extended period. At the beginning of WY 1989, the water level of Big Muskego Lake was 1.1 ft below the dam crest, and 2,510 acre-ft of water had to fill the lake before water and phosphorus could be discharged from the lake.

The water quality of Wind Lake indicates eutrophic conditions. Total phosphorus concentrations during spring turnover for both years were 56 μg/L, July and August chlorophyll *a* concentrations averaged 13 μg/L, and July and August water clarity averaged 1.3 m. The water quality of the lake in 1988 and 1989, however, improved because of the 1988 drought and reduced phosphorus loading. Total phosphorus concentrations in June, July and August that had averaged 49 μg/L in 1985-87 declined to 20 μg/L in 1988 and 22 μg/L in 1989.

Large amounts of phosphorus were released during summer anoxia into the water column from bottom sediments. Dissolved orthophosphate phosphorus above the bottom sediment in the summer of 1988 accumulated at a rate of 4.8 μg/L per day and reached a maximum concentration of 650 μg/L on September 21.

In WY 1988, algal populations, which are generally at their highest during summer, ranged from 28,200 cells/mL on February 16, 1988, to 1,610,000 cells/mL on July 7, 1988. A total of 143 species were identified. Blue-green algae numerically dominated the algal population. The proportion of blue-green algae in the total algal population ranged from 56 percent on February 16, 1988, to 99 percent on five other sampling dates. *Anacystis delicatissima* caused the largest algal bloom, during which a maximum concentration of 934,000 cells/mL was reached (September 7, 1988).

Zooplankton populations in WY 1988, which were highest in May, ranged from 52.5 to 686 organisms per liter. Eighteen species were identified. The cladoceran *Daphnia* dominated 12 of 18 samples. There was a seasonal succession in Wind Lake from cladocerans to copepods as summer progressed.

An in-lake water-quality data-collection program, such as that conducted during 1985-87, can provide important information about water-quality changes that occur over time.

REFERENCES CITED

Alden, W.C., 1918, The quaternary geology of southeastern Wisconsin: U.S. Geological Survey Professional Paper 106, 356 p.

Alt, D.F., and Iseri, K.T., 1986, Water Resources Division publications guide: U.S. Geological Survey, p. 205.

Bannerman, R., Baun, K., Bohn, M., Hughes, P.E., Graczyk, D.J., 1983, Evaluation of urban nonpoint source pollution management in Milwaukee County, Wisconsin--v. I, Urban stormwater characteristics, pollutant sources and management by street sweeping: U.S. Environmental Protection Agency, 178 p.

Bates, R.L., and Jackson, J.A., 1980, Glossary of geology (2d ed.): Falls Church, Va., American Geological Institute, 749 p.

Bengtsson, L., 1978, Effects of sewage diversion in lake Sondra Bergundasjon 1. Nitrogen and phosphorus budgets: Vatten, v.1, p. 2-9.

Britton, L.J., Averett, R.C., and Ferreira, R.F. 1975, An introduction to the processes, problems, and management of urban lakes: U.S. Geological Survey Circular 601-K, 22 p.

Carlson, R.E., 1977, A trophic state index for lakes: Limnology and Oceanography, March, v. 22, no. 2, p. 361-369.

Cole, G.A., 1979, Textbook of limnology (2d ed.): St. Louis, Mo., Mosby, 426 p.

Dion, N.P., Bortleson, G.C., McConnell, J.B., and Innes, J.K., 1976, Data on selected lakes in Washington, part 5: Washington State Department of Ecology, 125 p.

Durfor, C.N., and Becker, Edith, 1964, Public water supplies in the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.

Field, S.J., and Duerk, M.D., 1988, Hydrology and water quality of Delavan Lake in southeastern Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 87-4168, 61 p.

Field, S.J., 1986, Relationship of nonpoint-source discharges, streamflow, and water quality in the Galena River basin, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 85-4214, 48 p.

Field, S.J., and Graczyk, D.J., 1990, Hydrology, aquatic macrophytes, and water quality in Black Earth Creek and its tributaries, Dane County, Wisconsin, 1985-86: U.S. Geological Survey Water-Resources Investigations Report 89-8049, 44 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chap. A1, 545 p.

Foley, F.C., Walton, W.C., and Drescher, W.J., 1953, Ground water in the Milwaukee-Waukesha area, Wisconsin: U.S. Geological Survey Water-Supply Paper 1229, 96 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Inc., New Jersey, 604 p.

Gachter, R., and Mares, A., 1985, Does settling seston release soluble reactive phosphorus in the hypolimnion of lakes: Limnology and Oceanography, v. 30, no. 2, p. 364-371.

Green, J.H., and Hutchinson, R.D., 1965, Ground-water pumpage and water-level changes in the Milwaukee-Waukesha Area, Wisconsin, 1950-61: U.S. Geological Survey Water-Supply Paper 1809-I, 19 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Holdren, G.C., and .Armstrong, D.E., 1980, Factors affecting phosphorus release from intact lake sediment cores: Environmental Science and Technology 14:79-87.

Hutchinson, R.D., 1970, Water resources of Racine and Kenosha Counties, southeastern Wisconsin: U.S. Geological Survey Water-Supply Paper 1878, 63 p.

Kohler, G.J., 1982, Factors affecting species composition, dominance, and succession in shallow, hypereutrophic Big Muskego Lake: University of Wisconsin-Milwaukee, unpublished Master's thesis, 135 p.

Kuhn, Gerhard, and others, 1983, Hydrology of Area 54, Northern Great Plains and Rocky Mountain coal provinces, Colorado and Wyoming: U.S. Geological Survey Open-File Report 83-146, 102 p.

Langbein, W.B., and Iseri, K.T., 1960, General introduction and hydrologic definitions, Manual of hydrology, part 1, General surface-water techniques: U.S. Geological Survey Water-Supply Paper 1541-A, 29 p.

Langbein, W.B., and others, 1947, Major winter and nonwinter floods in selected basins in New York and Pennsylvania: U.S. Geological Survey Water-Supply Paper 915, 139 p.

Lee, D.R., and Cherry, J.A., 1978, A field exercise on groundwater flow using seepage meters and mini-piezometers: Journal of Geological Education, v. 27, p. 5.

Lillie, R.A., and Mason, J.W., 1983, Limnological characteristics of Wisconsin lakes: Wisconsin Department of Natural Resources Technical Bulletin 138, 116 p.

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1975, Hydrology for engineers (2d ed.): New York, McGraw-Hill Book Co., 482 p.

Mortimer, C.H., 1941, The exchange of dissolved substances between mud and water in lakes: Journal of Ecology, v. 29, p. 280-329.

_____1942, The exchange of dissolved substances between mud and water in lakes: Journal of Ecology, v. 30, p. 147-201.

Nurnberg, G.K., and Peters, R.H., 1984, The importance of internal phosphorus load to the eutrophication of lakes with anoxic hypolimnia: Verhandlung Internationale Vereinigung Limnologie, v. 22, p. 190-194.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chap. C3, 66 p.

Prescott, G.W., 1970, The freshwater algae (2d ed.): Dubuque, Iowa, W.C. Brown Company, University of Montana, 348 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Rapavich, W.M., Sonzogni, W.C., Standridge, J.H., Vennie, J.G., and Wedepohl, R.E., 1987, Incidence of algal toxins in Wisconsin water experiencing blue-green algae blooms: Wisconsin State Laboratory of Hygiene and Wisconsin Department of Natural Resources, Informational Paper, 8 p.

Sonzogni, W.D., 1974, Effect of nutrient input reduction on the eutrophication of the Madison lakes: University of Wisconsin, Ph.D. thesis, 342 p.

Stauffer, R.E., 1974, Thermocline migration algal bloom relationships in stratified lakes: University of Wisconsin, unpublished Ph.D. thesis, 352 p.

Theis, T. L., and McCabe, P. J., 1978, Phosphorus dynamics in hypereutrophic lake sediments: Water Research Bulletin, v. 12, no. 9, p. 667-685.

U.S. Department of Commerce, 1982, Evaporation atlas for the contiguous 48 United States: Washington, D.C., NOAA Technical Report NWS33, National Oceanic and Atmospheric Administration, National Weather Service.

U.S. Department of Commerce, 1987, Climatological data, annual summary: National Oceanic and Atmospheric Administration, v. 92, no. 13, 27 p.

_____1988, Climatological data, annual summary: National Oceanic and Atmospheric Administration, v. 93, no. 13, 26 p.

_____1989, Climatological data, annual summary: National Oceanic and Atmospheric Administration, v. 94, no. 13, 26 p.

U.S. Environmental Protection Agency, 1977, Guidelines for the pollutional classification of Great Lakes Harbor sediments: Environmental Protection Agency, Region V.

_____1988, The lake and reservoir restoration guidance manual: EPA 44015-88-002, Norton American Lake Management Society, 214 p.

U.S. Geological Survey, 1986-90, Water resources data--Wisconsin, water years 1985-89: U.S. Geological Survey Water Data Reports WI-85-1 through WI-89-1 (published annually).

Vollenweider, R.A., 1975, Input-output models with special reference to the phosphorus loading concept in limnology: Schweizerische Zeitschrift fur Hydrologie, v. 37, no. 1, p. 58-84.

Walkotten, W.J., 1976, An improved technique for sampling streambed sediments: U.S. Department of Agriculture Forest Service, Research Note PNW-281, Pacific Northwest Forest and Range Experimental Station, Portland, Oreg., 11 p.

Wetzel, R.G., 1983, Limnology (2d ed.): Philadelphia, Saunders, 767 p.

Wisconsin Department of Natural Resources, 1969, Wind Lake, Racine County, an inventory with planning recommendations: Lake-use Report FX-5, 6 p.

_____1971, Big Muskego Lake, Waukesha County, An inventory with planning recommendations: Lake-use report FX-3, 22 p.

_____1981, Wisconsin lakes: 89 p.

_____1983, Big Hills Lake, Waushara County, feasibility study results: Bureau of Water Resources Management, Management Alternatives, 10 p.

Wisconsin State Laboratory of Hygiene, Environmental Sciences Section, 1980, Manual of analytical methods, inorganic chemistry unit: Wisconsin State Laboratory of Hygiene, 398 p.

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).

Algae, algal.--A group of simple primitive plants that live in wet or damp places, generally 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 or more per liter of water (Britton and others, 1975).

Anaerobic.--Devoid of oxygen (Britton and others, 1975).

Anoxic.--See anaerobic (Britton and others, 1975).

Autumn turnover.--The mixing of the entire water mass of a lake in the autumn (Britton and others, 1975).

Base flow.--See Base runoff.

Base runoff.--Sustained or fair weather runoff. In most streams, base runoff is composed largely of ground-water effluent (Langbein and others, 1947).

Blue-green algae.--A group of algae with a blue pigment in addition to the green chlorophyll. The blue-green algae group usually causes nuisance conditions in water (Britton and others, 1975).

Chlorophyll *a*.--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).

Cubic feet per second.--A unit expressing rate of discharge. One cubic foot per second is equal a flow of water through a rectangular cross section, 1 foot wide and 1 foot deep, at an average velocity of 1 foot per second (Langbein and Iseri, 1960).

Diatom.--A unicellular or colonial alga having a siliceous shell (Britton and others, 1975).

Discharge.--The volumed or mass of water or a constituent passing a transect of channel in a unit of time. Discharge is a rate, usually expressed as a volume or mass per unit time--for example, cubic feet per second, grams per second, tons per day (modified from Alt and Iseri, 1986).

Dolomite.--A mineral, calcium-magnesium-carbonate, commonly with some iron replacing magnesium (Bates and Jackson, 1980).

Drainage area.--The drainage area of a stream at a specified location is the area, measured in a horizontal plane, that 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 together with all tributary surface streams and bodies of impounded surface water (Langbein and Iseri, 1960).

Ecosystem.--The community of plants and animals interacting together with the physical and chemical environment (Britton and others, 1975).

Epilimnion, epilimnetic.--The upper, relatively warm, circulating zone of water in a thermally stratified lake (Britton and others, 1975).

Eutrophication, eutrophic.--The natural process of enrichment and aging of a body of water that can be accelerated by human activity. Pertains to water bodies in which primary production is high because of a large supply of available nutrients (Britton and others, 1975).

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 and 10 inches deep. It is 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).

Evaporation, total.--The sum of water lost from a given land area during any specific time by transpiration from vegetation and building of plant tissue; by evaporation from water surfaces, moist soil, and snow; and by interception. It has been variously termed "evaporation," evaporation from land areas," "evapotranspiration," total loss," "water losses," and "fly off" (Langbein and Iseri, 1960).

Green algae.--Algae that have pigments similar in color to those of higher green plants. Some forms produce algal mats or floating "moss" in lakes (Britton and others, 1975).

Hardness (water).--A property of water that causes the formation of an insoluble residue when the water is used with soap and a scale in vessels in which water has been allowed to evaporate. It is due primarily to the presence of ions of calcium and magnesium. Generally expressed as milligrams per liter as calcium carbonate ($CaCO_3$) (Durfor and Becker, 1964). A general hardness scale is:

Description	Milligrams per liter as $CaCO_3$
Soft	0-60
Moderately Hard	61-120
Hard	121-180
Very Hard	More than 180

Hydraulic conductivity.--A measure of the ability of an aquifer to transmit water and is defined as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

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 most, relatively cold, noncirculating water zone in a thermally stratified lake (Britton and others, 1975).

Load.--The amount, by mass or volume, of a substance transported by a stream past a specific point (Kuhn and others, 1983).

Maximum depth.--The vertical distance (could be meters) between the lowest point on the lake bottom and the surface of the lake at its maximum stage (Dion and others, 1976).

Mean depth.--The mean depth 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, because of a moderate supply of nutrients. (See also Eutrophic and Oligotrophic.) (Britton and others, 1975).

Metalimnion, metalimnetic.--The middle layer of water in a thermally stratified lake, in which temperature decreases rapidly with depth (Britton and others, 1975).

Nutrient.--Any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes (Britton and others, 1975).

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

Organic.--Pertaining or relating to a compound containing carbon, especially as an essential component. Organic compounds usually have hydrogen bonded to the carbon atom (Bates and Jackson, 1980).

Orthophosphate.--The dissolved form of phosphorus that is immediately useful for algae (Cole, 1979).

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).

Phytoplankton, phytoplanktonic.--The plant part of the plankton (Britton and others, 1975).

Piezometer.--A tube on a pipe with a slotted intake at the bottom in which elevations of water levels can be determined (Freeze and Cherry, 1979).

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

Secchi depth.--Secchi-disc visibility is the depth at which a Secchi disk (a white-and-black disc 8 inches in diameter) disappears from view when lowered into the water. Secchi depth is a measure of water transparency or clarity. Because changes in biological production can cause changes in the color and turbidity of a lake, Secchi depth is often used as a gross measure of the density of plankton in the water (modified from Dion and others, 1976).

Sediment.--Fragmental material, 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 (Britton and others, 1975).

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).

Solubility.--The total amount of solute species that can be retained permanently in solution under a given set of conditions (fixed temperature and pressure) and in the presence of an excess of undissolved material of definitely known composition and crystal structure from which the solute is derived (Hem, 1985).

Species.--The basic or final unit for the classification of organisms (Britton and others, 1975).

Specific conductance.--Specific conductance is a measure of 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 degrees Celsius (Dion and others, 1976).

Spring turnover.--The mixing of the entire water mass of a lake in the spring.

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 can be applied to discharge whether or not it is affected by diversion or regulation (Langbein and Iseri, 1960).

Streamflow-gaging station.--A gaging station where a record of discharge of a stream is obtained. Within the Geological Survey this term is used only for those gaging stations where a continuous record of discharge is obtained (Langbein and Iseri, 1960).

Surface runoff.--That part of the runoff which travels over the soil surface to the nearest stream channel (Langbein and Iseri, 1960).

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

Thermal stratification (of a lake).--Vertical temperature stratification that consists of the following: The uppermost 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, known as the hypolimnion, in which the temperature from its upper limit to the bottom is nearly uniform (Langbein and Iseri, 1960).

Till.--Nonsorted, nonstratified sediment carried or deposited by a glacier (Bates and Jackson, 1980).

Unconsolidated material.--(a) A sediment that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at surface or at depth. (b)

Soil material that is in a loosely aggregated form (Bates and Jackson, 1980).

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 (Britton and others, 1975).

Water year.--In Geological Survey reports dealing with surface-water resources, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year that ended September 30, 1959, is called the "1959 water year" (Langbein and Iseri, 1960).

Yield.--A measurement of load or discharge per unit area--for example, tons per square mile, grams per square centimeter per day, tons per square mile per year (Alt and Iseri, 1986).

Zooplankton, zooplanktonic.--The animal part of the plankton (Britton and others, 1975).

APPENDIXES I - IV

Appendix I. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1988

[--, indicates organism not observed]

	Density in cells per milliliter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
BACILLARIOPHYTA	596	596	223	340	451	80	5892	179	65	19	17	105	--	--	40	263	--	389
Order Centrales																		
Chaetoceros sp.	--	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	--
Melosira granulata var. *angustissima*	--	170	15	11	--	--	--	--	--	--	--	--	--	--	--	113	--	--
Melosira italica	284	341	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhizosolenia longiseta	28	--	--	47	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus alpinus ?	--	28	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus hantzschii	--	--	--	--	8	23	589	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus invisitatus ?	--	--	--	36	325	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus niagarae	--	--	93	131	--	--	--	179	21	--	17	--	--	--	--	--	--	--
Order Pennales																		
Achnanthes clevei var. *rostrata*	--	--	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Achnanthes deflexa	--	--	--	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Achnanthes minutissima	--	--	--	11	--	--	--	--	--	--	--	--	--	--	40	75	--	--
Achnanthes sp.	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	63
Asterionella formosa	284	--	2	44	34	--	1677	--	--	--	--	--	--	--	--	--	--	--
Cocconeis placentula	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cocconeis placentula var. *lineata*	--	--	--	--	--	--	--	--	44	--	--	--	--	--	--	--	--	--
Cocconeis sp.	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella microcephala var. *crassa*	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella sp.	--	--	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Diatoma elongatum	--	--	--	--	--	--	121	--	--	--	--	--	--	--	--	--	--	--
Fragilaria construens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	75	--	--
Fragilaria crotonenis	--	--	16	--	--	--	349	--	--	--	--	--	--	--	--	--	--	326
Fragilaria leptostauron	--	--	--	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fragilaria vaucheriae	--	--	76	27	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hantzschia amphioxys	--	--	--	--	--	--	159	--	--	--	--	--	--	--	--	--	--	--
Navicula lacustris	--	--	--	--	--	--	80	--	--	--	--	--	--	--	--	--	--	--
Navicula mutica	--	--	--	--	--	--	--	--	--	19	--	--	--	--	--	--	--	--
Navicula oblonga	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Navicula pseudoreinhardtii var. *pseudoreinhardtii*	--	--	--	--	--	--	--	--	--	--	--	42	--	--	--	--	--	--
Navicula rhyncocephala	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix I. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1988--Continued

	Density in cells per milliliter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
Navicula sp.	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia acicularis	--	--	--	--	--	--	--	--	--	--	--	63	--	--	--	--	--	--
Nitzschia acuta	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia kutzingiana	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia palea	--	--	--	1	4	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia paleacea	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia subtilis	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia sp.	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Synedra acus var. *radians*	--	--	--	--	--	57	2917	--	--	--	--	--	--	--	--	--	--	--
Synedra delicatissima	--	--	6	--	74	--	--	--	--	--	--	--	--	--	--	--	--	--
Synedra ulna	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Synedra sp.	--	57	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chlorophyta	3889	4743	3264	2365	2139	993	4447	9782	3955	9182	16144	7142	6664	18146	3435	1811	11742	2902
Ankistrodesmus convolutus	--	--	--	--	--	18	57	--	--	--	--	--	--	--	--	--	--	--
Ankistrodesmus falcatus var. *mirabilis*	--	--	788	675	--	167	81	--	--	--	--	--	--	--	--	--	--	8
Ankistrodesmus falcatus var. *tumidus*	--	--	--	--	--	--	--	--	--	--	--	--	188	--	--	--	--	--
Botryococcus braunii	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1757	--	--	--
Chlamydomonas epiphytica	--	--	--	--	--	308	1033	137	121	126	136	41	--	--	--	--	--	--
Chlamydomonas globosa	--	--	--	--	--	462	1481	663	284	147	447	342	--	--	--	--	--	--
Chlamydomonas sp. 1	--	--	--	--	--	--	--	--	--	--	--	--	--	1835	--	38	412	--
Chlamydomonas sp. 2	--	--	--	--	--	--	--	--	--	--	--	--	--	306	--	--	206	--
Chlamydomonas sp. 3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	103	--
Chlamydomonas sp. 4	--	--	--	338	450	--	--	--	--	--	--	--	--	--	--	--	--	--
Chlorococcum humicola	--	--	--	--	--	--	424	916	764	143	3261	295	--	--	--	--	--	221
Chlorococcum sp.	28	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Closteriopsis longissima	57	57	--	--	338	--	--	--	--	--	--	37	--	204	--	--	309	--
Closterium gracile	28	1818	--	113	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Closterium sp.	369	--	--	--	--	--	--	--	25	105	--	--	--	--	40	--	--	--
Coelastrum microporum	--	--	900	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coelastrum sphaericum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3399	--
Cosmarium bioculatum	--	--	--	--	--	--	--	210	67	--	26	--	--	--	--	--	--	--
Cosmarium circulare	--	--	--	--	--	--	--	--	21	--	92	--	--	--	--	--	--	--
Cosmarium depressum var. *achondrumi*	--	--	--	--	--	--	--	--	63	--	--	--	--	--	--	--	--	--
Cosmarium sp.	--	--	--	--	--	--	--	--	--	--	--	--	751	1223	--	--	412	--
Crucigenia quadrata	454	227	--	--	--	--	--	588	--	--	--	--	--	--	--	--	--	--
Crucigenia tetrapedia	--	--	--	--	--	--	--	--	--	--	--	--	--	2039	--	--	412	--

Appendix I. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1988--Continued

	Density in cells per milliliter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
Crucigenia sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	302	1236	--
Dictyosphaerium pulchellum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	412	--
Dimorphococcus lunatus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2568
Elakatothrix viridis	142	57	--	--	--	--	--	126	--	--	42	--	--	--	--	--	--	--
Eudorina elegans	--	284	--	--	--	--	--	408	--	--	--	--	--	--	--	--	--	--
Franceia Droescheri	--	--	--	--	113	38	126	189	42	42	22	42	--	--	--	--	--	--
Gloeocystis sp.	--	341	--	--	--	--	--	--	--	--	--	--	--	816	--	--	--	--
Golenkinia radiata	--	--	--	--	563	--	--	--	--	--	--	--	--	--	--	--	--	--
Gonatozygon pilosum	--	--	--	--	--	--	83	--	--	--	--	--	--	--	--	--	--	--
Gonium sp.											--	--	--	408	--	--	--	--
Heteromastix sp.	--	--	--	--	225	--	--	--	--	--	--	--	--	--	--	--	--	--
Oocystis elliptica	--	--	--	--	--	--	--	--	64	84	--	121	--	--	--	--	--	--
Oocystis gloecystiformis	--	85	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oocystis nodulosa	312	568	--	450	--	--	--	324	53	284	1527	1402	--	--	--	--	--	--
Oocystis novae-semliae	341	227	--	--	--	--	--	844	410	3884	4479	1363	--	--	--	--	--	105
Oocystis solitaria	312	28	225	--	--	--	--	383	584	1021	1434	884	--	--	--	--	--	--
Oocystis sp. 1	142	341	338	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oocystis sp. 2	--	114	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oocystis spp.	--	--	--	--	--	--	--	--	--	--	--	--	3660	7645	160	151	4429	--
Pandorina morum	--	227	--	--	--	--	--	3722	612	1846	2872	244	--	--	--	--	--	--
Pediastrum boryanum	--	--	675	--	--	--	--	--	--	1046	--	896	--	--	--	--	--	--
Pleodorina illinoisensis	--	--	--	--	--	--	--	--	--	--	--	--	1314	--	--	--	--	--
Scenedesmus abundans	57	--	--	450	--	--	284	688	304	--	48	326	--	--	--	--	--	--
Scenedesmus armatus var. *bicaudatus*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	160	--	--	--
Scenedesmus dimorphus	--	--	--	--	--	--	158	72	--	--	--	--	--	--	--	--	--	--
Scenedesmus quadricauda	--	--	--	--	--	--	--	364	--	--	--	--	--	--	--	--	--	--
Scenedesmus quadricauda var. *maximus*	114	--	--	--	--	--	720	--	328	221	1728	1063	--	--	--	--	--	--
Scenedesmus sp.	284	114	--	--	--	--	--	--	--	--	--	--	563	1121	--	151	412	--
Selenastrum minutum	142	--	225	113	450	--	--	--	--	--	--	--	--	--	--	--	--	--
Sorastrum spinulosum	--	--	--	--	--	--	--	--	63	--	--	--	--	--	--	--	--	--
Sphaerocystis schroeteri	1079	227	--	--	--	--	--	--	--	--	--	--	--	2243	1278	1169	--	--
Staurastrum paradoxum	--	--	--	--	--	--	--	--	21	21	--	--	--	--	--	--	--	--
Staurastrum planum	--	--	--	--	--	--	--	--	--	--	30	--	--	--	--	--	--	--
Staurastrum sp.	28	--	--	113	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tetraëdron minimum	--	28	113	113	--	--	--	--	84	23	--	63	188	--	40	--	--	--
Tetraëdron pentaedrium	--	--	--	--	--	--	--	--	45	--	--	23	--	--	--	--	--	--
Tetraspora sp.	--	--	--	--	--	--	--	168	--	--	--	--	--	--	--	--	--	--
Unidentified chlorophyte	--	--	--	--	--	--	--	--	--	189	--	--	--	--	--	--	--	--
Unidentified green algal flagellate	--	--	--	--	--	--	--	--	--	--	--	--	--	306	--	--	--	--

Appendix I. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1988--Continued

	Density in cells per milliliter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
Chrysophyta	28	--	113	788	11930	11189	744	263	--	--	--	--	657	612	--	--	309	--
Dinobryon divergens	28	--	--	--	--	--	--	263	--	--	--	--	--	--	--	--	--	--
Dinobryon sertularia	--	--	113	788	11705	11161	744	--	--	--	--	--	--	--	--	--	--	--
Dinobryon sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	103	--
Rhizochrysis limnetica	--	--	--	--	--	28	--	--	--	--	--	--	--	--	--	--	--	--
Small chrysophyte flagellates	--	--	--	--	--	--	--	--	--	--	--	--	657	612	--	--	206	--
Unicellular flagellate	--	--	--	--	225	--	--	--	--	--	--	--	--	--	--	--	--	--
Cyanophyta	407710	103830	106357	73945	36016	15863	36403	104418	56408	40322	113636	277174	1601605	1100031	361152	365037	1148665	117151
Anabaena sp.	--	--	--	--	--	--	--	735	--	--	--	--	--	--	4113	--	--	--
Aphanizomenon sp.	454	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Aphanocapsa delicatissima	--	--	--	6415	--	--	--	--	--	--	--	--	929359	834071	292787	287760	933515	116615
Aphanocapsa elachista	--	--	--	--	--	--	--	14374	10422	--	37497	--	--	--	6948	5205	--	--
Aphanocapsa elachista var. *conferta*	369484	94515	4389	45919	25211	9040	18725	--	--	3088	--	34566	--	--	--	--	--	--
Aphanocapsa elachista var. *planktonica*	--	--	71242	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Aphanothece clathrata	26412	--	25323	13168	8441	--	--	--	--	--	--	--	463929	63101	6230	--	38622	--
Aphanothece sp.	--	--	--	--	900	--	--	--	--	--	--	--	--	--	5151	--	--	--
Chroococcus dispersus	57	114	788	2026	--	--	--	--	--	--	--	--	2252	6320	3993	--	4326	--
Chroococcus limneticus	341	--	675	338	338	--	--	432	--	--	651	527	188	--	--	--	--	--
Chroococcus minimus	--	--	3039	--	1126	6563	14318	--	--	--	--	--	--	--	--	--	--	--
Chroococcus minutus	4658	2158	--	3039	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chroococcus prescotii	--	--	--	--	--	--	--	--	--	--	--	--	1501	--	--	--	--	--
Chroococcus turgidus	--	--	--	450	--	--	--	--	--	--	--	--	375	1427	--	151	1030	--
Chroococcus sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	80	--	--	140
Coelosphaerium sp.	1079	4771	--	563	--	--	--	--	--	--	--	--	1126	--	--	21422	9269	--
Dactylococcopsis acicularis	--	--	--	--	--	--	--	105	--	--	35	--	--	--	--	--	--	--
Gloeothece linearis	--	--	225	563	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gomphosphaeria lacustris	--	--	--	--	--	--	--	--	1205	446	419	5608	25336	13558	15734	23043	66841	--
Lyngbya birgei	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2753	1030	--
Lyngbya contorta (filaments)	--	--	--	--	--	260	892	42	--	21	--	19	--	--	--	--	--	--
Lyngbya limnetica	227	682	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Marssoniella elegans	1250	1022	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Merismopedia punctata	--	--	--	--	--	--	--	--	564	--	--	--	--	--	--	--	--	--
Merismopedia tenuissima	511	--	--	--	--	--	--	--	--	--	--	3328	--	1631	--	--	--	--
Microcystis aeruginosa	--	--	--	--	--	--	--	84284	44217	36767	75034	233126	--	--	19088	8071	--	--
Oscillatoria angusta	--	--	--	1126	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix I. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1988--Continued

	Density in cells per milliliter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
Oscillatoria tenuis	--	--	--	--	--	--	1566	4446	--	--	--	--	--	--	--	--	--	--
Oscillatoria sp.	227	227	--	--	--	--	--	--	--	--	--	--	--	4689	--	2489	16582	--
Phormidium autumnale	--	--	--	--	--	--	902	--	--	--	--	--	--	--	--	--	--	--
Phormidium corium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	396
Phormidium sp.	3010	341	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pseudanabaena sp.	--	--	563	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Spirulina sp.	--	--	113	113	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Synechococcus sp.	--	--	--	--	--	--	--	--	--	--	--	--	177539	175234	7028	14143	77450	--
Synechocystis sp.	--	--	--	225	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrrhophyta	--	--	--	--	--	--	--	--	--	--	53	--	94	102	40	--	206	--
Ceratium hirundinella	--	--	--	--	--	--	--	--	--	--	53	--	--	102	40	--	103	--
Unidentified dinoflagellates	--	--	--	--	--	--	--	--	--	--	--	--	94	--	--	--	103	--
Cryptophyta	397	426	338	225	901	115	185	133	--	--	435	--	1689	1121	40	--	721	168
Cryptomonas erosa	--	--	--	--	--	--	--	--	--	--	--	--	--	102	40	--	103	168
Cryptomonas ovata	--	--	225	--	113	115	185	133	--	--	435	--	--	--	--	--	--	--
Cryptomonas sp.	28	170	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhodomonas minuta	369	256	113	225	788	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhodomonas sp.	--	--	--	--	--	--	--	--	--	--	--	--	1689	1019	--	--	618	--
Euglenophyta																		
Trachelomonas sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	38	--	--
Total cells per milliliter	412620	109595	110295	77663	51437	28240	47671	114775	60428	49523	130285	284421	1610709	1120012	364707	367149	1161643	120610
Number of species	34	30	31	48	22	13	24	26	25	20	22	23	18	23	19	18	26	10
Dry weight milligrams per liter	5.1	6.7	8.9	3.8	4.4	2.5	0.9	8.3	14.7	15.1	8.8	6.2	5.0	4.0	21.0	14.0	5.0	5.1

Appendix II. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1989

[--, indicates organism not observed]

	Density in cells per milliliter, on given date			
	10/18 1988	6/07 1989	7/11	8/08
Bacillariophyta	3253	108	544	1086
Order Centrales				
Cyclotella atomus	--	--	105	21
Melosira granulata	3246	--	--	251
Melosira italica	--	--	146	251
Stephanodiscus niagare	3	--	--	--
Stephanodiscus sp.	--	--	21	21
Order Pennales				
Achnanthes minutissima	--	6	--	82
Asterionella formosa	--	--	9	54
Cocconeis sp.	--	6	3	27
Fragilaria brevistrata	--	--	6	--
Fragilaria construens	--	--	76	136
Fragilaria construens var. *venter*	--	--	36	--
Fragilaria crotonensis	--	90	18	--
Fragilaria leptostauron var. *dubia*	--	--	15	--
Fragilaria vaucheriae	--	--	--	54
Navicula gottlandica	--	--	--	27
Navicula sp.	--	6	6	--
Nitzschia acicularis	--	--	6	--
Nitzschia linearis	--	--	12	27
Nitzschia paleacea	--	--	76	54
Nitzschia sp.	4	--	--	--
Synedra radians	--	--	9	54
Synedra sp.	--	--	--	27
Chlorophyta	7329	981	4080	4080
Actinastrum hantzschii	--	--	--	2176
Ankistrodesmus falcatus	--	109	--	--
Ankyra judayi	--	327	544	--
Chlorella sp.	--	--	272	--
Chlorococcum humicola	284	--	--	--
Chlorococcum sp.	--	218	--	272
Chlorogonium sp.	--	--	--	272
Closterium gracile	--	--	--	272
Dimorphococcus lunatus	6638	--	--	--
Eudorina elegans	263	--	--	--
Franceia Droescheri	9	--	--	--
Mougeotia sp.	87	--	--	--

Appendix II. Species, density, and dry weight of phytoplankton collected from Wind Lake, Wisconsin, water year 1989--Continued

	Density in cells per milliliter, on given date			
	10/18 1988	6/07 1089	7/11	8/08
Oocystis solitaria	47	--	--	--
Oocystis sp.	--	109	--	544
Selenastrum minutum	--	--	--	544
Staurastrum sp.	1	--	--	--
Schroederia setigera	--	109	--	--
Sphaerocystis schroeteri	--	--	3264	--
Tetraëdron minimum	--	109	--	--
Chrysophyta				
Unknown flagellate	--	1853	4080	2720
Cyanophyta	145652	12099	112336	82144
Aphanizomenon flos-aquae	--	7521	--	544
Aphanocapsa delicatissima	145652	1526	22032	11424
Aphanocapsa elachista				
var. *conferta*	--	--	8160	18496
Aphanothece clathrata	--	2507	21760	29104
Aphanothece saxicola	--	--	55760	10880
Chroococcus dispersus	--	109	--	2448
Chroococcus sp.	--	--	1360	2176
Glaucocystis sp.	--	109	--	1088
Lyngbya limnetica	--	109	--	--
Microcystis aeruginosa	--	--	544	--
Microcystis incerta	--	--	--	2448
Pseudanabaena catenata	--	218	--	--
Synechococcus sp.	--	--	2720	3536
Euglenophyta				
Trachelomonas sp.	--	109	--	--
Pyrrophyta				
Ceratium hirundinella	--	--	272	--
Cryptophyta	134	1090	1904	2448
Cryptomonas erosa	126	--	--	--
Cryptomonas ovata	8	--	--	--
Rhodomonas minuta	--	1090	1904	2448
Total cells per milliliter	156368	16240	123216	92478
Number of species	13	20	28	32
Dry weight (milligrams per liter)	13.6	0.5	2.7	7.9

Appendix III. Species, density, and biomass of net zooplankton collected from Wind Lake, Wisconsin, water year 1988

[--, indicates organism not observed]

	Density in organisms per cubic meter, on given date																	
	10/15 1987	10/29	11/17	12/10	1/28 1988	2/16	4/8	5/2	5/11	5/25	6/7	6/22	7/7	7/18	8/10	8/23	9/7	9/21
Protozoa	1206	--	--	--	--	--	--	--	391	2414	81183	10714	1428	3741	4310	617	238	4331
Ceratium hirundinella	1206	--	--	--	--	--	--	--	391	2414	81183	10714	1428	3741	4310	617	238	--
Ceratium sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4331
Rotatoria	--	--	5973	1151	4896	11029	162097	275390	194531	26552	12366	18429	82142	5174	1293	3087	5477	394
Asplanchna sp.	--	--	5973	1151	576	842	34946	1172	3125	1724	10753	18429	--	570	431	309	1667	--
Filinia longiseta	--	--	--	--	--	--	24731	17578	1953	--	--	--	--	293	--	--	1667	197
Kellicottia longispina	--	--	--	--	4320	9950	96237	246875	165234	12759	1075	--	714	2879	--	309	--	197
Keratella cochlearis	--	--	--	--	--	--	269	781	391	345	--	--	--	--	--	--	--	--
Keratella quadrata	--	--	--	--	--	237	5914	8984	23828	11724	538	--	714	570	--	--	238	--
Philodina sp.	--	--	--	--	--	--	--	--	--	--	--	--	80714	862	862	2469	1905	--
Crustacea																		
Cladocera	110167	74202	65704	65005	71140	19180	67205	322657	270704	76552	87635	89143	34206	39948	65948	47839	57619	25787
Alona sp.	--	--	--	--	--	597	269	391	781	345	538	--	--	--	--	--	714	--
Bosmina longirostris	15279	20274	27476	32215	21025	10432	7258	14453	42969	27931	18280	4714	4286	2017	2155	617	4286	3937
Chydorus sphaericus	--	--	--	--	--	--	57796	293750	176563	12414	4839	5143	--	--	1293	1543	2619	984
Daphnia catawba	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20866
Daphnia dubia	94888	52712	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Daphnia galeata mendotae	--	--	38228	32790	50115	--	--	--	--	--	--	--	--	--	--	--	--	--
Daphnia pulex	--	1216	--	--	--	8151	1882	14063	50391	35862	63978	79286	30000	37931	62500	45679	50000	--
Copepoda	50259	51090	35440	33941	99943	22302	50000	87501	98047	38276	74731	54857	67857	62655	29310	15432	37143	26574
Diacyclops bicuspidatus thomasi	39001	43791	27476	22052	75749	14388	30645	69141	73047	13448	12903	6000	13571	15241	12500	2778	8571	7677
Diaptomus ashlandi	11258	6488	5973	11697	23906	7554	8602	8594	15234	17931	48387	46714	39286	32759	15086	10494	24048	16929
Nauplii	--	811	1991	192	288	360	10753	9766	9766	6897	13441	2143	15000	14655	1724	2160	4524	1968
Total number per cubic meter	161632	125292	107117	100097	175979	52511	279302	685548	563673	143794	255915	173143	185713	111518	100861	66975	100477	57086
Number of species	5	5	5	5	6	8	11	11	12	11	10	7	8	10	8	9	11	8
Dry weight (grams per cubic meter)	0.5434	0.3411	0.6446	0.3998	0.7667	0.0957	0.2140	0.2625	0.2672	0.1586	0.2086	0.3174	0.2471	0.2879	0.1966	0.0975	0.2981	0.2307

Appendix IV. Species, density, and biomass of net zooplankton collected from Wind Lake, Wisconsin, water year 1989

[--, indicates organism not observed]

	Density in organisms per cubic meter, on given date			
	10/18 1988	6/07 1989	7/11	8/08
Protozoa				
Ceratium hirundinella	2726	6949	54647	875
Rotatoria	1514	10907	1740	4530
Asplanchna sp.	--	10907	1044	522
Kellicottia longispina	--	--	696	3486
Keratella cochlearis	1514	--	--	170
Philodina sp.	--	--	--	352
Crustacea				
Cladocera	77528	39194	28542	10614
Alona sp.	--	1741	--	--
Bosmina longirostris	23016	253	--	--
Chydorus sphaericus	2120	2485	--	4178
Daphnia catawba	50878	--	--	--
Daphnia dubia	--	5952	8006	5392
Daphnia pulex	1514	26531	13923	--
Daphnia retrocurva	--	--	--	1044
Daphnia rosea	--	2232	6613	--
Copepoda	42398	19582	46293	45601
Diacyclops bicuspidatus thomasi	20594	5699	10442	14791
Diaptomus ashlandi	18776	7931	21928	27507
Nauplii	3028	5952	13923	3303
Total number per cubic meter	124166	76632	131222	61620
Number of species	8	10	8	10
Dry weight (grams per cubic meter)	0.8025	0.7158	0.3802	0.3268