HYDROLOGY AND WATER QUALITY OF POWERS LAKE, SOUTHEASTERN WISCONSIN

by Stephen J. Field

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 90-4126

Prepared in cooperation with the
POWERS LAKE MANAGEMENT DISTRICT

Madison, Wisconsin
1993

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

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

Copies of this report may be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Denver Federal Center, Box 25425
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION TABLE AND ABBREVIATIONS

For the use of readers who prefer the metric (International System) units, the conversion factors for the inch-pound units used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
pound (lb)	453.6	gram (g)
acre	0.4047	hectare (ha)
gallon (gal)	0.003785	cubic meter (m^3)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature, in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation: $°F = 9/5\ °C + 32$.

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

HYDROLOGY AND WATER QUALITY OF POWERS LAKE, SOUTHEASTERN WISCONSIN

By Stephen J. Field

ABSTRACT

This report describes the hydrology and water quality of Powers Lake, a recreational lake in a densely populated area of southeastern Wisconsin, from October 16, 1986 - October 15, 1987.

The hydrologic budget for the study period showed that direct precipitation on the lake and ground water were dominant sources of water entering the lake (37 and 36 percent, respectively) and that streamflow dominated the outflow. Surface runoff contributed 27 percent of the inflow--23 percent from Powers Lake inlet and 4 percent from shoreline drainage. Streamflow through Powers Lake outlet accounted for 62 percent of the outflow and evaporation accounted for 38 percent. Based on the streamflow from Powers Lake outlet, the lake's hydraulic residence time was 3.8 years.

During the study period, precipitation was 27.16 inches or 4.08 inches below long-term (1951-80) average. The data were adjusted or normalized to represent an average year of precipitation and runoff to help evaluate the water quality of the lake for an average year. For an average year, precipitation dominated inflow (42 percent), followed by ground water (32 percent), Powers Lake inlet (21 percent), and shoreline drainage (5 percent). Streamflow through Powers Lake outlet accounted for 61 percent of an average year's outflow budget and the remaining 39 percent was evaporation. Based on an average year's streamflow from Powers Lake outlet, the lake's hydraulic residence time was 4.2 years.

Phosphorus budgets were prepared for the study period and for an estimated normal year. The phosphorus budget for the study period showed that, of the total inputs (516 pounds), surface runoff contributed the largest amount; shoreline drainage contributed 44 percent, and Powers Lake inlet contributed 36 percent. Direct precipitation contributed 11 percent; ground water, 2 percent; and septic systems, 7 percent. Of the total outputs, 83 pounds (16 percent) was lost from the lake via the outlet; 433 pounds (84 percent) was lost to the sediments as the phosphorus that was attached to particles settled to the lake bottom. An estimated phosphorus budget for a normal year showed that of the total inputs (744 pounds), surface runoff contributed the largest amount; Powers Lake inlet contributed 45 percent and shoreline drainage contributed 35 percent. Precipitation contributed 9 percent; ground water, 1 percent; and septic systems, 10 percent.

The health of the lake was evaluated using Carlson's Trophic State Index and Vollenweider's model. Carlson's Trophic State Index showed that Powers Lake was moderately enriched and in the mesotrophic range. Comparison of guidelines from Vollenweider's model showed that the total phosphorus input for the study period and for an estimated average year would not cause eutrophic conditions.

INTRODUCTION

Background

Powers Lake is located in Kenosha and Walworth Counties in southeastern Wisconsin (fig. 1). It is close to large cities, Milwaukee, 40 mi (miles) to the northeast, and Chicago, Ill., 50 mi to the southeast, and is used extensively for recreational purposes--swimming, fishing, and boating. Despite the apparently good water quality of Powers Lake, concerns about future water quality were expressed by some of the more than 600 residents in the area. In 1985, some of these concerned individuals formed the Powers Lake Management District under chapter 33 of the Wisconsin Statutes. Under this Statute, such a district can be formed (Wisconsin Statutes, Chapter 33.21) and taxes levied to manage the lake (Wisconsin Statutes, Chapter 33.30(3)(c)). The Lake District Board of Commissioners felt a water-quality study of the lake was necessary to provide background information to manage the lake. A prestudy of Powers Lake was done in 1986 by the U.S. Geological Survey, in

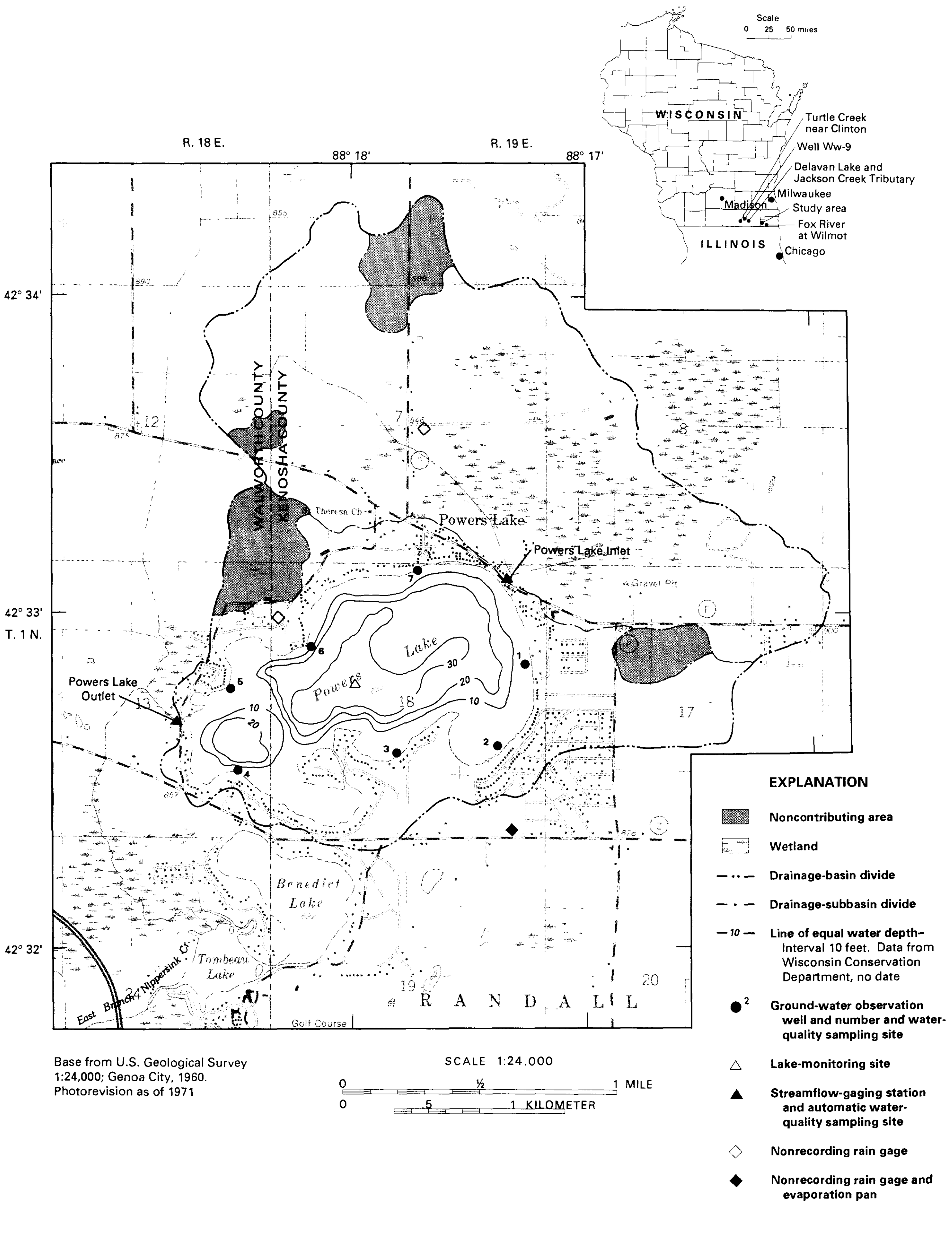


Figure 1. Powers Lake drainage basin and monitoring sites.

cooperation with the Powers Lake Management District. The prestudy consisted of sampling the lake in early March, April, June, July, and August 1986 for depth profiles of dissolved oxygen, water temperature, pH, and specific conductance. During open water, water transparency, phosphorus and chlorophyll *a* concentrations were also determined. The data from this monitoring formed the basis of the study-year monitoring plan.

Purpose and Scope

This report summarizes the results of the intensive monitoring program of Powers Lake and its drainage basin from October 16, 1986, through October 15, 1987, and provides an evaluation and interpretation of the data for use by local and State agencies for developing lake- and land-management alternatives for preserving and protecting the water quality of Powers Lake. Because prestudy data suggested that phosphorus was the nutrient limiting algal growth, phosphorus was the major emphasis of this study.

The primary objectives of the study were to determine the phosphorus loads into the lake from surface water, septic systems, ground water, and precipitation. The in-lake objectives were to: (1) determine the chemical and physical characteristics of the lake water, (2) identify the summer phytoplankton and zooplankton present, and (3) determine the phosphorus discharges from the lake from surface and ground water. Water-quality monitoring of Powers Lake continued in 1988 at a much-reduced schedule from that described in this report.

Acknowledgments

Special recognition is made of the late Marvin D. Duerk, who provided valuable assistance in collection of the data for this study. His efforts in assuring that data were collected during a variety of adverse conditions were an important part of establishing the excellent data base for this study. His contributions to water-resources studies in Wisconsin will be sorely missed in the future.

Thanks are extended to the following people who contributed to the Powers Lake project: Kenneth Koenig, U.S. Geological Survey, who collected much of the data for this study; Neal O'Reilly, Wisconsin Department of Natural Resources, who assisted in the design of the monitoring program; Thomas Perkins, Kenosha County Sanitation, for his assistance on population and septic-system data; Robert Tucker, President of the Powers Lake District Association, who supervised field observer activities; Bruce Schall, who read the evaporation pan and rain gage; David Petersen and Diane Fedyna, who read rain gages; Kathy and Douglas Stryker, who collected phosphorus samples at Powers Lake inlet; and Patricia Borchardt, who read lake stage at Powers Lake outlet.

PHYSICAL SETTING

Lake Basin and Shoreline Characteristics

The basin has moderate relief with gently undulating plains and is part of the Fox River (Illinois) system. Powers Lake is in the headwaters of the East Branch of the Nippersink River, which flows south through Tombeau Lake from the outlet of Powers Lake, then southwest where it joins the North Branch of the Nippersink River, and eventually to the Fox River.

The characteristics of Powers Lake and its drainage basin are shown in table 1. The major surface-water inflow to the lake is from an unnamed tributary, referred to in this report as Powers Lake inlet, at the northeastern end of the lake (fig. 1); this basin has a drainage area of 1.83 mi^2 (square miles). The tributary basin includes two small depressions (0.12 mi^2) that do not contribute to surface runoff, and a 0.5 mi^2 wetland in the central part.

The bridge at the inlet is a small concrete box culvert that narrows down to a 32-in. (inch) circular culvert. This culvert, if unchecked, frequently collects logs and debris that plug the culvert, reduce the flow during high flows, and raise the water upstream.

The shoreline of Powers Lake is densely populated and is occupied by 300 dwellings (Thomas Perkins, Kenosha County Sanitation, oral commun., 1988) within 300 ft (feet) of the shoreline. The shoreline area is not included in the tributary drainage to the lake. The direct (shoreline) drainage to the lake of this urbanized area is 0.88 mi^2. Twenty percent of this area consists of undrained depressions that do not contribute to overland runoff.

Table 1.--Characteristics of Powers Lake and its drainage basin

Characteristic	Measurements
Drainage areas	
Powers Lake inlet[1]	1.83 square miles
Powers Lake shoreline drainage[2]	.88 square mile
Powers Lake surface area	.71 square mile
Powers Lake outlet	3.42 square miles
Shape of lake	
Maximum length[3]	1.3 miles
Maximum width[3]	.8 mile
Shoreline length[3]	5.2 miles
Depth	
Maximum[4]	33 feet
Mean[4]	16 feet
Volume (at lake stage of 9.10 feet)	7,450 acre-feet
Hydraulic residence time (average year)	4.2 years

[1] Includes two noncontributing areas totaling 0.12 square mile.
[2] Includes two noncontributing areas totaling 0.18 square mile.
[3] Data from U.S. Geological Survey, Genoa City quadrangle, 1:24,000.
[4] Data from Wisconsin Conservation Department lake survey map (no date).

The outlet of Powers Lake is a small concrete box culvert. There is no method of controlling lake stage. Prior to the study, the channel downstream of the outlet was occupied by beavers that caused water to back up through the culvert, thereby causing the lake stages to be higher than normal. Both the inlet and outlet were unobstructed during the study period.

Watershed Characteristics

Geology

Powers Lake was formed as an ice-block depression in a terminal moraine of the Lake Michigan Glacier during the late Wisconsin glaciation (Alden, 1918) that ended about 10,000 years ago. Consolidated rocks of Precambrian, Cambrian, Ordovician, and Silurian ages underlie the area (Borman, 1976; Hutchinson, 1970). Unconsolidated Quaternary glacial deposits of outwash, ice-contact materials, and till overlie the consolidated deposits. Organic deposits formed during and after glaciation overlie these glacial deposits in part of the Powers Lake inlet basin.

Soils

Soils of the Powers Lake basin are described by Link and Demo (1970) in Kenosha County and by Haszel (1971) in Walworth County. The uplands are well-drained clay loams, silty clay loams, and gravely loams overlying sand and gravel. Dominant soils of the uplands are the Fox, Casco, and Rodman Series. Other minor upland soils at the eastern edge of the basin are the Warsaw, Plano, and St. Charles Series, which are also well-drained loam to silty clay loams overlying sand and gravel. In the low-lying areas, which are predominantly in the wetlands (fig. 1) of the Powers Lake inlet basin, very poorly drained organic soils are present. The dominant soils in these wetlands is Houghton muck.

DATA COLLECTION AND METHODS OF ANALYSIS

Water-quality samples from Powers Lake and its tributaries were analyzed by either of two laboratories. Chemical analyses of water samples at Powers Lake inlet were performed by the U.S. Geological Survey National Water Quality Laboratory using standard analytical methods described by Fishman and Friedman

(1985). Lake and well-water analyses were performed by the Wisconsin State Laboratory of Hygiene using standard analytical methods described by the Wisconsin State Laboratory of Hygiene (1980). Analyses for dissolved constituents were performed on samples that were filtered in the field through a 0.45-μm (micrometer) filter. Analyses for total or total recoverable constituents were performed on unfiltered water samples. Preservation and shipment of samples followed standard protocols established by the appropriate laboratory. All water-quality analyses are published in the U.S. Geological Survey annual data publication (U.S. Geological Survey, 1988).

Streams

Water inflow to and outflow from the lake were computed from stage and discharge measured at two locations (fig. 1)--Powers Lake inlet and Powers Lake outlet. Stages at the inlet were recorded continuously, and stages at the outlet, which served as a lake-stage record for the lake, were read daily by a local observer.

Water samples for analysis of total phosphorus were collected at the inlet by U.S. Geological Survey personnel on a monthly interval, and by a local observer during storms. Total phosphorus samples from the lake surface were assumed to represent the phosphorus concentration in water leaving the lake via the outlet, and were used to supplement samples collected at the outlet. Concentrations in concurrent samples from the outlet and from surface samples collected at the center of the lake were similar. Flow-integrated samples were collected at the inlet and outlet using the equal-width increment method described by Guy and Norman (1970). Phosphorus loads at each monitoring station were computed using the integration method described by Porterfield (1972).

Ground Water

Seven shallow wells (minipiezometers) were installed and well-water levels were measured quarterly to determine the ground-water discharge into or out of the lake. Water-quality samples were also collected quarterly from selected wells to determine the phosphorus load into the lake from ground water. The minipiezometers were installed approximately 10 ft from the shoreline and were driven into the lake bed an average depth of 3 ft. The installation and description of these small wells are described by Lee and Cherry (1978).

Precipitation and Evaporation

Precipitation quantity was monitored at three sites (fig. 1) during nonfreezing weather. Records from the National Weather Service station at Burlington, (U.S. Department of Commerce, 1986 and 1987) 10 mi to the north, were used when these stations were not operating. Because phosphorus concentrations in precipitation are low, 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, 15 mi east of Powers Lake (Field and Duerk, 1988).

Evaporation from the lake's surface was estimated using daily readings during nonfreezing periods from an evaporation pan located in the southeastern part of the basin. During freezing periods or periods when no data at Powers Lake were available, estimates were made using a linear regression of Powers Lake monthly evaporation-pan data, evaporation-pan data from Arlington, Wis., 65 mi northwest of Powers Lake (U.S. Department of Commerce, 1986 and 1987), or by a mass-transfer method for ice cover described by Dunne and Leopold (1978).

Lake Sampling

Chemical and Physical Characteristics

One site was sampled in the center of the lake at a depth of about 34 ft. Water-quality samples were collected with an Alpha-type or Kemmerer sampler[1], once a month in October, January, February, and April through September. Discrete samples were collected 1.5 ft below the water surface and 1.5 ft above the lakebed.

---

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

Depth profiles of water temperature, dissolved oxygen, and pH were determined using the sampling frequency described above using an Ocean Data Equipment Corporation meter. The meter was calibrated using known standards for pH and conductance and a Winkler titration for dissolved oxygen prior to lake sampling.

Plankton

Samples for phytoplankton and zooplankton were collected monthly in June, July, and August. Samples for phytoplankton were collected from the upper 3 ft of the lake using 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 Chadwick and Associates, 5721 South Spotswood Street, Littleton, CO 80120.

HYDROLOGY

Precipitation

Precipitation for the study period was 27.16 in. The monthly totals are shown below. The precipitation for the study period was 4.08 in. less than Burlington's long-term (1951-80) average of 31.24 in. (National Oceanic and Atmospheric Administration, 1987).

Month	Oct (16-31)	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct (1-15)
Precipitation	.34	.75	.81	.93	0	1.17	5.49	4.94	.63	3.06	6.86	1.89	.29

Evaporation

Evaporation from the lake surface during the study period was calculated as 31.8 in. on the basis of evaporation-pan data and the mass-transfer method (Dunne and Leopold, 1978). This is 1.2 in. greater than the 30-inch long-term average annual evaporation reported for the area (Linsley and Franzini, 1964). Monthly evaporation-pan readings obtained by an observer at Powers Lake and evaporation-pan data at the National Weather Service station at Arlington, Wis., 65 mi northwest of Powers Lake, are shown in table 2. An annual pan coefficient of 0.77 was used to determine the evaporation from the lake surface (National Oceanic and Atmospheric Administration, 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 Powers Lake.

Streamflow

Summaries of the streamflow characteristics for the Powers Lake basin, Fox River, and Turtle Creek gaging stations are shown in table 3. Daily discharge data for these stations are published in the U.S. Geological Survey annual data publication (U.S. Geological Survey, 1988). Daily discharge hydrographs for Powers Lake inlet and outlet are shown in figure 2.

Both the Turtle Creek and Fox River gaging stations are near the Powers Lake basin. The Powers Lake basin is in the headwaters of the Fox River. However, the drainage area from the Fox River is very large (868 mi^2). Accordingly, the data from the Turtle Creek gaging station also are shown because Turtle Creek adjoins the Powers Lake basin and is a smaller (199 mi^2) basin. No other gaging stations with long-term records are nearby. Forty-eight years of streamflow records for the Turtle Creek and the Fox River were used to evaluate the streamflow characteristics of the unnamed Powers Lake inlet tributary and the outlet. Based on these long-term data, the recorded streamflows for Turtle Creek and Fox River were about 10 percent greater than normal. This was probably caused by the ground-water contribution to the streams, which appeared to be greater than normal (see section "Ground Water") even though the precipitation was 4 in. (13 percent) less than normal.

Table 2.--Evaporation data for Powers Lake, October 16, 1986 - October 15, 1987

[--, indicates no data]

	Evaporation pan data (inches)		
	Powers Lake	Arlington[1]	Estimated evaporation[2] (inches)
October 16-30	[3]0.77	0.89	--
November	--	--	0.76
December	--	--	.30
January	--	--	.06
February	--	--	.12
March	--	--	1.82
April	5.48	--	--
May	5.52	--	--
June	7.44	9.33	--
July	6.71	7.78	--
August	5.97	6.23	--
September	3.81	4.49	--
October 1-15	1.63	1.93	.--
TOTAL PAN EVAPORATION	37.33		3.06
Pan coefficient	× 0.77		
Evaporation	28.74		
Total annual evaporation from lake surface	28.74 (measured) +	3.06 (estimated) =	31.80

[1] Data from National Oceanic and Atmospheric Administration, 1986, 1987, Climatological data, annual summary--Wisconsin: Asheville, N.C., Nation Climatic Data Center, v. 91, 92, no. 13, 27 p.

[2] Estimated using linear regression of Powers Lake monthly evaporation pan data based on method by Dunne and Leopold (1978).

[3] Estimated value. Value of Arlington reduced by 13 percent, as shown by comparison of Arlington and Powers Lake data for periods of concurrent record.

Table 3.--Summary of streamflow characteristics for Powers Lake, Fox River at Wilmot, and Turtle Creek at Clinton gaging stations

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

Station name	Period	Drainage area	Total discharge[1] (acre feet)	Mean daily discharge (ft^3/s)	Maximum instantaneous discharge (ft^3/s)	Minimum daily mean discharge (ft^3/s)	Mean discharge [$(ft^3/s)/mi^2$]	Runoff (inches)
Short term								
Powers Lake inlet	10-16-86 to 10-15-87	1.83	635	0.88	9.1	0.00	0.48	6.50
Powers Lake outlet	10-16-86 to 10-15-87	3.42	1,970	2.7	11	.02	.79	10.78
Fox River at Wilmot	10-16-86 to 10-15-87	868	470,000	649	2,280	193	.75	10.15
Turtle Creek at Clinton	10-16-86 to 10-15-87	199	93,400	129	854	59	.65	8.80
Long term								
Fox River at Wilmot	1939 to 1987	868	--	549	7,520	35	.63	8.59
Turtle Creek at Clinton	1939 to 1987	199	--	125	16,500	8	.63	8.62

[1] Total discharge is the sum of daily mean discharges for the period.

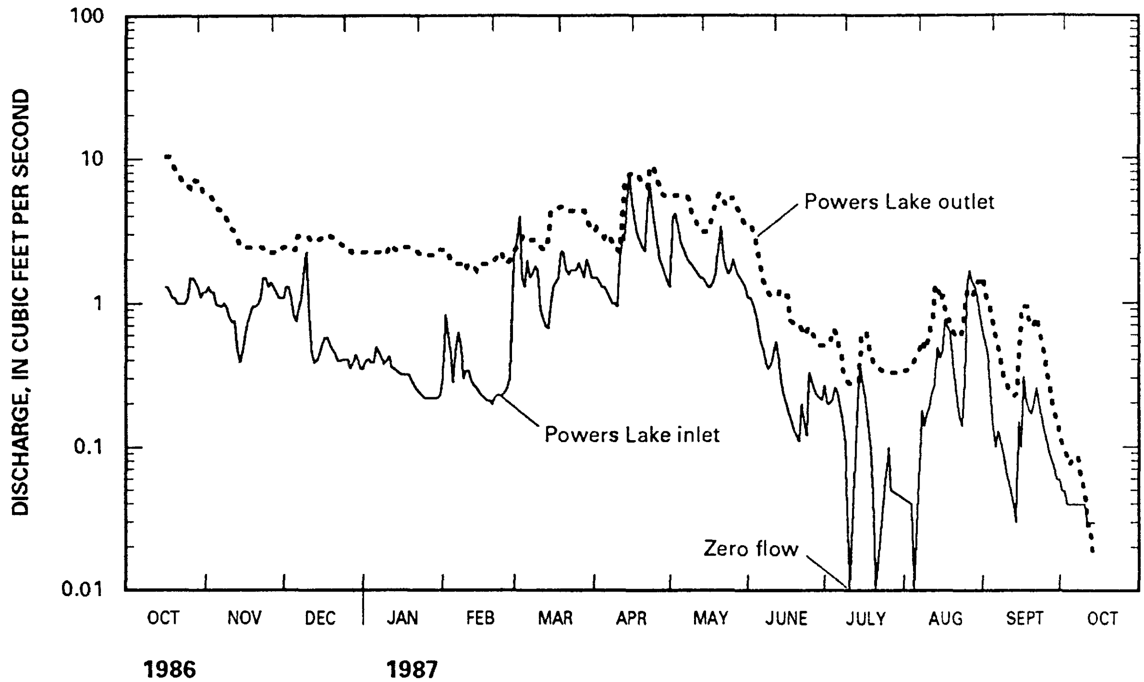


Figure 2. Streamflow at Powers Lake inlet and outlet during the study period.

The maximum streamflows at the inlet and outlet were not very high. The maximum instantaneous flows for both the Turtle Creek and Fox River gaging stations during the study period were less than the mean annual flood for the 1940-86 water-year period.

It is important to note the streamflow condition prior to the study because it affected the amount of lake storage at the beginning of the study period. Intense rains in September 1986 prevented the installation of the gaging station on October 1, the start of the water year. Streamflows indicated by the gaging-station data at Fox River at Wilmot recorded an instantaneous maximum discharge of 3,810 ft^3/s (cubic feet per second) on October 2, 1986. This was comparable to a 5-year flood frequency recurrence interval. An instantaneous peak discharge of 1,410 ft^3/s occurred at Turtle Creek near Clinton on September 27, 1986; this was comparable to the mean annual flood.

The daily discharge hydrograph for Powers Lake inlet (fig. 2) shows the effect of the large wetland on the basin runoff. Large amounts of evaporation and transpiration (ET) from wetlands occur during the summer months and cause streamflow at the inlet to recede rapidly. During winter, these ET effects are minimal and streamflow recedes more slowly.

Streamflow data from Powers Lake outlet show considerably more discharge, 1,970 acre-ft, than the inlet, 635 acre-ft. Discharge from these stations are shown in figure 2. The data suggests large amounts of ground water are being discharged to the lake.

The shoreline drainage runoff was estimated because the inflow gaging station does not monitor the total surface-water inflow to Powers Lake. The unmonitored area that drains directly into Powers Lake is a developed urban area, and surface runoff was calculated using the surface-runoff component from a nearby gaging station, Jackson Creek tributary 15 mi to the northwest, which also partly drains an urban area.

A hydrograph separation, using a technique described by Linsley, Kohler, and Paulhus (1975), was made for Jackson Creek tributary. The total flow was separated into surface runoff and base flow. Surface runoff is water that flows overland and enters the stream; base flow is ground water that discharges to the stream channel. The estimated surface runoff for October 16, 1986, to October 15, 1987, was 3.40 in. This runoff was used to represent the runoff from the Powers Lake shoreline drainage. The value appears reasonable compared to the following data collected at Madison, Wis., 65 mi to the northwest where only surface runoff was measured: Spring Harbor storm sewer, 4.14 in. runoff for October 15, 1986 - October 15, 1987 (U.S. Geological Survey, 1988, 1989); Monroe Street detention pond inlet, 3.43 in. runoff for February 28 - October 15, 1987 (P.E. Hughes, U.S. Geological Survey, written commun., 1988).

Ground Water

Ground water is present in unconsolidated glacial deposits approximately 100 to 150 ft thick (Hutchinson, 1970; Borman, 1976). Depth to the water table ranges from zero near the wetlands and lakes to about 100 ft below the land surface in uplands.

Ground water moves from areas of recharge to areas of discharge. The rate at which ground water is replenished depends on the amount and intensity of precipitation, the time of year, the infiltration capacity of the soil, and the permeability of the underlying materials. The regional gradient of the ground-water table in the Powers Lake basin is from the northwest to the southeast (Hutchinson, 1970; Borman, 1976).

The seven minipiezometers installed in the lake bed (fig. 1) were used to determine the direction of ground-water movement around the lake. The relation between the altitude of the water surface in these wells and the elevation of the lake-surface is shown in figure 3. All wells showed positive gradients, which indicate ground-water discharge (inflow) to the lake. Well numbers 1, 2, 5, and 6 showed the greatest gradient, whereas well numbers 3, 4, and 7 showed the smallest gradient.

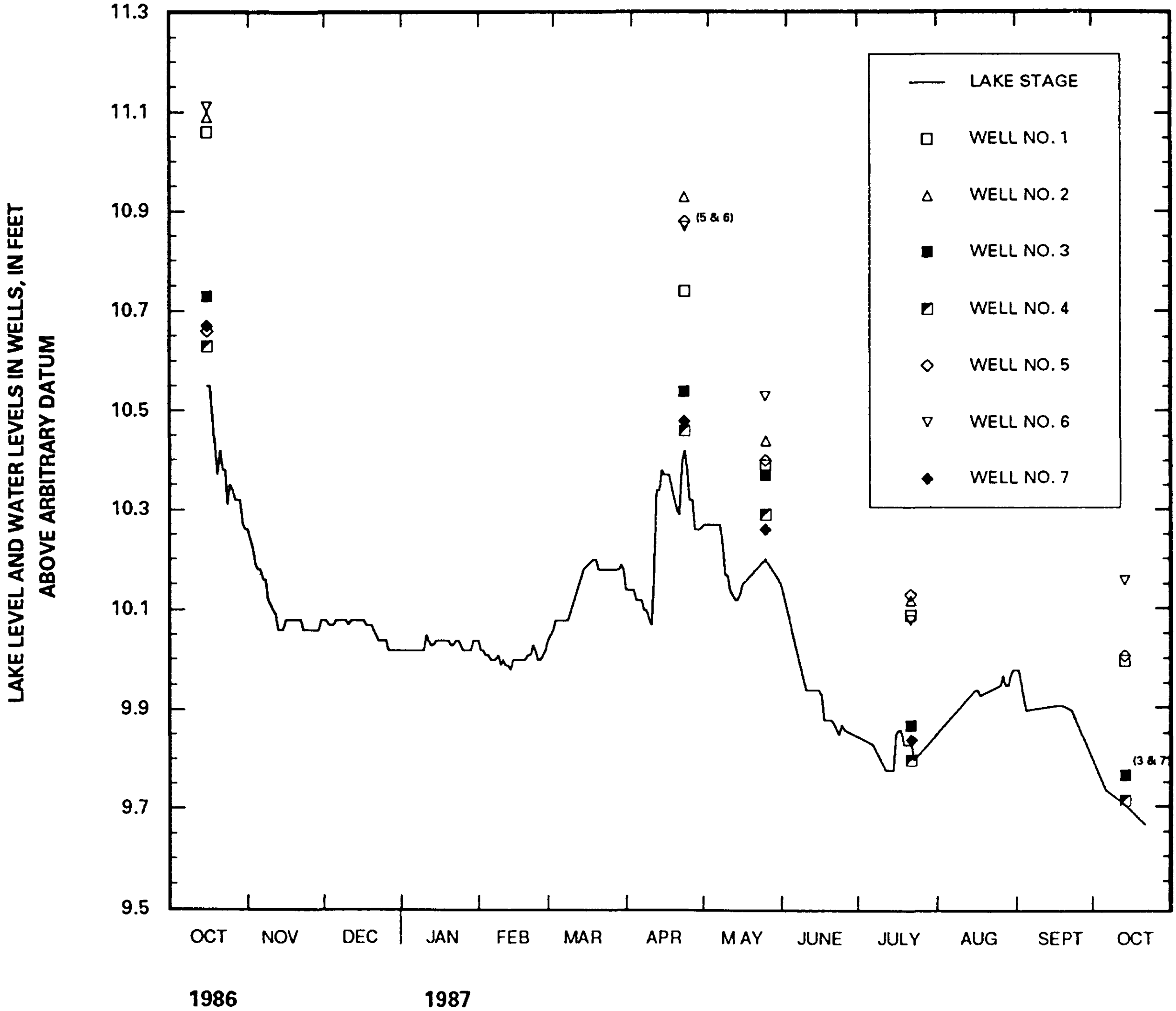


Figure 3. Relation between water levels in wells within 10 feet of Powers Lake's shoreline and the lake's water surface.

Water-level fluctuations in a well with a long-term record near the Powers Lake basin are shown in figure 4. Well Ww-9 is located about 25 mi northwest of Powers Lake and is a drilled artesian well, in dolomite 287 ft deep. Figure 4 shows that ground-water levels during the 1-year study period were above the normal for the 41-year (1947-87) long-term record.

Ground-water inflow to the lake was estimated during two periods as the residual of the hydrologic-budget equation:

$$Gi = WS - (P + Qi) + (Qo + E),$$

where WS = change in volume of stored water;
P = volume of precipitation falling directly on the lake, in acre-feet;
Qi = surface-water inflow, in acre-feet;
Qo = surface-water outflow, in acre-feet;
Gi = ground-water inflow, in acre-feet; and
E = volume of water evaporation from the lake, in acre-feet.

During the first period (January 31 - February 25, 1987) the lake was ice covered and evaporation was assumed to be zero. Recharge to the ground-water system from the lake also was considered to be zero because the shallow wells near the lake's edge showed positive gradients toward the lake. Streamflow components were determined by streamflow measurements and discharge records at the gaging station. Average ground-water inflow to the lake during this period was 1.4 ft^3/s. Discharge for this period may not represent that for the entire study period. However, it does serve as an indication of the magnitude of the ground-water inflow.

The second period used to estimate the ground-water inflow to the lake was October 16, 1986, through October 15, 1987. Ground-water inflow during this period was calculated as 989 acre-ft, equivalent to a daily mean inflow of 1.4 ft^3/s.

It is important to recognize that each of the individual components of the hydrologic-budget equation are imprecise; therefore, the calculated ground-water inflow also is imprecise. However, the two estimates of a daily mean inflow of 1.4 ft^3/s agree. The residual for the study period (989 acre-ft) was used to represent the annual ground-water inflow in the hydrologic budget.

Lake Stage

Water-level fluctuations of lake stages above an assumed datum are shown in figure 3. The data are published by the U.S. Geological Survey (1988). The maximum lake stage occurred at the start of the study period, October 16, 1986, 10.55 ft, and the minimum at the end of the study period, October 15, 1987, 9.70 ft (estimated). The lake-stage change of -0.85 ft is a loss of water from the lake of 387 acre-ft.

Hydrologic Budget

The annual hydrologic budget for Powers 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 = WS
Inflow = P + Qi + Gi
Outflow = Qo + E,

where WS = change in volume of stored water;
P = volume of precipitation falling directly on the lake, in acre-feet;
Qi = surface-water inflow, in acre-feet;
Qo = surface-water outflow, in acre-feet;
Gi = ground-water inflow, in acre-feet; and
E = volume of water evaporation from the lake, in acre-feet.

Therefore the hydrologic budget for Powers Lake is written as

$$WS - P - Qi - Gi + Qo + E = 0.$$

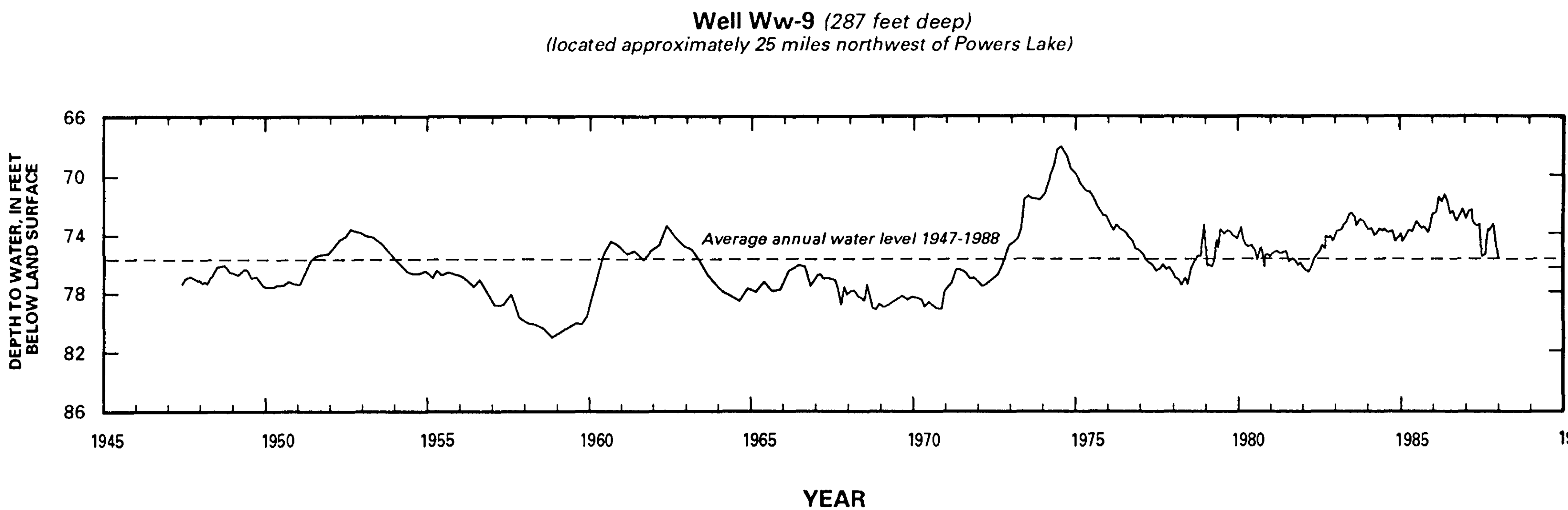


Figure 4. Water-level fluctuations in well Ww-9 near the Powers Lake basin.

A water budget was calculated for the study period, October 16, 1986 - October 15, 1987, using the data collected at the monitoring network previously described. Each term in the hydrologic budget was measured or estimated. The budget is shown in table 4.

The hydrologic budget for the study period shows that precipitation and ground water are the largest components of the inflow budget, 37 and 36 percent, respectively. Streamflow composes the balance of the inflow; 23 percent of the inflow is from Powers Lake inlet and 4 percent is from shoreline (overland) drainage. Streamflow dominates the outflow in the hydrologic budget (62 percent), and evaporation composes the remainder of the loss (38 percent).

The hydrologic budget for the study period does not represent a normal year. On the basis of long-term data for Turtle Creek at Clinton and the Fox River at Wilmot, streamflow averaged 10 percent greater than normal. Precipitation was 4.08 in. (or 13 percent) less than normal, and ground-water inflows (based on ground-water levels) were above normal.

Estimates of inflow and outflow terms of the hydrologic budget adjusted to a normal year are required for use later in this report. These inflow terms were estimated as follows: The average inflow at Powers Lake inlet was adjusted by the average long-term streamflow ratio of the gaging stations (Turtle and Fox Rivers) to the study-period streamflow; the average runoff from the shoreline was adjusted by the ratio of the average precipitation (31.24 in.) to the study-period precipitation (27.16 in.); the average precipitation on the lake surface was determined by use of the normal precipitation (32.24 in.); and the average ground-water inflow was determined as described below.

The above-normal streamflow discharge indicated by the index stations at Turtle Creek and Fox River is likely caused by greater-than-normal ground-water discharge. The hydrograph of well Ww-9 (fig. 4) indicates that above-average ground-water levels occurred during the study period. To determine the long-term average ground-water contribution to Powers Lake, ground-water discharge during the study period (989 acre-ft) was adjusted by the average long-term streamflow ratio of these index stations to the study-period streamflow.

The outflow terms of the hydrologic budget were also adjusted to a normal year. The average outflow at Powers Lake outlet was adjusted by the average long-term streamflow ratio of the gaging stations (Turtle and Fox Rivers) to the study-period streamflow. The long-term evaporation was 30 inches as reported by Linsley and Franzini (1964).

Table 4.--Hydrologic budget for Powers Lake, study year and normal year

	Study year October 16, 1986 - October 15, 1987		Normal year	
	Acre-feet	Percentage of total	Acre-feet	Percentage of total
Inflow				
Powers Lake inlet	635	23	576	21
Shoreline drainage	129	4	149	5
Precipitation on lake surface	1,030	37	1,180	42
Ground water (estimated)	989	36	890	32
Total inflow	2,780	100	2,800	100
Change in storage-- lake volume decrease	387			
Outflow				
Powers Lake outlet	1,970	62	1,770	61
Evaporation	1,200	38	1,140	39
Total outflow	3,170	100	2,910	100

The normal-year-inflow hydrologic budget shows that precipitation and ground water were the largest components, 42 and 32 percent, respectively; this relation is similar to that for the study period. For the normal year outflow budget, streamflow from Powers Lake outlet was 61 percent and evaporation was 39 percent, and is also similar to that for the study period.

Hydraulic Residence Time

The hydraulic residence time for Powers Lake is the time period required for the full volume of the lake, 7,450 acre-ft, to be replaced by inflowing waters. This is important for determining the expected response time of the lake to changes in nutrient loadings. The smaller the lake volume and/or greater stream inflow, the shorter the residence time. The mean hydraulic residence time (North American Lake Management Society, 1988) is calculated as--

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

Based on the hydrologic budget of 1,970 acre-ft of streamflow from Powers Lake outlet for the study period, the calculated hydraulic residence time is 3.8 years. Based on a normal year when streamflow from Powers Lake outlet averaged 1,770 acre-ft, the hydraulic residence time is 4.2 years. In contrast, Fowler Lake in Waukesha County in 1984, which has a small volume and a large stream inflow, had a hydraulic residence time of 7 days (P.E. Hughes, U.S. Geological Survey, written commun., 1988).

WATER QUALITY

Physical and Chemical Characteristics of the Lake Water Column

Powers Lake water-quality analyses are published in the USGS annual data publication (U.S. Geological Survey, 1988). Water in Powers Lake is hard, with hardness of water averaging 220 mg/L (milligrams per liter) as calcium carbonate. Powers Lake stratifies in both winter and summer. Stratification affects the chemical and biological properties of Powers Lake. Water temperature is a very important characteristic, because life processes, chemical reactions, and the solubility of chemical constituents in water are temperature dependent.

Water temperature and dissolved oxygen in Powers Lake is discussed in detail, and pH and specific conductance is discussed briefly; the depth profiles of these physical and chemical characteristics are shown in figure 5.

Water Temperature

Climatic factors affect the temperature of Powers Lake. Complete mixing of the lake is restricted by thermal stratification in the summer and by ice cover in the winter. Thermal stratification of 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 (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 warmer surface water and the underlying denser, colder water. This barrier is marked by a sharp temperature gradient known as the thermocline. The zone where the thermocline occurs is called the metalimnion. It separates the warmer, less dense, upper zone of water called the epilimnion, from the cooler, more dense, lower zone called the hypolimnion. Once stratification begins, the temperature of the hypolimnetic water changes little throughout the stratification period.

Powers Lake is only weakly thermally stratified throughout the summer (fig. 5). The metalimnion is not a barrier to fish migration, but it inhibits the exchange of water between the two layers 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 later summer, and disappears in the fall when air temperatures cool the surface water and wind action results in the erosion of the thermocline (fig. 5).

As surface water cools, it becomes denser and 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 fall turnover. When the water temperature drops below 4°C, the water again becomes less dense and "floats" near

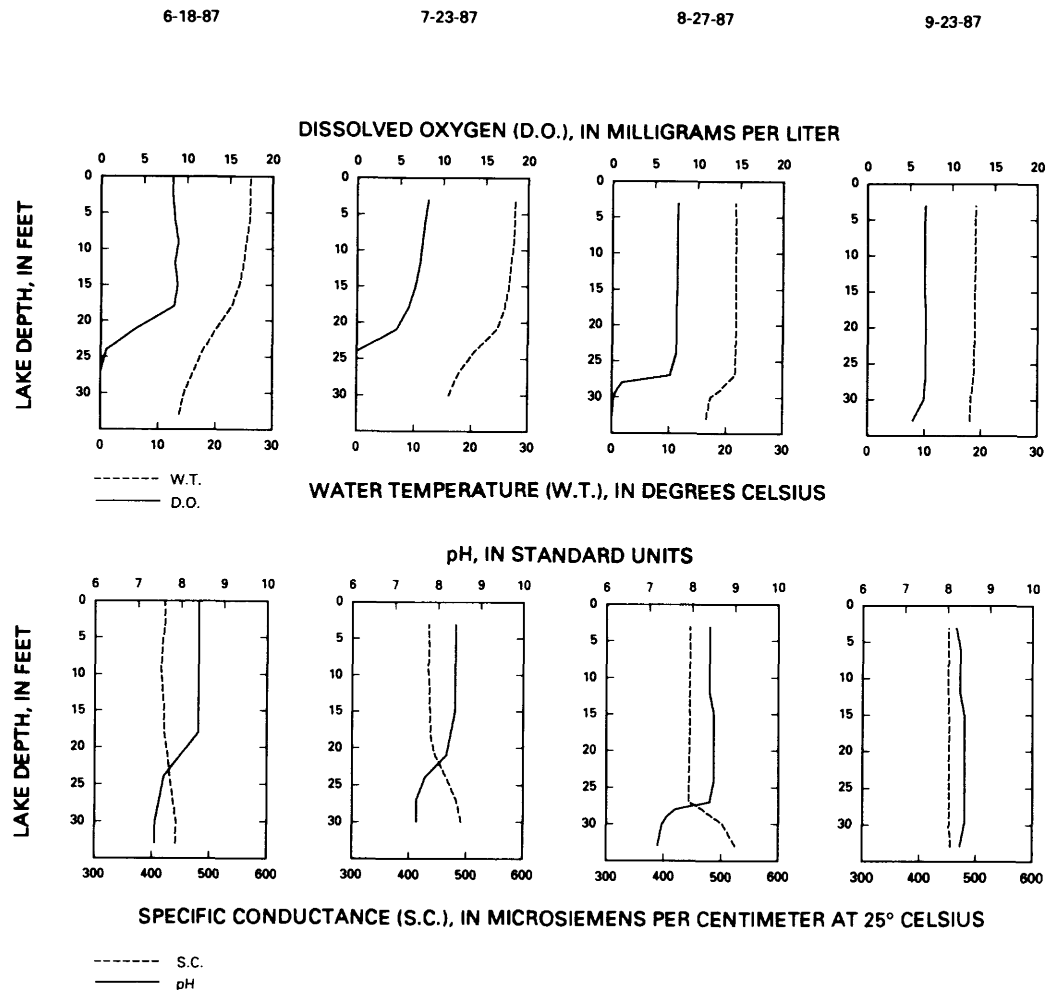


Figure 5. Depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance in Powers Lake, October 1986 through September 1987.

isolating the lake's liquid water from the atmosphere and preventing wind-driven mixing for 3 to 4 months. Although no ice-on/ice-off dates were recorded at Powers Lake, nearby Delavan Lake was ice covered from December 13, 1986, through March 9, 1987 (K.L. MacKinnon, Delavan Lake Sanitary District, written commun., 1987).

Winter stratification occurs as the colder (less than 4°C), less dense 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 becomes denser and begins to approach the temperature of the warmer, 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 begins following spring turnover.

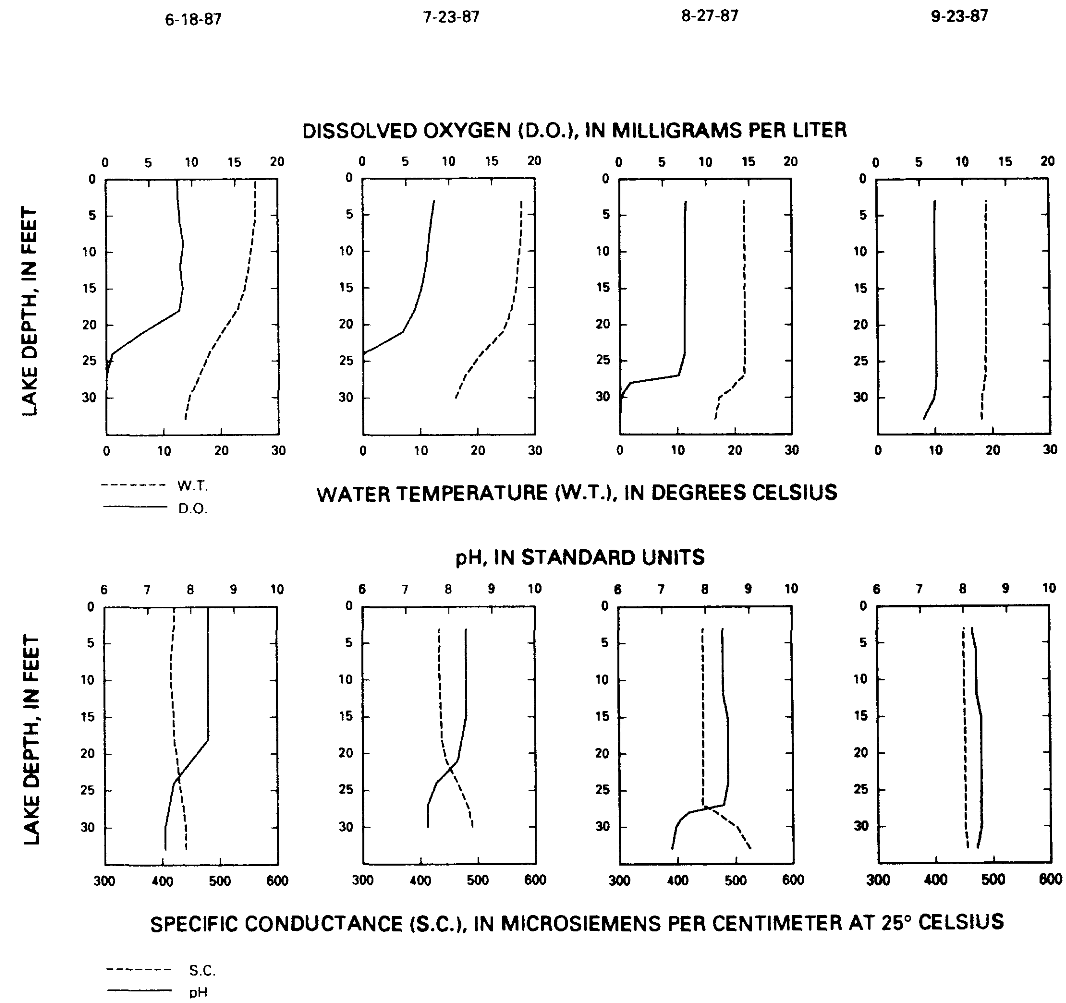


Figure 5. (Continued)

Dissolved Oxygen

Dissolved-oxygen is one of the most critical factors affecting a lake ecosystem, and it is essential to all aquatic organisms that require oxygen. Dissolved-oxygen depth profiles at the center of the lake are shown in figure 5. 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, at warmer temperatures, the metabolic rate of organisms increases, but less oxygen is available for metabolism.

In early summer, as the thermocline develops, the upper, warmer layer (epilimnion) cuts off the surface supply of dissolved oxygen to the lower, colder layer (hypolimnion). The hypolimnion thus becomes isolated from the atmosphere. Moderate populations of planktonic algae are produced because the waters of Powers Lake are moderately nutrient-rich. These organisms die, fall to the bottom of the lake, and decompose. The oxygen demand from this decaying material depletes the oxygen content of the water beginning at the lake bottom. The oxygen depletion then progresses upward but stays confined to the hypolimnion. Depletion can progress until all the oxygen is consumed (anoxia).

Oxygen depletion during summer stratification of the bottom water began in 1987 about June 1. The anoxic zone reached a maximum thickness by July 23, when depths greater than 24 ft were devoid of oxygen; this represents approximately 30 percent of the lake bottom area. Anoxia was last noted on August 27. Fall turnover likely occurred shortly after September 23, and oxygen was circulated throughout the entire lake. Oxygen was present throughout the entire water column during the winter of 1987.

These anoxic conditions are common in mesotrophic lakes, and anoxia, in varying degrees, is common in many of the mesotrophic lakes in southeastern Wisconsin. Anoxia can release phosphorus (if in large enough quantities in the lake sediments) from the bottom sediments.

pH

The pH is a measure of the hydrogen-ion concentration and is important, because it affects the solubility of many chemical constituents and is influenced by biological activity. The photosynthetic and respiration processes of planktonic 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 when they respire at night. When carbon dioxide concentrations decrease, pH increases; when carbon dioxide concentrations increase, pH decreases.

The phytoplankton in Powers Lake metabolize much of the available carbon dioxide as they photosynthesize during the daytime and thereby raise the pH of the epilimnion. However, no photosynthesis occurs near the lake bottom and carbon dioxide is not metabolized, thereby lowering the pH of the hypolimnion (fig. 5).

Specific Conductance

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

The profile measured following spring turnover on April 6, 1987, as illustrated in figure 5, shows that specific conductance was uniform at 460 μS/cm (microsiemens per centimeter at 25 degrees Celsius). During winter and summer thermal stratification, specific conductance increases slightly at the lake bottom due to the accumulation of dissolved constituents either from dissolution of precipitates, materials settling from the epilimnion, or release of dissolved materials, such as iron and manganese, from the bottom sediments during anoxic periods.

Phosphorus

Phosphorus, if present in high concentrations, can cause algal blooms; if present in low concentrations, plant productivity can be reduced. Phosphorus generally is the nutrient that limits productivity (Wetzel, 1983). Nitrogen, however, often becomes the nutrient limiting algal growth when there is a great excess of phosphorus. When phosphorus and nitrogen are present in excess amounts, algal growth continues until other nutrients or light availability become the limiting growth factors.

Total-phosphorus concentrations at 1.5 to 3.5 ft below the surface of Powers Lake during the study ranged from below the detection limit of 0.005 mg/L on February 23, 1987, to 0.029 mg/L on April 6, 1987; the median concentration was 0.012 mg/L for 9 samples. These total-phosphorus concentrations are low, indicative of very good to good water quality (Lillie and Mason, 1983). The phosphorus concentration of 0.029 mg/L on April 6, 1987, is only slightly greater than 0.020 mg/L, or the level where the eutrophic classification begins (G.C. Gerloff, University of Wisconsin, written commun., 1984; Wisconsin Department of Natural Resources, 1981 and 1983). A maximum total phosphorus concentration of 0.02 mg/L has been recommended for Powers Lake by the Southeastern Wisconsin Regional Planning Commission (SEWRPC), (1979).

Powers Lake data indicate only minor problems of internal phosphorus release. Lake-bottom samples (1.5 ft above bottom) indicate little if any internal release of dissolved phosphorus from the bottom sediments. Dissolved orthophosphate-phosphorus concentration maximums were below the detection limit of 0.004 mg/L on many days.

Nitrogen

Nitrogen, like phosphorus, when in abundant supply can cause algal blooms. Not all nitrogen sources can be controlled, for example, species of blue-green algae possess heterocysts in their cell walls (Wetzel, 1983) that enable them to fix nitrogen from the atmosphere. Samples were not collected for nitrogen analysis except during spring turnover. Lakes with a total-nitrogen:total-phosphorus ratio larger than 15:1 are considered phosphorus limited; a ratio from 10:1 to 15:1 indicate a transition situation; and a ratio smaller than 10:1 generally indicate nitrogen limitation (Lillie and Mason, 1983). Nitrogen:phosphorus ratios in samples collected following spring turnover for Powers Lake on April 17, 1986, and April 6, 1987, were 200:1 and 21:1, respectively, suggesting that phosphorus is the limiting factor for algal production.

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 provide a measurement of water clarity. A Secchi disc is an 8-in.-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 algae and zooplankton concentrations and types, water color, and turbidity. Algae is the most dominant factor in Powers Lake, and, therefore, Secchi-disc water clarity is correlated with the algal population. Secchi-disc water clarity is least during summer when algal populations are largest. A minimum Secchi-disc water clarity of 6.6 ft was measured on July 23, 1987. A maximum Secchi-disc water clarity of 19.7 ft was measured on April 6, 1987.

Chlorophyll *a*

Chlorophyll *a* is the primary photosynthetic pigment of all oxygen-evolving photosynthetic organisms and 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 during summer when algal populations are usually highest. The data for the study period show an exception to this generalization. Chlorophyll *a* concentrations reached a maximum of 13.0 μg/L (micrograms per liter) on January 16, 1987, suggesting an algal bloom under ice cover; a maximum open-water concentration of 6 μg/L was recorded on October 16, 1986 and August 27, 1987. A chlorophyll *a* minimum concentration of less than 5 μg/L was recorded on April 6, June 18, and July 23, 1987.

Plankton

Algae

Algae are small, generally microscopic plants found in all lakes and are primary producers that form the base of the aquatic food chain. They convert energy and nutrients through photosynthesis into the compounds necessary to support life in the aquatic system. Oxygen, which is vital to higher forms of life in a lake, also is produced in the photosynthetic process.

Algal blooms may reach nuisance proportions in fertile or eutrophic lakes and cause surface scum or slime. High concentrations of wind-blown algae may accumulate on shorelines, where they die and decompose, causing noxious odors and unsightly conditions. The decay process consumes oxygen; decay sometimes depletes available oxygen supplies and results in fish kills. Certain species of decomposing blue-green algae release toxic materials into the water.

Total algal populations in Powers Lake are shown in table 5 for the June, July, and August samplings. Fifty-six species were found. Blue-green algae (Cyanophyta) dominate the summer algal population--88 percent in June, 98 percent in July, and 96 percent in August. Of the blue-green algae, *Aphanothece saxicola* dominated the June and July samplings, and the July sample was dominated by another *Aphanothece* genera--*Aphanothece nidulans*. The colonies of *Aphanothece* often develop on lake bottoms, become loosened, float to the surface, and then are washed ashore, sometimes forming a "soupy" mass (Prescott, 1970).

Table 5.--Species list and density (in cells per milliliter) of phytoplankton taxa collected from Powers Lake, Wisconsin, June 18, July 23, and August 27, 1987

[--, no species present; sp., species; /mL, per milliliter; mg/L, milligrams per liter]

Algal type (Taxa)	June 18	July 23	August 27
Diatoms (Bacillariophyta)	968	56	507
Order Centrales			
Cyclotella comta	792	--	--
Cyclotella meneghiniana	--	14	--
Cyclotella sp.	--	28	28
Melosira granulata	--	--	71
Melosira italica	--	--	28
Rhizosolenia longiseta	--	14	312
Order Pennales			
Fragilaria crotonensis	176	--	7
Fragilaria pinnata	--	--	4
Synedra delicatissima	--	--	57
Green algae (Chlorophyta)	2,150	1,160	2,060
Chlamydomonas sp. 1	57	28	85
Chlamydomonas sp. 2	57	--	--
Chlorella sp.	114	85	71
Chodatella longiseta	--	--	57
Coelastrum sphaericum	--	--	7
Crucigenia sp.	--	170	--
Dictyosphaerium pulchellum	--	--	454
Elakotothrix sp.	--	28	--
Gloeocystis planctonica	904	--	--
Gloeocystis sp.	--	--	170
Gonium formosum	--	454	284
Kirchneriella sp.	454	--	--
Oocystis parva	--	--	114
Oocystis pusilla	--	--	28
Oocystis submarina	568	--	--
Oocystis sp.	--	114	--
Sphaerocystis schroeteri	--	284	795
Golden-brown algae (Chrysophyta)	1,080	142	--
Dinobryon bavaricum	--	28	--
Ochromonas sp.	341	--	--
Pseudokephyrion sp.	284	114	--
Synura sp.	454	--	--
Blue-green algae (Cyanophyta)	36,200	95,200	112,000
Anabaena sp.	--	57	--
Aphanocapsa delicatissima	909	3,520	2,780
Aphanothece nidulans	--	7,380	51,100
Aphanothece saxicola	31,800	51,500	24,500
Coelosphaerium kuetzingianum	568	2,610	2,130
Chroococcus dispersus	454	--	--
Chroococcus limneticus	--	3,550	114

Table 5.--Species list and density (in cells per milliliter) of phytoplankton taxa collected from Powers Lake, Wisconsin, June 18, July 23, and August 27, 1987--Continued

[--, no species present; sp., species; /mL, per milliliter; mg/L, milligrams per liter]

Algal type (Taxa)	June 18	July 23	August 27
Blue-green algae (Cyanophyta)--Continued			
Chroococcus minutus	--	57	--
Chroococcus sp.	1,990	369	--
Dactylococcopsis fascicularis	--	--	14
Gloeothece linearis	--	341	--
Gloeothece linearis var. composita	--	21,600	24,910
Merismopedia tenuissima	--	1,590	1,820
Microcystis aeruginosa	--	170	--
Oscillatoria limnetica	--	284	--
Rhabdoderma gorskii	--	824	284
Rhabdoderma irregulare	--	--	4,200
Synechococcus sp.	568	1,360	284
Dinoflagellates (Pyrrhophyta)	284	84	56
Ceratium hirundinella	114	28	28
Peridinium inconspicua	170	28	--
Peridinium wisconsinense	--	28	28
Cryptomonads (Cryptophyta)	625	426	1,750
Cryptomonas marsonii	57	--	28
Cryptomonas sp.	--	28	114
Cyathomonas truncata	--	256	43
Rhodomonas lacustris	--	142	1,560
Rhodomonas minuta	568	--	--
Total cells/mL	41,300	97,100	117,000
Number of species	21	33	34
Dry weight (mg/L)	4.0	1.5	2.9

Considering the moderately good water quality of Powers Lake (see "Trophic Condition" section), it was surprising to note such a large population of blue-green algae. Blue-green algae are not ordinarily used as food by zooplankton (microscopic animals) or fish populations and may become overabundant and out of balance in the lake ecosystem.

Certain genera of blue-green algae including *Microcystis, Anabaena, Aphanizomenon, Gloeotrichia, Oscillatoria,* and *Lyngbya* are capable of producing toxins under certain conditions during algal blooms; incidents of domestic animal deaths and positive laboratory tests for toxins have been reported in Wisconsin (Repavich and others, 1987). Powers Lake contains three of these genera--*Microcystis, Anabaena,* and *Oscillatoria,* but in very low numbers. It is important to note, however, that even if a genera is present, it does not mean toxins will be produced. In Delavan Lake, for example, the lake exhibited toxicity before 1986 but not during a study in 1986 (Repavich and others, 1987).

Zooplankton

Zooplankton are microscopic animals that inhabit the same environments as phytoplankton. Zooplankton are an important link in the aquatic food chain. They feed on algae and, in turn, provide a food source for fish. During the June, July, and August samplings, 12 species of zooplankton were found in differing degrees of abundance (table 6). The rotifers dominated the July sampling; clodocerans and copepods were codominant in the June sampling; copepods dominated the August sampling. Most rotifers are nonpredatory and feed on bacteria, small algae, and particulate organic matter. Clodocerans and copepods feed on both algae and other zooplankton. The dominant species present in June and August was a copepod, *Diacyclops bicuspidatus thomasi*; in July the rotifer *Asplanchna* sp. dominated.

Phosphorus Loads

Annual phosphorus loads, yields, and precipitation for Powers Lake inlet and outlet are shown in table 7. Also shown are annual phosphorus loads, yields, and precipitation for Delavan Lake inlet, 15 mi northwest of Powers Lake, that correspond to the Powers Lake study period and for the 1984-88 water years. Delavan Lake inlet has the longest phosphorus load data available in the area for comparison. Although loads are computed and reported to the nearest pound, the loads can be in considerable error, especially where loads had to be estimated. They are, however, the author's best estimate.

Inputs

Powers Lake Inlet

During the 1-year study period, the total phosphorus load at Powers Lake inlet was 186 lb (pounds) for a basin yield of 102 lb/mi^2 (pounds per square mile). Because precipitation was less than normal, the phosphorus load also was likely less than normal. Phosphorus data for the Powers Lake inlet were compared with similar data for the Delavan Lake inlet. The data in table 7 show the phosphorus load at the Delavan Lake inlet during the study period for Powers Lake to be 55 percent of the 5-year average (1984-88).

Table 6.--Species list, density and biomass of net zooplankton collected from Powers Lake, Wisconsin, June 18, July 23, and August 27, 1987

[#/m^3, number per cubic meter; g/m^3, grams per cubic meter; --, no species present]

Zooplankton (Taxa)	June 18	July 23	August 27
Protozoans (Protozoa)			
Ceratium hirundinella	1,040	5,170	3,740
Rotifers (Rotatoria)			
Asplanchna sp.	--	74,600	6,950
Kellicottia longispina	688	--	4,280
Trichocera sp.	--	--	5,880
Crustaceans (Crustacea)			
Cladocerns (Cladocera)			
Bosmina longirostris	351	--	--
Daphnia dubia	3,470	15,500	14,400
Daphnia pulex	2,080	--	--
Daphnia rosea	9,350	2,220	3,210
Chydoridae (immature)	5,880	--	3,210
Copepods (Copepoda)			
Diacyclops bicuspidatus thomasi	19,100	8,130	93,000
Diaptomus ashlandi	6,580	6,650	15,000
Nauplii	1,730	2,220	3,740
Total (#/m^3)	50,200	115,000	153,000
Number of species	9	6	9
Dry weight (g/m^3)	.6180	.0813	.2174

Table 7.--Total phosphorus loads and yields in the Powers Lake drainage basin and at Delavan Lake inlet at Lake Lawn, Wisconsin

[--, no data available]

Year	Powers Lake					Delavan Lake inlet		
	Inlet		Outlet					
	Load (pounds)	Yield (pounds per square mile)	Load (pounds)	Yield (pounds per square mile)	Precipitation (inches)	Load (pounds)	Yield (pounds per square mile)	Precipitation (inches)
[1]1984	--	--	--	--	--	7,040	323	32.0
[1]1985	--	--	--	--	--	6,730	309	38.9
[1]1986	--	--	--	--	--	15,100	693	51.2
[2]1987	186	102	83.2	24.3	27.2	3,741	172	31.0
1988	--	--	--	--	--	1,400	64	29.1

[1] Water year.
[2] October 16, 1986 - October 15, 1987.

The Delavan Lake inlet phosphorus data are the only long-term data in the vicinity of Powers Lake. Seventy-six percent of the Delavan Lake inlet basin is agricultural land, compared to 73 percent of the Powers Lake inlet basin. The study-year yield of Powers Lake inlet (102 lb) was adjusted by the ratio of the 5-year average Delavan Lake inlet phosphorus yield (312 lb) to the 1987 Delavan Lake inlet phosphorus yield (172 lb) to determine its long-term average yield (184 lb); this resulted in a long-term average load of 337 lb of phosphorus for Powers Lake inlet.

The phosphorus yield from Powers Lake inlet (102 lb/mi^2) during the study period appears somewhat high for a basin with a large wetland; however, this yield is low compared to yields from agricultural basins that can be as high as 2,000 lb/mi^2 (Field, 1986). Wetlands are considered beneficial to the water quality of a lake because they trap nutrients. A wetland in a subbasin of Delavan Lake produced an average phosphorus yield of 56 lb/mi^2 for water years 1984 and 1985 (Field and Duerk, 1988). The elevated yields through Powers Lake inlet possibly are related, in part, to high phosphorus concentrations during low flow.

Phosphorus concentrations at low rates of inflow--less than 1 ft^3/s--are abnormally high. Phosphorus concentrations ranged from 0.02 to 0.34 mg/L; the median concentration was 0.11 mg/L for 26 samples (U.S. Geological Survey, 1987 and 1988). This median is only slightly less than the median total phosphorus concentration (0.13 mg/L) for high rates of inflow---flows greater than 1 ft^3/s. These high concentrations during low rates of inflow indicate possible phosphorus loading from point sources. The concentrations during cool seasons are much lower than those during warm seasons. The reason for these high concentrations are not apparent from the data collected during the study. Also, Perkins (Perkins, 1988) found very high fecal coliform/fecal streptococcus counts during summer in the inlet water, which also could indicate point-source contamination.

Shoreline Drainage

An area of 0.88 mi^2 of the Powers Lake shoreline is not included in the tributary drainage to the lake. Twenty percent of this area (0.18 mi^2) consists of undrained depressions, but surface runoff from the remaining 0.70 mi^2 flows directly to the lake.

Surface runoff and phosphorus loads from this shoreline area were not measured, so the phosphorus load to the lake was estimated based on phosphorus yields measured by Hughes (P.E. Hughes, U.S. Geological Survey, written commun., 1988) for a residential area in Madison, Wisconsin, located about 65 mi northwest of Powers Lake. Hughes determined a phosphorus yield for the period February 28 - October 15, 1987, of 221 lb/mi^2; this yield was adjusted by the ratio of the precipitation for the same time period at Powers Lake (24.2 in.) to precipitation at Madison (21.7 in.) to adjust for yield difference caused by differences in precipitation amounts. This adjusted yield, 246 lb/mi^2, was multiplied by the Powers Lake shoreline drainage area (0.70 mi^2) to estimate the phosphorus load to the lake during the period February 28 - October 15, 1987 (172 lb). This load

(172 lb) was then multiplied by the ratio of the study period phosphorus load at Powers Lake inlet (186 lb) to the February 28 to October 15, 1987, phosphorus load at Powers Lake inlet (140 lb) to estimate the phosphorus contribution from the shoreline drainage during the study period (229 lb). This study-period load (229 lb) was adjusted by the ratio of the average-year precipitation (31.2 in.) to the study-year precipitation (27.2 in.) to estimate the shoreline drainage area's load for an average year (263 lb).

If a different method of calculation is used, the phosphorus load estimated with Hughes' data appears to be low. A total phosphorus load of 459 lb was computed by use of a numerical model of Tasker and Driver (1988) that incorporated data collected throughout the United States. The model estimates only loads for April through October and does not include an estimate for the winter period. Because the data collected by Hughes at Madison was collected, in part, at the same time as that at Powers Lake and reflects similar climatic conditions, and because Madison is relatively close to Powers Lake, the estimate of a 229-lb phosphorus yield from the shoreline area for the study period using the Hughes' data appear preferable to the estimate made using Tasker and Driver's model.

Precipitation

Total phosphorus concentrations in precipitation were not measured. To estimate this concentration, the volume-weighted mean total phosphorus concentration of bulk precipitation (0.02 mg/L) measured in Field and Duerk's (1988) study of the Delavan Lake basin for the 1984 and 1985 water years was used. Adjusting this value to the precipitation during the study period provided an estimated phosphorus load of 56 lb. For a normal precipitation year, the estimated load was 64 lb.

Ground Water

Phosphorus contributions to the lake from ground-water inflow were calculated using concentrations of phosphorus in samples collected from selected minipiezometers installed in shallow water at the lake's edge. These concentration data are shown below.

Date	Concentration of dissolved orthophosphate phosphorus (milligrams per liter)				
	Well number (figure 1)				
	1	3	5	6	7
May 28, 1987	0.004	0.115	<0.004	--*	<0.004
July 23, 1987	<.004	.016	--*	<.004	<.004
October 15, 1987	.018	--*	--*	.010	.004

* No data.

Dissolved orthophosphate phosphorus concentrations in water samples collected from the piezometers ranged from <0.004 to 0.115 mg/L; the median concentration was 0.004 mg/L. This median concentration was used to estimate the phosphorus concentration in the ground water. The total phosphorus contribution to Powers Lake from ground water for the study period is estimated to be 11 lb based on a water input of 989 acre-ft and a total phosphorus concentration of 0.004 mg/L. For a normal year, it is estimated to be 10 lb based on a water input of 890 acre-ft and a total phosphorus concentration of 0.004 mg/L.

Septic Systems

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

Soil types, pattern of seasonal-usage, and distance to the water table all affect septic-system efficiency in phosphorus removal. Septic systems installed near the water table do not treat wastewater effectively before it reaches the ground water (Fetter and others, 1977; Perkins, 1988).

Septic-tank drainfields upstream from Powers Lake inlet culvert may not function properly during high flows. The culvert, if not maintained, lodges with logs and other debris that raise water upstream. This can cause drainfields to malfunction and enhance leaching of phosphorus from these drainfields to the stream.

Perkins (1988) made a septic leachate survey of Powers Lake in the summer of 1987. The septic leachate survey was conducted from a boat, equipped with a septic leachate detector, near the shoreline. Septic leachate from malfunctioning septic systems commonly is discharged through a small area of lake bottom. The septic leachate detector uses a combined fluorometer/conductance device to detect the leachate. Organic residuals of septic leachate fluoresce when correctly stimulated. Inorganics which are dominated by chloride (Cl^-) and sodium (Na^+), provide a relative change in conductivity of water when compared to nearby unaffected water (Environmental Devices Corporation, 1978, p. 1). Perkins detected 20 plumes of waste-water origin along the shoreline and all plumes were close to developed properties where ground water was close to the land surface (fig. 6). Minipiezometers with the highest water levels (wells 1, 2, and 6), indicating sites of the largest rate of ground-water discharge to the lake, coincide with some of the septic-system plumes located by Perkins.

Other investigations have estimated water usage by owners of private septic systems as follows: Siegrist and others (1976), 42.6 gal/d (gallons per day); Probst (1975), 42 gal/d; and U.S. Department of Health (1967), 75 gal/d. Concentrations of septic-tank effluent phosphorus have been reported as follows: Barshied and El-Baroudi (1974), 7.7 mg/L; Otis and others (1973, 5 sites), 16 mg/L. S.J. Field and D.J. Graczyk (U.S. Geological Survey, written commun., 1988) found a phosphorus concentration of 19 mg/L in untreated sewage from a municipal sewage-treatment plant.

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

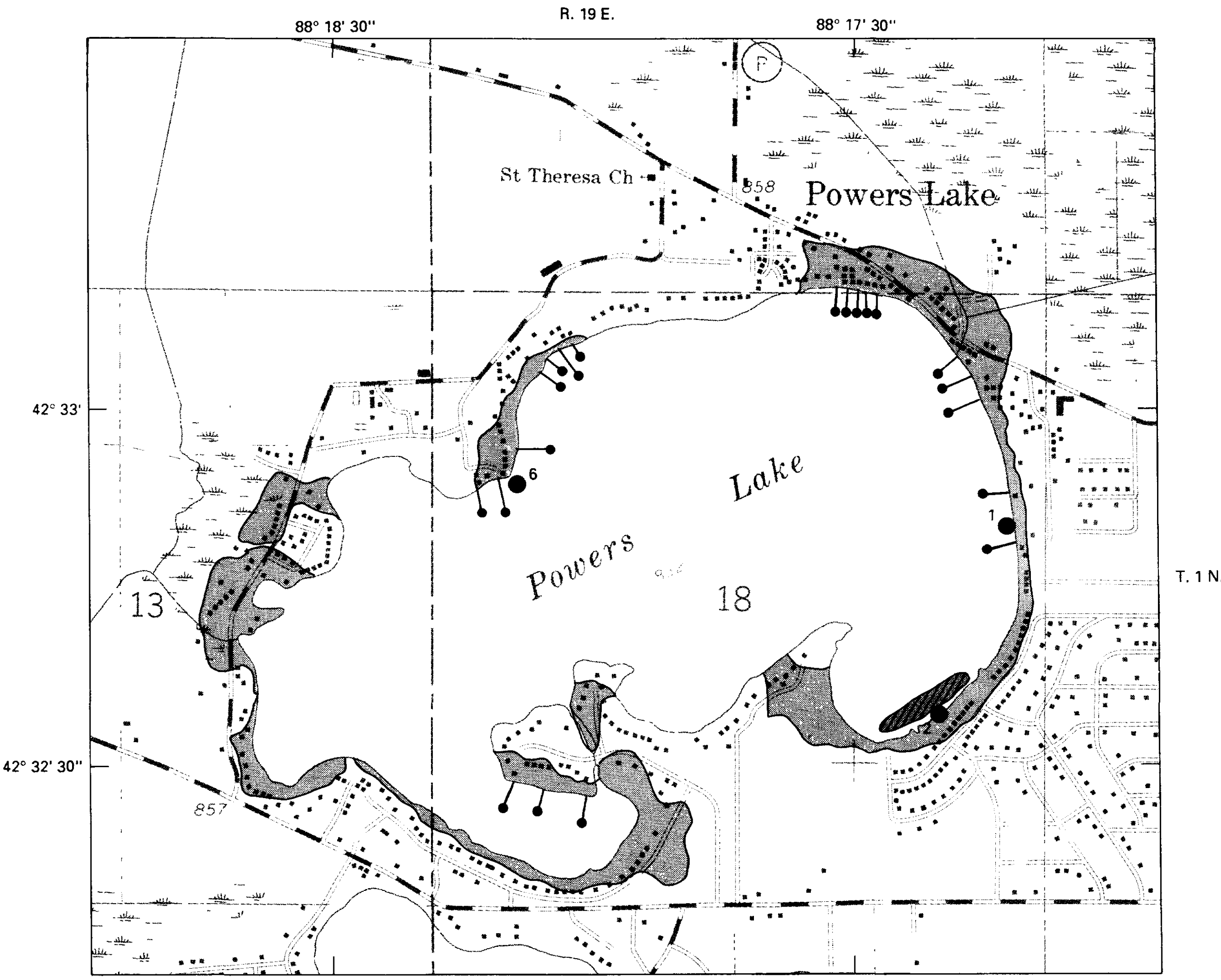
(1) Census data for Powers Lake from 1985 indicated that there were 2.5 persons per household and that 40 percent of the dwellings are occupied year-round (David Kendziorski, Southeastern Wisconsin Regional Planning Commission, oral commun., 1988). A septic-tank study by the Fox Valley Water Quality Planning Agency (Fetter and others, 1977) has been used by SEWRPC to estimate phosphorus contributions from septic systems to lakes in southeastern Wisconsin (David Kendziorski, oral commun., 1988). SEWRPC recommends that loads be computed for all dwellings located in areas with high-water tables; the dwellings are divided into two categories--those within 200 ft of the shoreline and those greater than 200 ft. Perkins (1988) identified 93 dwellings within 200 ft of the lake's edge, and 8 dwellings greater than 200 ft from the shoreline in high ground-water areas.

(2) Persons with septic systems in areas where water tables are close to the land surface are likely to use small amounts of water to limit septic-tank problems. Phosphorus loads to septic tanks were only computed for dwellings located in high-water areas; a minimum water usage of 42 gal/d per capita was assumed (Siegrist and others, 1976), and a concentration of 16 mg/L was assumed to be the phosphorus concentration of septic effluent. These figures yield an estimated 2.0 lb of phosphorus per capita per year.

(3) The Southeastern Wisconsin Regional Planning Commission, in studies of lakes in southeastern Wisconsin, estimated that 15 to 30 percent of the phosphorus load to a septic-tank reaches the lake (Dave Kendziorski, oral commun., 1988).

With the above assumptions, phosphorus loads to septic tanks of residences within 200 ft of the shoreline can be calculated as follows: Phosphorus loads from septic tanks = (number of persons/house = 2.5) × (number of permanent and seasonal homes[2] = 65) × (pounds of phosphorus/person/year = 2.1) × (soil retention factor: 70 percent, minimum; 80 percent, probable; 90 percent, maximum). Performing the above calculation gives the following phosphorus loads (in pounds) from septic systems to the lake: minimum, 34; moderate, 68; maximum, 102.

[2] A seasonal home is assumed to be occupied 50 percent of the time; it is equivalent to half of a permanent home.



Base enlarged from U.S. Geological Survey
1:24,000; Genoa City, 1960.
Photorevision as of 1971

SCALE 1:24,000

0 ½ MILE

0 .5 KILOMETER

EXPLANATION

Area with numerous septic-tank plumes

Areas where ground water is less than 5 feet from land surface

Plume from septic system

Ground-water observation well and number

Figure 6. Areas bordering Powers Lake where depth to ground water is less than 5 feet, and locations of septic-system plumes (Modified from Perkins, 1987, figure 1).

The phosphorus loadings for the 8 permanent and seasonal homes greater than 200 ft from the lake in high water table areas were less than for those homes close to the lake because of the long flow paths from the septic system to the lake. With this and the previously described assumptions, the data are applied to the following formula for those residences greater than 200 ft from the shoreline: Phosphorus loads from septic tanks = (number of persons/house = 2.5) × (number of permanent and seasonal homes[2] = 6) × (pounds of phosphorus/person/year = 2.1) × (soil retention factor: 90 percent, minimum; 95 percent, probable; 100 percent, maximum). Performing the above calculation gives the following phosphorus loads (in pounds) from septic systems to the lake: minimum, 0; moderate, 2; maximum, 3.

A minimum contribution was considered to represent the study-year load and the moderate contribution was considered to represent a normal-year load.

Outputs

The total phosphorus load that left the lake through the outlet during the study period was 83 lb. No recharge of ground water from the lake occurred, so no phosphorus left the lake by entering ground water. The difference (433 lb), between the outlet total phosphorus load (83 lb) and total input phosphorus load (516 lb), adsorbed to sediments in the lake.

Phosphorus Budget

Phosphorus budgets for the study period and a normal year are shown in table 8. The phosphorus budget for the study period shows that of the total input (516 lb), shoreline drainage contributed the largest amount (44 percent) followed by Powers Lake inlet (36 percent), direct precipitation (11 percent), septic systems (7 percent), and ground water (2 percent). Of the total outputs, 83 lb (16 percent) was lost from the lake in outflow and 433 lb (84 percent) was adsorbed on sediments. A phosphorus budget estimated for a normal year indicates that of the total input (744 lb), Powers Lake inlet contributed the largest amount (45 percent), followed by shoreline drainage (35 percent), septic systems (10 percent), precipitation (9 percent), and ground water (1 percent). No estimate was made of phosphorus loss from the lake during a normal year, because these data were not required to evaluate the lake's health.

Table 8.--Phosphorus budgets for Powers Lake, study year and normal year

	Phosphorus budget			
	Computed for period October 16, 1986, to October 15, 1987		Estimated for a normal year	
	Phosphorus (pounds)	Percentage of total	Phosphorus (pounds)	Percentage (of total)
Input				
Powers Lake inlet	186	36	337	45
Shoreline drainage	229	44	263	35
Precipitation	56	11	64	9
Ground water	11	2	10	1
Septic systems	34	7	70	10
Total inputs	516	100	744	100
Output				
Powers Lake outlet	83	16		
Evaporation	0	0		
Sedimentation	433	84		
Total outputs	516	100		

Assessment of Hydrologic and Phosphorus Input Budget

Reckow's model (1980) was used to evaluate the hydrologic and phosphorus input budget for a normal year. Rechow's model determines a lake's average phosphorus concentration on the basis of the total-hydrologic and phosphorus input budget, and is given as--

$$P = \frac{L}{11.6 + 1.2\ qs},$$

where P = lake's average total-phosphorus concentration, in milligrams per liter;
L = total-phosphorus loading, in grams per square meter per year; and
qs = areal-water loading, in meters per year. The areal-water loading is determined by dividing the normal-year total inflow ($3.46 \times 10^6\ m^3$) by the lake surface area ($1.84 \times 10^6\ m^2$).

With a normal-year, areal-water loading of 1.88 m and total-phosphorus input of 744 lb, solving for the above equation yields an average in-lake phosphorus concentration of 0.013 mg/L for Powers Lake. Spring turnover concentrations (average-lake top and bottom concentration) for Powers Lake were 0.009 mg/L on April 17, 1986; 0.015 mg/L on April 6, 1987; and 0.010 mg/L on April 13, 1988. The normal-year water and phosphorus loading-budget values appear reasonable, compared to measured in-lake spring total-phosphorus concentrations.

Trophic Condition

A lake's trophic state indicates the degree of nutrient enrichment. The trophic status of Powers Lake was evaluated by the application of two commonly used methods--Carlson's Trophic State Index (TSI) and the Vollenweider model. Carlson's TSI evaluates the in-lake conditions and Vollenweider's model evaluates the phosphorus loading to a lake.

Carlson's Trophic-State Index

The in-lake trophic condition can be evaluated by using Carlson's TSI (Carlson, 1977). The TSI is computed on the basis of total phosphorus and chlorophyll *a* concentrations, and Secchi-disc transparency readings for lake ice-free periods. Carlson developed equations for all three parameters, but the Wisconsin Department of Natural Resources (DNR) modified those for chlorophyll *a* and total phosphorus for Wisconsin lakes (Ronald Martin, Wisconsin Department of Natural Resources, oral commun., 1985). Carlson's TSI ranged from 0 for nonproductive 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 TSI ranges to classify Wisconsin lakes; they use TSI's of less than 40 to define oligotrophic conditions, 40 to 50 to define mesotrophic conditions, and greater than 50 to define eutrophic conditions in evaluating the trophic status (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 to remain consistent with other Wisconsin lake trophic-state evaluations by the DNR.

These three categories encompass a wide range of lake water-quality conditions. The waters of oligotrophic lakes are clear, algal populations are low, and the deepest layers are likely to contain oxygen throughout the year. Mesotrophic lakes have a moderate supply of nutrients and experience moderate algal blooms and occasional oxygen depletions. Eutrophic lakes are nutrient-rich lakes that experience many water-quality problems, such as seasonal algal blooms and oxygen depletion in parts of the lakes. Eutrophic conditions can kill fish if severe oxygen depletions occur.

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

TSI (Secchi) = 60 - 33.2 (log Secchi depth, in meters)

TSI (chlorophyll *a* = 33.60 + 17.64 (log chlorophyll *a* 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 with the different boundaries for total phosphorus, Secchi disc, and chlorophyll *a* are shown below.

Trophic level	Trophic state	Total phosphorus (µg/L)	Secchi disc (m)	Chlorophyll *a* (µg/L)
Eutrophic				
	50	20	2.0	8.5
Mesotrophic				
	40	10	4.0	2.3
Oligotrophic				

The calculated TSI's for Powers Lake (fig. 7) are generally in the range of mesotrophic lakes. Only the lake ice-free periods are plotted.

Vollenweider's Model

Total-phosphorus loads to Powers Lake can be evaluated by use of Vollenweider's model (1971, 1975) which predicts critical levels of total-phosphorus loading to lakes. The total-phosphorus loading to Powers Lake for the study period using Vollenweider's model is shown in figure 8.

Vollenweider's "dangerous" rate is the rate at which the receiving waters would become eutrophic or remain eutrophic. Vollenweider's model for evaluating total-phosphorus loading to a lake is based on mean lake depth/hydraulic residence time and phosphorus loading per unit of lake-surface area. On the basis of the external load of total phosphorus of 516 lb during the study period, a phosphorus loading rate of 0.0000261 $(lb/ft^2)/yr$ (pounds per square foot per year) [0.127 $(g/m^2)/yr$ (grams per square meter per year)] was calculated. For an estimated normal-year, total-phosphorus load of 744 lb, a phosphorus loading rate of 0.0000376 $(lb/ft^2)/yr$ [0.184 $(g/m^2)/yr$] was calculated. Total-phosphorus external loading for both conditions is less than Vollenweider's dangerous classification. Vollenweider's classification does not consider internal loading, which appears to be minimal in Powers Lake.

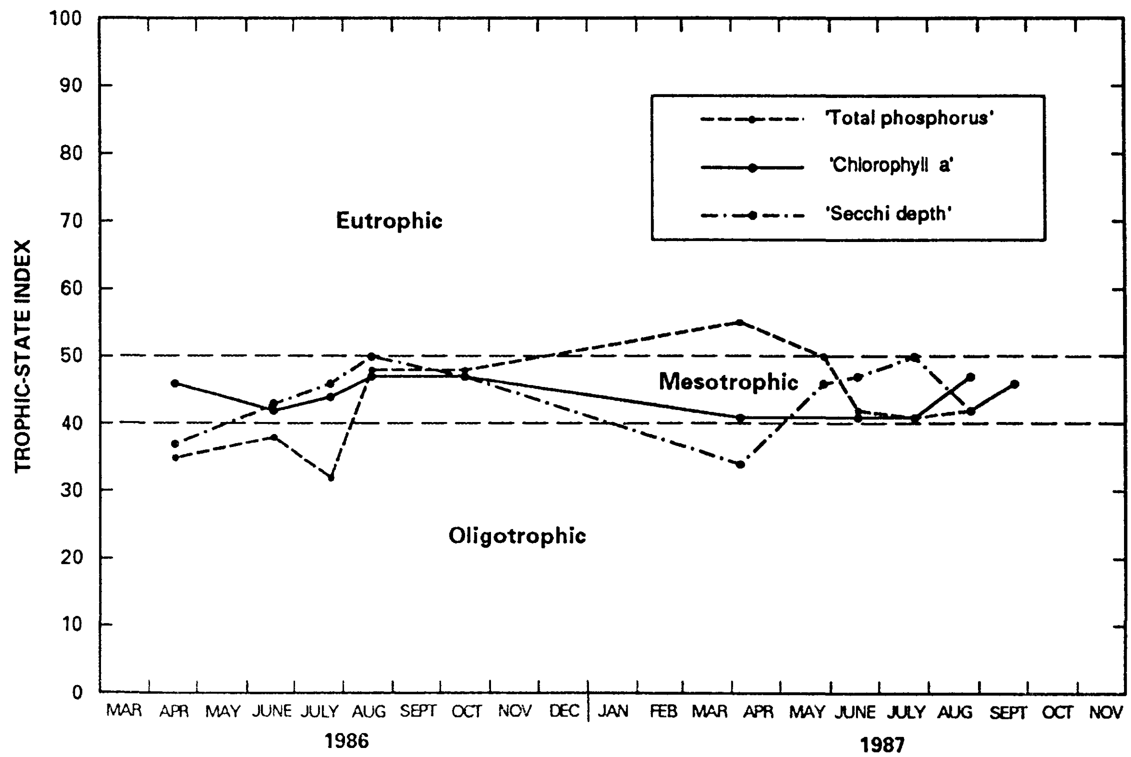


Figure 7. Trophic-state indices, March 1986 through September 1987.

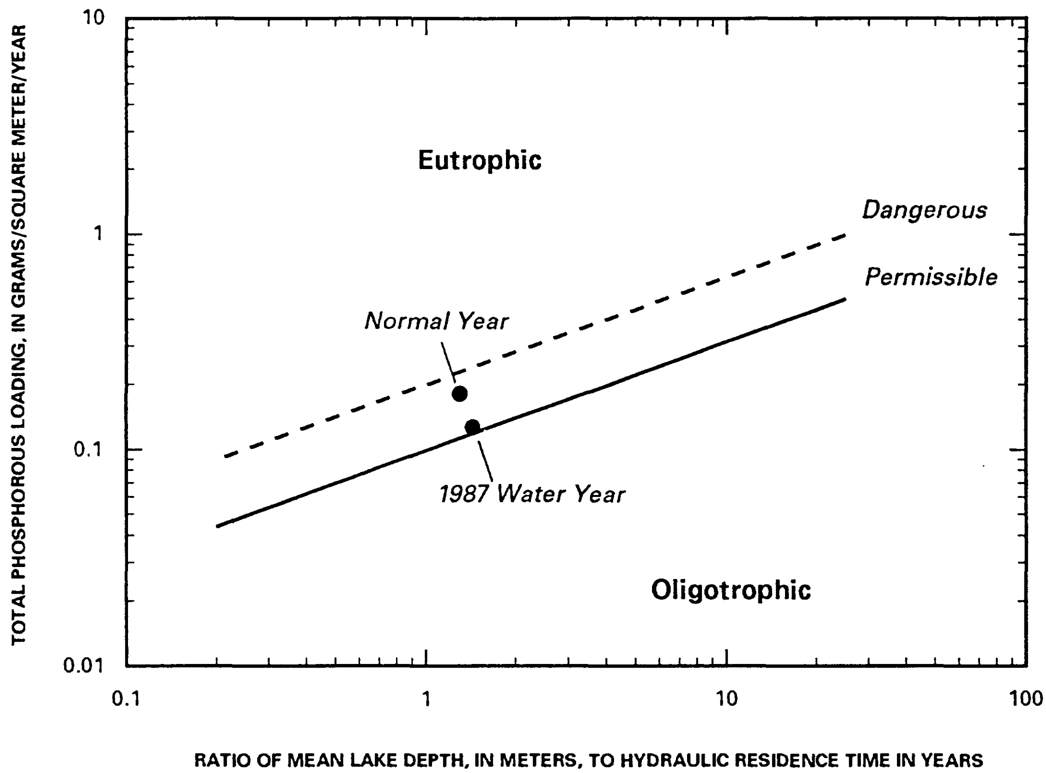


Figure 8. Phosphorus-loading classifications for Powers Lake. (Modified from Vollenweider model, 1975, figure 6).

SUMMARY AND CONCLUSIONS

A 1-year hydrologic and water-quality investigation of Powers Lake was conducted from October 16, 1986, through October 15, 1987. A hydrologic budget was prepared for the study period. Precipitation on the lake surface was 27.16 in. (4.08 in. less than the long-term average) and accounted for 37 percent of the inflow. Ground water was the second largest component of the inflow, 36 percent. Surface runoff contributed 27 percent: Powers Lake inlet contributed 23 percent and shoreline drainage, 4 percent. Most of the loss in the hydrologic budget occurred through Powers Lake outlet; it accounted for 62 percent of the total losses. Evaporation comprised the remaining 38 percent. Based on streamflow through Powers Lake outlet, the lake's hydraulic residence time was 3.8 years.

The hydrologic budget for the study period, in which precipitation and ground-water inflow predominated, showed that the year was not representative of a normal year. A hydrologic-inflow budget was estimated for a normal year for Powers Lake. Precipitation, the largest component, was 42 percent of the budget, ground water was 32 percent, Powers Lake inlet was 21 percent, and overland runoff from shoreline drainage was 5 percent. Streamflow through Powers Lake outlet accounted for 61 percent of the normal-year outflow budget, and the remaining 39 percent was lost by evaporation. Based on a normal year streamflow from Powers Lake outlet, the lake's hydraulic residence time was 4.2 years.

Carlson's TSI calculation indicates that the trophic state of Powers Lake is in the mesotrophic range. The external loadings of phosphorus for the study period and a normal year were assessed by means of Vollenweider's model using the calculated hydraulic residence time of 3.8 years for the study period and 4.2 years for a normal year; this model indicated that phosphorus loadings for both scenarios were less than dangerous.

The phosphorus budget for Powers Lake for the study year was calculated. The total phosphorus input from all external sources for the study period was 516 lb. The dominant contribution came from runoff: 44 percent came from shoreline drainage and 36 percent came from Powers Lake inlet. Precipitation contributed 11 percent, ground water contributed 2 percent, and septic systems contributed 7 percent.

For a normal year, the total phosphorus input from all external sources was estimated to be 744 lb. Again, the dominant contribution came from surface water runoff: 45 percent came from Powers Lake inlet and 35 percent came from shoreline drainage. Precipitation contributed 9 percent, ground water contributed 1 percent, and septic systems contributed 10 percent.

Phosphorus concentrations at Powers Lake inlet for low flows in summer are higher than during winter. The reasons for these high concentrations are not apparent from the data collected during the study.

During summer thermal stratification, the bottom waters of the lake become anoxic. Anoxia began about June 1, 1987, and reached a maximum on July 23, 1987, when depths greater than 24 ft were anoxic. Anoxia was last noted on August 27, 1987. During these anoxic periods, very little phosphorus appears to be released from the bottom sediments; this suggests that internal loading of phosphorus does not appear to be a problem at this time.

Fifty-six species of algae were found during the sampling months of June, July, and August. Undesirable blue-green algae (Cyanophyta) dominate these summer months, 88 percent in June, 98 percent in July, and 96 percent in August.

Twelve species of zooplankton were found in various degrees of abundance during the same sampling periods as for algae. The rotifers dominated the July sampling, cladocerans and copepods were codominant in the June sampling, and copepods dominated the August sampling.

Powers Lake is a mesotrophic lake; phosphorus loadings will not cause eutrophic conditions. The following factors are important to note:

1. The drainage basin upstream from Powers Lake inlet contains a large wetland. This wetland controls runoff and reduces phosphorus loadings to the lake.

2. Runoff at Powers Lake inlet is controlled by a small culvert opening. If not maintained, this culvert lodges with logs and other debris that raise water levels upstream. This can cause septic-tank drainfields upstream from the inlet culvert to malfunction and enhance leaching of phosphorus from these drainfields to the stream.

3. An in-lake water-quality-monitoring program, such as that conducted during the prestudy, can provide important information about water-quality changes that occur over time.

REFERENCES

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, v. 1, 429 p.

Barshied, R.D., El-Baroudi, H.M., 1974, Physical-chemical treatment of septic tank effluent: Journal Water Pollution Control Federation, v. 46, no. 10, 2,342 p.

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

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

Borman, R.G., 1976, Ground-water resources and geology of Walworth County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 34, 45 p.

Britton, L.J., Averett, R.C., and Ferreira, 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(2), p. 361-369.

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

Dunne, Thomas, and Leopold, L.B., 1978, Water in environmental planning: W. H. Freeman and Company, San Francisco, 818 p.

Ellis, B., and Childs, K.E., 1973, Nutrient movement from septic tanks and lawn fertilization: Michigan Department of Natural Resources, Technical Bulletin 73-5.

Environmental Devices Corporation, 1978, ENDICO, Data sheet number 62: Marion, Massachusetts, 4 p.

Fetter, C.W., Much, R.R., Anderson, D., 1977, Characterization of non-point waste sources: Fox Valley Water Quality Planning Agency, Report No. 4, Septic Tank Study, 48 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.

Fishman, M.J., and Friedman, L.C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey, Open-File Report 85-495, 709 p.

Guy, P., and Norman, V.W., 1970. Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, chapter C2, 50 p.

Haszel, O.V., 1971, Soil survey, Walworth County, Wisconsin: Soil Conservation Service, U.S. Department of Agriculture, 107 p.

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

Kuhn, G., 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.

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, 5 p.

Lillie, R.A., and Mason, J.W., 1983, Limnological characteristics of Wisconsin lakes: Wisconsin Department of Natural Resources Technical Bulletin No. 138, 116 p.

Link, E.G., and Demo, O.R., 1970, Soil survey of Kenosha and Racine Counties, Wisconsin: U.S. Department of Agriculture, Soil Conservation Service, 113 p.

Linsley, R.K. and Franzini, J.B., 1964, Water-resources engineering: New York, McGraw-Hill Book Co., 654 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.

Much, R.R., and Kemp, G., 1978, Characterization of non-point waste sources, Report No. 6, Summary of non-point waste loads: Fox Valley Water Quality Planning Agency, Wisconsin, 135 p.

National Oceanic and Atmospheric Administration, 1982, Climatological data, annual summary--Wisconsin: Asheville, N.C., National Climatic Data Center, v. 90, no. 13, 27 p.

_____1985, Climatological data, annual summary--Wisconsin: Asheville, N.C., National Climatic Data Center, v. 90, no. 13, 27 p.

_____1986, Climatological data, annual summary--Wisconsin: Asheville, N.C., National Climatic Data Center, v. 91, no. 13, 27 p.

_____1987, Climatological data, annual summary--Wisconsin: Asheville, N.C., National Climatic Data Center, v. 92, no. 13, 27 p.

North American Lake Management Society, 1988, The lake and reservoir restoration guidance manual, first edition, United States Environmental Protection Agency, EPA 44015-88-002, 298 p.

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.

Otis, R.J., Boyle, W.C., and Sauer, D.K., 1973, The performance of household wastewater treatment units under field conditions: Small Scale Waste Management Program.

Perkins, T., 1987, Powers Lake septage leachate survey, summer of 1987, 1988: Kenosha County Planning and Development, Informational Paper, 18 p.

Porterfield, G., 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.): W.C. Brown Company, Dubuque, Iowa, University of Montana, 348 p.

Probst, T., 1975, Stockbridge sanitary district infiltration/inflow analysis report: Menasha, Wisconsin, McMahon Associates, Inc.

Rapavich, W.M., Sonzogni, W.C., Standridge, J.H., Vennie, J.G., and Wedepohl, R.E., no date, 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.

Reckow, K.H., and others, 1980, Modeling phosphorus loading and lake response under uncertainty: a manual and compilation of export coefficients: U.S. Environmental Protection Agency, EPA 44015-80-011, Washington, D.C., 213 p.

Siegrist, R.M., Boyle, W.H., and Boyle, W.C., 1976, Characteristics of rural household wastewater: Journal of the Environmental Engineering Division, American Society of Chemical Engineers.

Southeastern Wisconsin Regional Planning Commission, 1979, A regional water quality management plan for southeastern Wisconsin: 2000, Planning Report No. 30.

Tasker, G.D., and Driver, N.E., 1988, Nationwide regression models for predicting urban runoff water quality at unmonitored sites: Water Resources Bulletin, American Water Resources Association, v. 24, no. 5, p. 1,091-1,101.

Tilchin, M.J., Gold, A.J., Gannon, J.E., and Marshall, B.R., no date, Nutrient movement from seasonal-use lakeside septic systems: Informational Paper, 14 p.

U.S. Department of Commerce, 1986, Climatological data annual summary: National Oceanic and Atmospheric Administration, v. 91, no. 13, 27 p.

_____1987, Climatological data annual summary: National Oceanic and Atmospheric Administration, v. 92, no. 13, 26 p.

U.S. Department of Health, Education and Welfare, 1967, Manual of septic-tank practice: Public Health Service Publication No. 526.

U.S. Geological Survey, 1988, Water resources data--Wisconsin, water year 1987: U.S. Geological Survey Water-Data Report WI-87-1, 380 p.

_____1989, Water resources data--Wisconsin, water year 1988: U.S. Geological Survey Water-Data Report WI-88-1, 429 p.

Vollenweider, R.A., 1971, Scientific fundamentals of eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication: Paris Organization for Economic Cooperation and Development, 159 p.

_____1975, Input-output models with special reference to the phosphorus loading concept in limnology: Schweizerische Zeitschrift fur Hydrologie, v. 37, no. 1, p. 53-84.

Wetzel, R.G., 1983, Limnology (2d ed.): New York, 767 p.

Wisconsin Department of Natural Resources, Office of In-Lake Renewal, 1981, Long Lake, Waushara County, feasibility study results: Bureau of Water Resources Management, Management Alternatives, 22 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.

Wisconsin Statutes, 1981-82: chap. 33, v. 1, section 21, p. 863.

_____1981-87: chap. 33, v. 1, section 30(3)(c), v. 1, p. 866.

GLOSSARY OF TECHNICAL TERMS

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, 125 p.)

Aerobic.--Having oxygen. (Britton and others, 1975, 22 p.)

Alga, algae, algal.--A group of simple primitive plants that live in wet or damp places, and generally are microscopic in size, containing chlorophyll and lacking roots, stems, and leaves. (Britton and others, 1975, 22 p.)

Algal bloom.--A high concentration of a particular algal species, amounting to 1/2 million to 1 million cells per liter of water or more. (Britton and others, 1975, 22 p.)

Algicide.--A chemical that kills algae. (Britton and others, 1975, 22 p.)

Anaerobic.--Devoid of oxygen. (Britton and others, 1975, 22 p.)

Anoxic.--See anaerobic. (Britton and others, 1975, 22 p.)

Autumn turnover.--The mixing of the entire water mass of a lake in the autumn. (Britton and others, 1975, 22 p.)

Average discharge.--As defined in the annual series of U.S. Geological Survey reports on surface-water supply--the arithmetic average of all complete water years of record whether or not they are consecutive. Average discharge is not published for less than 5 years of record. The term "average" is generally reserved for average of record and "mean" is used for averages of shorter periods, namely, daily mean discharge. (Langbein and Iseri, 1960, 29 p.)

Blue-green algae.--A group of algae with a blue pigment, in addition to the green chlorophyll. Blue-green algae group usually causes nuisance conditions in water. (Dion and others, 1976, 125 p.)

Cambrian.--The earliest period of the Paleozoic era, thought to have covered the span of time between 570 and 500 million years ago. (Bates and Jackson, 1980, 749 p.)

Chlorophyll *a*.--Chlorophyll *a* is a green photosynthetic pigment present in plant cells, including algae. The concentration of chlorophyll *a* in water is a commonly accepted indicator of algal biomass. (Dion and others, 1976, 125 p.)

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, 125 p.)

Cubic feet per second.--A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing water an average velocity of 1 foot per second. (Langbein and Iseri, 1960, 25 p.)

Cubic feet per second day [(ft^3/s)-d)].--The column of water represented by a flow of 1 cubic foot per second for 24 hours. (Langbein and Iseri, 1960, 25 p.)

Cubic feet per second per square mile [$(ft^3/s)/mi^2$].--The average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area. (Langbein and Iseri, 1960, 25 p.)

Diatom.--A unicellular or colonial alga having a siliceous shell. (Dion and others, 1976, 125 p.)

Discharge.--In its simplest concept discharge means outflow. The discharge of drainage basins is distinguished as follows:

Yield. Total water runout or crop; includes runoff plus underflow.
Runoff. That part of water yield that appears in streams.
Streamflow. The actual flow in streams, whether or not subject to regulation, or underflow.

Each of these terms can be reported in total volumes (such as acre-feet) or time rates (such as cubic feet per second or acre-feet per year). The differentiation between runoff as a volume and streamflow as a rate is not accepted. (Langbein and Iseri, 1960, 25 p.)

Drainage area.--The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide. (Langbein and Iseri, 1960, 25 p.)

Drainage basin.--A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water. (Langbein and Iseri, 1960, 25 p.)

Epilimnion, epilimnetic.--The upper, relatively warm, circulating zone of water in a thermally stratified lake. (Dion and others, 1976, 125 p.)

Eutrophication, eutrophic.--The natural process of enrichment and aging of a body of water that may be accelerated by the activities of man. Pertains to water bodies in which primary production is high because of a large supply of available nutrients. (Dion and others, 1976, 125 p.)

Evaporation pan.--An open tank used to contain water for measuring the amount of evaporation. The U.S. Weather Bureau class A pan is 4 feet in diameter, 10 inches deep, set up on a timber grillage so that the top rim is about 16 inches from the ground. The water level in the pan during the course of observation is maintained between 2 and 3 inches below the rim. (Langbein and Iseri, 1960, 25 p.)

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, 25 p.)

Evapotranspiration.--Water withdrawn from a land area by evaporation from water surfaces and moist soil and by plant transpiration. (Langbein and Iseri, 1960, 25 p.)

Gage height.--The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on a gage. (Langbein and Iseri, 1960, 25 p.)

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. (Dion and others, 1976, 125 p.)

Hardness.--Water hardness is defined as the sum of the polyvalent cations expressed as the equivalent quantity of calcium carbonate ($CaCO_3$). As a general rule, hard-water lakes are more productive of plants and animals than soft-water lakes, but there are many exceptions. (Dion and others, 1976, 125 p.)

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, 25 p.)

Hypolimnion, hypolimnetic.--The lower, relatively cold, noncirculating water zone in a thermally stratified lake. (Dion and others, 1976, 125 p.)

Limnology.--That branch of hydrology pertaining to the study of lakes. (Langbein and Iseri, 1960, 25 p.)

Load.--The amount, by weight or volume, of a substance transported by a stream past a specific point during a specified length of time. (Kuhn and others, 1983, 102 p.)

Maximum depth.--The difference, in feet of elevation, between the bottom and the surface of the lake. (Dion and others, 1976, 125 p.)

Mean depth.--The mean depth, in feet, for a specified lake stage, is obtained by dividing the volume of the lake by its area. (Dion and others, 1976, 125 p.)

Mesotrophic.--Intermediate stage in lake classification between the oligotrophic and eutrophic stages, in which primary production occurs at a greater rate than in oligotrophic lakes, but at a lesser rate than in eutrophic lakes. This is due to a moderate supply of nutrients. (See also Eutrophic and Oligotrophic.) (Dion and others, 1976, 125 p.)

Metalimnion, metalimnetic.--The middle layer of water in a thermally stratified lake, in which temperature decreases rapidly with depth. (Dion and others, 1976, 125 p.)

Nutrient.--Any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes. (Dion and others, 1976, 125 p.)

Oligotrophic.--Pertaining to waters in which primary production is low as a consequence of a small supply of available nutrients. (Britton and others, 1975, 22 p.)

Ordovician.--The second earliest period of the Paleozoic era (after the Cambrian and before the Silurian), thought to have covered the span of time between 500 and 440 million years ago. (Bates and Jackson, 1980, 749 p.)

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, 749 p.)

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, 125 p.)

Phytoplankton, phytoplanktonic.--The plant part of the plankton. (Dion and others, 1976, 125 p.)

Plankton.--The individual plant, animal, or bacterium in the plankton community. (Cole, 1979, 426 p.)

Precambrian.--All geologic time, and its corresponding rocks, before the beginning of the Paleozoic; it is equivalent to about 90 percent of geologic time. Precambrian time has been divided according to several different systems, all of which use the presence or absence of evidence of life as a criterion. (Bates and Jackson, 1980, 749 p.)

Quaternary.--The second period of the Cenozoic era, following the Tertiary; also, the corresponding system of rocks. It began 2 to 3 million years ago and extends to the present. It consists of two unequally long epochs: the Pleistocene, up to about 8,000 years ago, and the Holocene since that time. The Quaternary was originally designated an era rather than a period, with the epochs considered to be periods, and it is still sometimes used as such in the geologic literature. The Quaternary may also be incorporated into the Neogene, when the Neogene is designated as a period of the Tertiary era. (Bates and Jackson, 1980, 749 p.)

Recurrence interval (return period).--The average interval of time within which a given flood will be equaled or exceeded once. (Langbein and Iseri, 1960, 25 p.)

Secchi-disc visibility.--Secchi-disc visibility is the depth at which a white-and-black disc (8 inches in diameter) disappears from view when lowered into the water. Secchi-disc visibility 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-disc visibility often is used as a gross measure of the plankton in the water. (Dion and others, 1976, 125 p.)

Sediment.--Fragmental material, both mineral and organic, that is in suspension or is being transported by the water mass or has been deposited on the bottom of the aquatic environment. (Dion and others, 1976, 125 p.)

Silica.--The chemically resistant dioxide of silicon: SiO_2. It occurs naturally in five crystalline polymorphs (the minerals quartz, tridymite, cristobalite, coesite, and stishovite); in cryptocrystalline form (chalcedony); in amorphous and hydrated forms (opal); in less pure forms (e.g., sand, diatomite, tripoli, chert, flint); and combined in silicates as an essential constituent of many minerals. (Bates and Jackson, 1980, 749 p.)

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, 749 p.)

Species.--The basic or final unit for the classification of organisms. (Dion and others, 1976, 125 p.)

Specific conductance.--Specific conductance is a measure of the water's ability to conduct an electric current and is used as an approximation of the dissolved-solids concentration in the water. It is measured in units of microsiemens (formerly micromhos) per centimeter at 25 degrees Celsius. (Dion and others, 1976, 125 p.)

Streamflow.--The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation. (Langbein and Iseri, 1960, 25 p.)

Streamflow-gaging station.--A gaging station where a record of discharge of a stream is obtained. Within the U.S. Geological Survey, this term is used only for those gaging stations where a continuous record of discharge is obtained. (Langbein and Iseri, 1960, 25 p.)

Surface water.--Water on the surface of the earth. (Langbein and Iseri, 1960, 25 p.)

Suspended sediment.--Fragmented material, both mineral and organic, that is maintained in suspension in water. (Dion and others, 1976, 125 p.)

Thermal stratification (of a lake).--Vertical temperature stratification that shows the following: The upper layer of the lake, known as the epilimnion, in which water temperature is virtually uniform; a stratum next below, known as the thermocline, in which there is a marked drop in temperature per unit of depth; and the lowermost region or stratum, known as the hypolimnion, in which the temperature from its upper limit to the bottom is nearly uniform. (Langbein and Iseri, 1960, 25 p.)

Unconsolidated material.--(a) A sediment that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth. (b) Soil material that is in a loosely aggregated form. (Bates and Jackson, 1980, 749 p.)

Water quality.--That phase of hydrology that deals with the kinds and amounts of matter dissolved and suspended in natural water, the physical characteristics of the water, and the ecological relationships between aquatic organisms and their environment. (Dion and others, 1976, 125 p.)

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 ended September 30, 1959, is called the "1959 water year." (Langbein and Iseri, 1960, 25 p.)

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, 429 p.)

Zooplankton, zooplanktonic.--The animal part of the plankton. (Dion and others, 1976, 125 p.)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1993 - 747-136