In cooperation with the McHenry County Soil and Water Conservation District

Water Quality of Nippersink Creek and Wonder Lake, McHenry County, Illinois, 1994-2001

Scientific Investigations Report 2004-5085

U.S. Department of the Interior
U.S. Geological Survey

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Gale A. Norton, Secretary

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Cover photograph: Nippersink Creek above Wonder Lake, McHenry County, Illinois; view looking downstream from Thompson Road. Photograph by David H. Dupré.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
inches per square mile (in/mi^2)	0.981	centimeters per square kilometer (cm/km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton	0.9072	metric ton

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

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 (NGVD 29) have been converted to NAVD 88 for use in this publication.

Horizontal coordinate information is referenced North American Datum of 1983 (NAD 83). Historical data collected and stored as North American Datum of 1927 (NAD27) have been converted to NAD83 for use in this publication.

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

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

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One-thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Water Quality of Nippersink Creek and Wonder Lake, McHenry County, Illinois, 1994-2001

By David H. Dupré and Dale M. Robertson

Abstract

Wonder Lake, McHenry County, Illinois was formed when an earthen dam was constructed across Nippersink Creek in 1929. The U.S. Geological Survey (USGS), in cooperation with the McHenry County Soil and Water Conservation District, operated two streamflow and water-quality monitoring sites (upstream and downstream of Wonder Lake) from July 1994 through June 1997, and examined the water quality of the lake during 1999-2000. From 1999 through 2001, the USGS National Water-Quality Assessment Program operated the same upstream monitoring station to assess the streamflow, sediments, nutrients, and other chemical and physical characteristics of Nippersink Creek. Interpolation and regression methods were used to compute loads of sediment and nutrients delivered to Wonder Lake through Nippersink Creek by the combination of data sets collected as part of these studies.

Since the formation of Wonder Lake, sediment and nutrient loading from Nippersink Creek has caused lake water-quality degradation. Wonder Lake effectively trapped 75 percent of the 15,900 tons of suspended sediment delivered during 1994-97. The average daily sediment load delivered during 1994-2001 was 25 tons. High sediment loading from the watershed reduces water clarity and hinders lake navigation. Nutrient loading from Nippersink Creek results in eutrophic conditions within Wonder Lake as evaluated on a Trophic State Index. The load of total phosphorus trapped in Wonder Lake is from 6 to 28 percent of the delivered load from Nippersink Creek. If the lake could be restored to its original capacity, the sediment trapping efficiency may be increased.

INTRODUCTION

The construction of an earthen dam across Nippersink Creek in 1929 created Wonder Lake, McHenry County, northeastern Illinois (fig. 1). This 830-acre reservoir is incorporated into the Village of Wonder Lake and lies within the 97.0-mi^2 watershed. Wonder Lake is important economically, socially, and ecologically to the area. Changes in lake-water quality are of chief concern to the sustainability of this area for recreational uses.

The water quality of lakes is affected by streams draining their watersheds (Leopold, Wolman, and Miller, 1964). This effect may be more pronounced in lakes or reservoirs with short water residence times, which usually are measured in months, rather than lakes or reservoirs with longer residence times, which usually are measured in years. The amounts of water, sediment, and nutrients delivered to Wonder Lake through Nippersink Creek are affected by many natural processes and human factors that are dynamic, rather than static, over time (Hack, 1960). Residence times decrease as a reservoir fills with settled sediments. This decrease in residence time contributes to the dynamic nature of the lentic system.

Nitrogen and phosphorus are essential nutrients for primary productivity in freshwater aquatic systems; however, when these nutrients are in excess, they can promote extensive aquatic-plant growth (macrophytes, periphyton, and phytoplankton), which can lead to eutrophic (productive) conditions. Typically, the limiting growth factor for most aquatic plants and algae in the Midwest is phosphorus. Nitrogen availability also is important in algae growth. When these plants and algae die and decompose, the process consumes dissolved

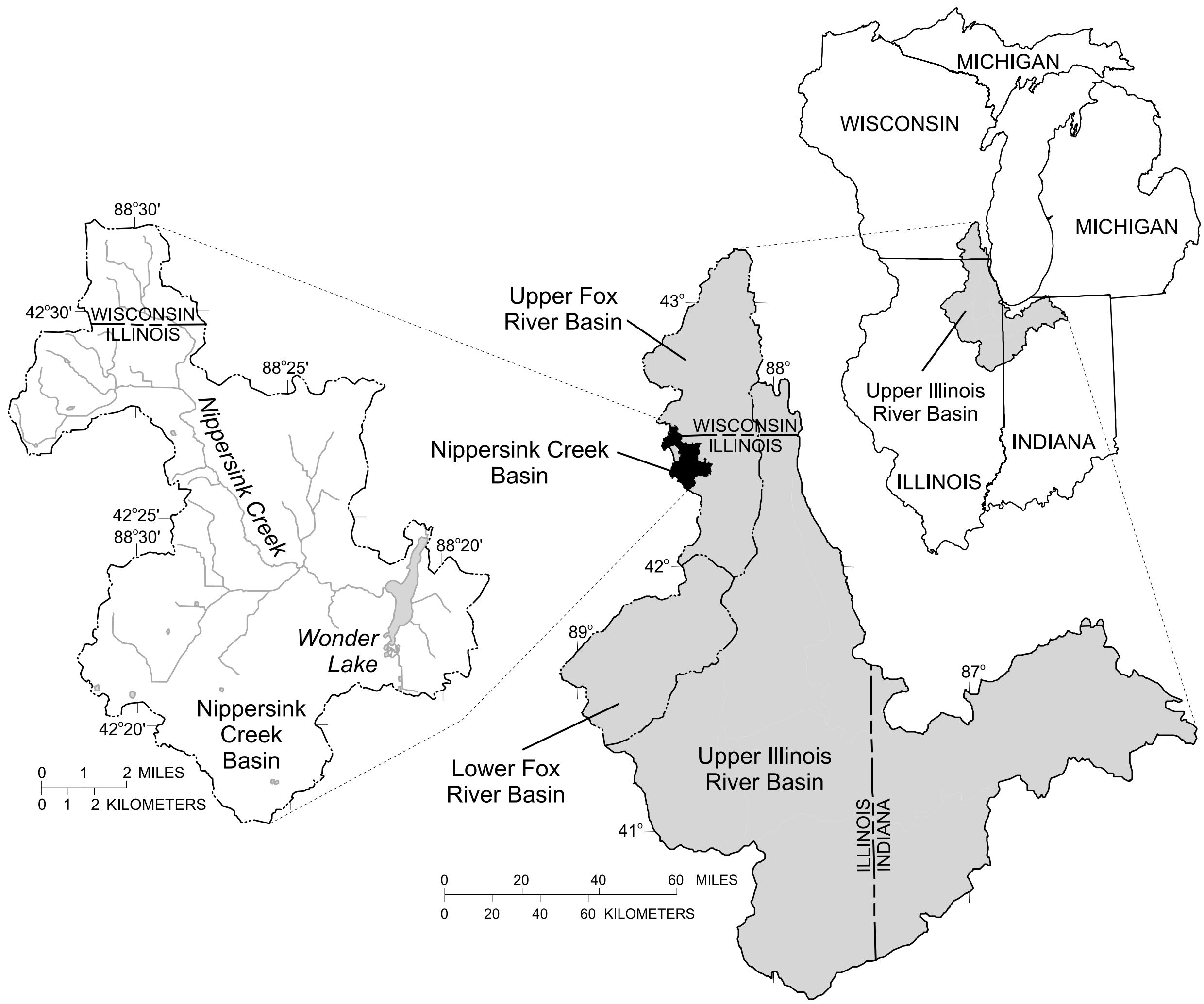

Figure 1. Location of the Nippersink Creek Basin in northeastern Illinois and southeastern Wisconsin.

oxygen in the water (Westlake, 1975a). This cycle can decrease dissolved oxygen concentrations to less than 2 mg/L (hypoxic conditions) in lakes, especially in deeper areas of stratified lakes, during part of the year. Low dissolved oxygen concentrations are undesirable because rough-fish populations survive better than game-fish populations in this condition.

To help understand the causes of the degradation in the water quality of the lake, data from three U.S. Geological Survey (USGS) studies were combined and examined. The USGS, in cooperation with the McHenry County Soil and Water Conservation District (SWCD), operated two streamflow and water-quality monitoring sites (one upstream of the lake and one downstream of the lake) (fig. 2) from July 1994 through June 1997, and examined the water quality of Wonder Lake during 1999-2000. From 1999 through 2001, the USGS National Water-Quality Assessment (NAWQA) Program operated one monitoring station (the upstream site) to assess the streamflow, sediments, nutrients, and other chemical and physical characteristics of Nippersink Creek. Data collected at the monitoring stations during these studies were used to calculate loads of sediment, nitrogen, and phosphorus delivered to Wonder Lake from Nippersink Creek during Water Years (WY) 1995-2001. A WY is the 12-month period from October 1 through September 30, and is designated by the calendar year in which it ends.

Cochran and Wilken, Inc. (1996) summarized past water-quality studies on the lake and estimated the amount of sediment deposited within

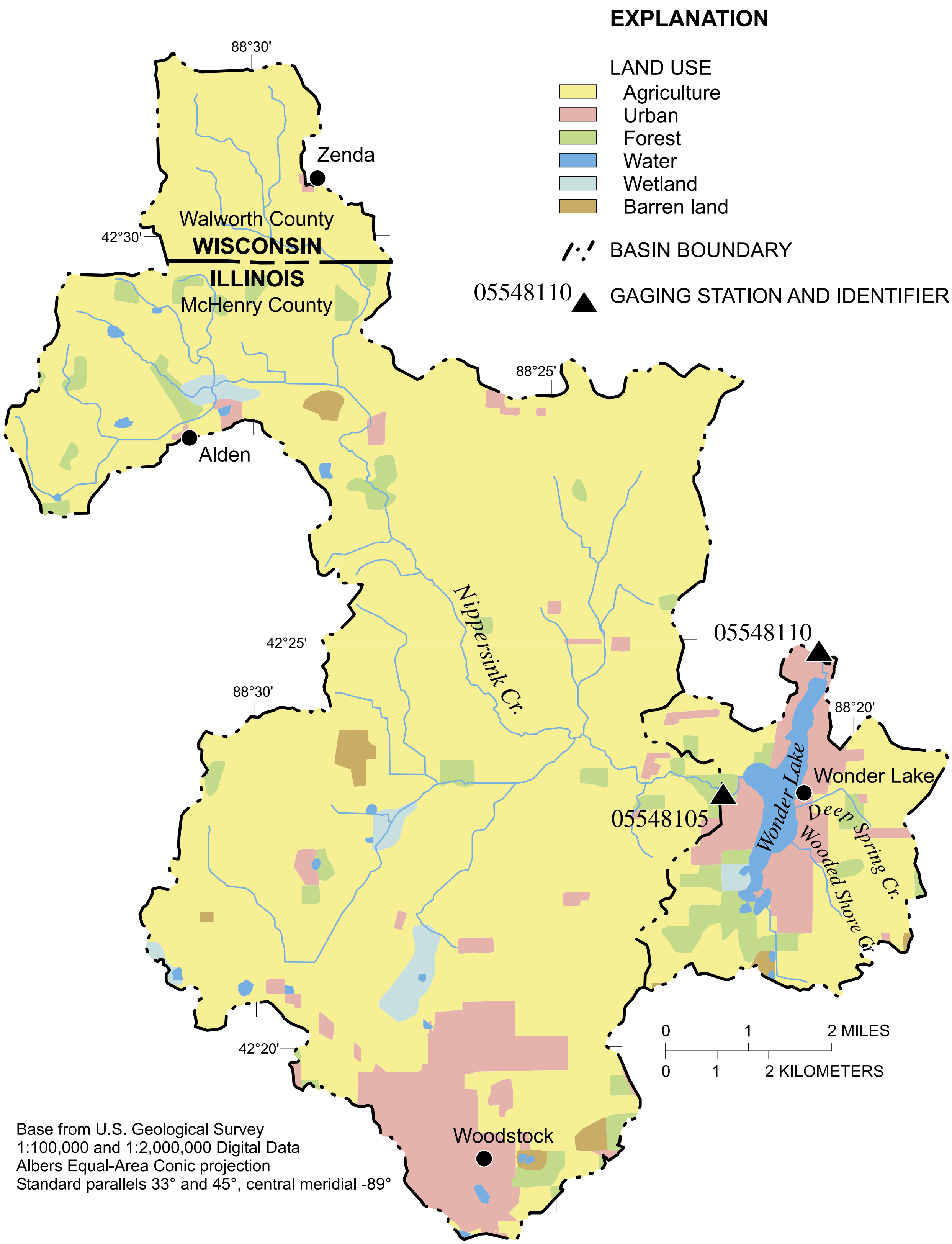

Figure 2. Land use in the Nippersink Creek Basin, northeastern Illinois and southeastern Wisconsin.

the lake since 1929. Prior to 1994, studies on the lake focused on water quality and fish biodiversity within the lake; no efforts were made to document the streamflow or delivery of sediment and nutrients to Wonder Lake.

Purpose and Scope

This report describes the water quality of Wonder Lake and Nippersink Creek, McHenry County, Illinois. Sediment and nutrient data were collected during 1994-97 and 1999-2001. The sediment trapping efficiency of Wonder Lake is estimated for the period 1994-97. The water-quality conditions of the lake are evaluated with a Trophic State Index (TSI) with data collected in 1999 and 2000. The data collected as part of these studies were combined for analysis in this report. Annual loads of sediment were calculated using an interpolation technique and annual loads of nutrients were computed with multivariate regression techniques.

Description of the study area

Wonder Lake is in the upper Fox River Subbasin of the upper Illinois River Basin (fig. 1). Wonder Lake is on the main branch of Nippersink Creek, 17 river miles upstream of the Fox River (Healy, 1979). Wonder Lake's watershed area is 97.0 mi^2.

The watershed area of Nippersink Creek at the monitoring station above Wonder Lake (station 05548105, fig. 2) is 84.5 mi^2, and includes parts of Walworth County, Wisconsin and McHenry County, Illinois. The station at Nippersink Creek below Wonder Lake (station 05548110, fig. 2) has a 97.3 mi^2 watershed area, and about 0.3 mi^2 does not contribute drainage to the lake.

The 1990 land use upstream of Wonder Lake is 86.9 percent agricultural, and 4.4 percent urban (fig. 2; Vogelmann and others, 2001). Changes in urban areas from 1970 through 1990 are shown in figure 3 (Arnold and others, 1999). Changes in population from 1970 through 2000 are given in table 1. There was a 133 percent overall increase in McHenry County population between 1970 and 2000 (U.S. Bureau of the Census, 1991 and 2003).

If the trend in population within McHenry County is similar to that in the Wonder Lake watershed, there will be a larger urban land usage within the Wonder Lake watershed. The construction of roads, homes, and municipal infrastructure was evident during multiple visits to the area during the course of the study.

Originally, Wonder Lake was planned to be 75 percent of its present size. A possible surveying error may be the cause of the difference in lake size. The entire South Bay area was not anticipated to be under water (fig. 4). Because of this possible error, the present lakefront property includes lots that were not designed as part of the initial development (Richard Hilton, Master Property Owner's Association of the Wonder Lake Area, oral commun., 2001). These differences from the original plans contribute to the management and decision-making processes within the watershed and with its stakeholders.

Methods

Two streamflow monitoring stations were installed on Nippersink Creek in 1994, one above and one below Wonder Lake, to monitor stage and establish a discharge rating using standard USGS protocols (Rantz and others, 1982). These stations were in operation from July 1994 through June 1997 (Gary Johnson, U.S. Geological Survey, oral commun., 2001). The USGS NAWQA Program operated the station upstream of Wonder Lake during 1999 - September 2001. The USGS did not operate the downstream station after 1997. Three other intermittent streams (Galt Creek, Deep Spring Creek, and Wooded Shore Creek) contribute

Table 1. Population change for the period 1970-2000 in McHenry County, Ill. (modified from Arnold and others, 1999).

[%, percent]

Population			
1970	1980	1990	2000
111,456	147,897	183,241	260,077
Change in population			
1970-80	1980-90	1990-2000	1970-2000
32.7%	23.9%	41.9%	133%

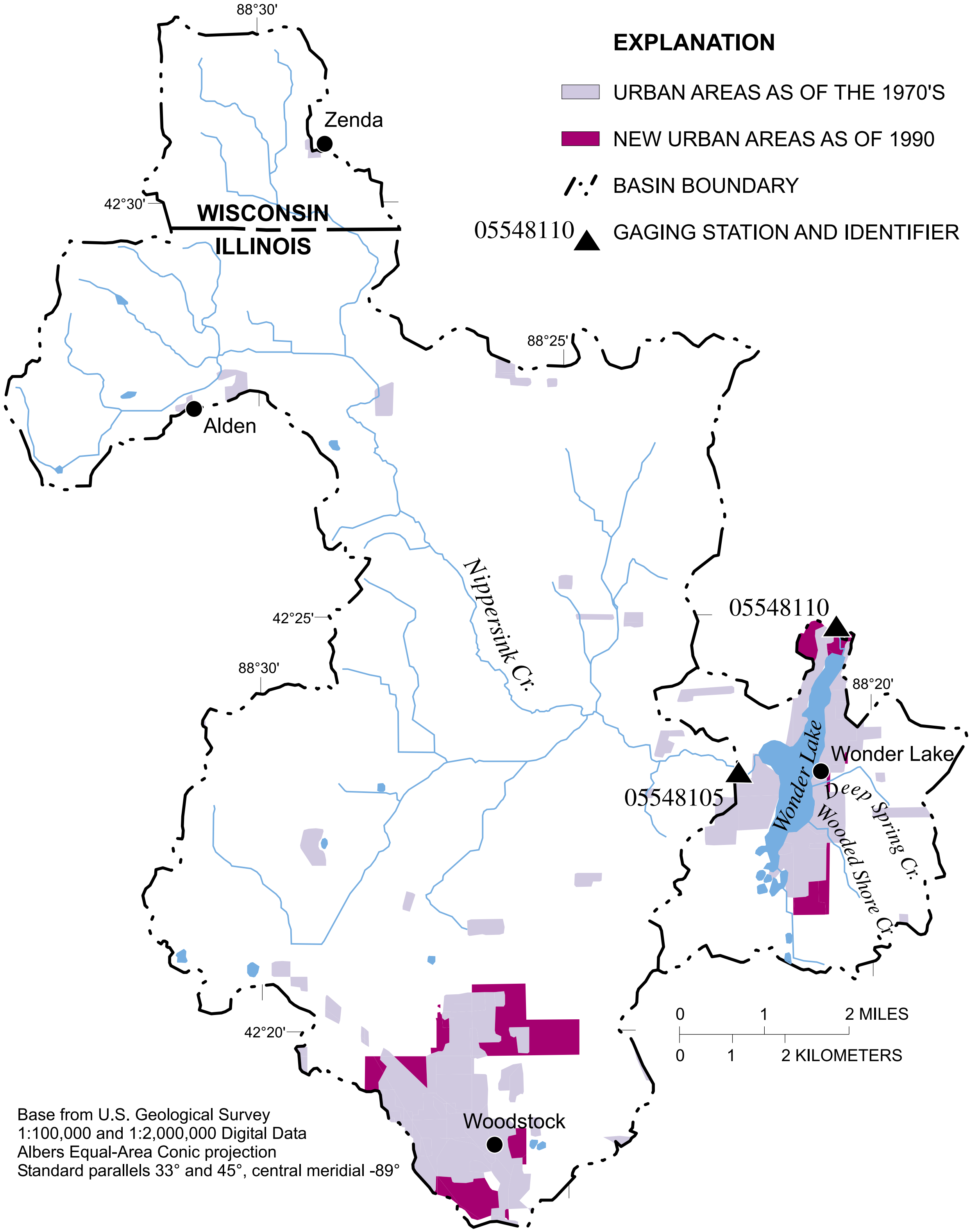

Figure 3. Urbanization in the Nippersink Creek Basin, northeastern Illinois and southeastern Wisconsin.

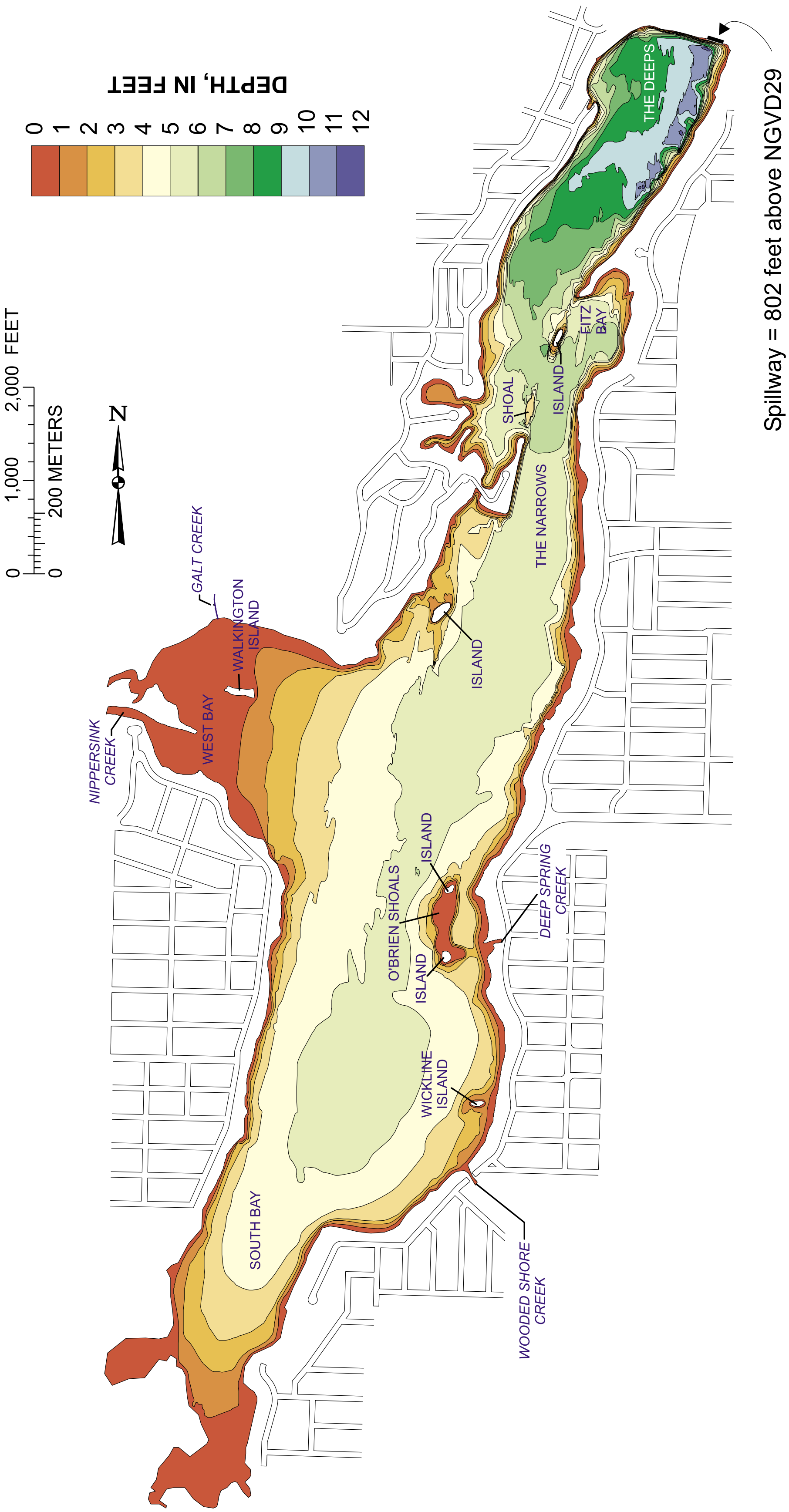

Figure 4. Bathymetry of Wonder Lake, McHenry County, Ill., 1994.

directly to Wonder Lake (fig. 4). Because of study limitations, streamflow magnitude and duration were not measured in these tributaries. The annual flow into Wonder Lake from these tributaries is not considered substantial.

To calculate nutrient mass loadings from 1994 through 1999, streamflow needed to be estimated at the station above Wonder Lake for WY 1998. Flow estimation was accomplished by extrapolating flow data from another station on Nippersink Creek, 12.3 river miles downstream (Nippersink Creek near Spring Grove), by use of a drainage-area ratio. The watershed area at the station above Wonder Lake is 44 percent of the area measured near Spring Grove. Similarly, the mean daily discharge during the period of record above Wonder Lake also was 44 percent of the mean daily discharge near Spring Grove. Therefore, this extrapolation method should approximate the annual streamflow conditions for WY 1998 (Gary Johnson, U.S. Geological Survey, oral commun., 2001).

Sediment and nutrient samples were collected using the equal-width-increment (EWI) method (Guy, 1970; Edwards and Glysson, 1988; Shelton, 1994). Additional grab samples were collected by local observers, as well as with an automated sampler using a fixed-interval, fixed-volume technique (Guy, 1970; Porterfield, 1972; Edwards and Glysson, 1988; Shelton, 1994; Johnson, 1997). The grab samples were necessary during periods when EWI sampling was not possible, and during periods when no observers were available. Grab samples were not collected during 1999-2001. Analyses for dissolved constituents were performed on samples filtered in the field through a 0.45 μm (micrometer) pore-size filter. Suspended sediment and total constituents were determined by analyzing unfiltered water samples (Guy, 1969). The USGS National Water-Quality Laboratory (NWQL) performed chemical analyses of water samples using standard analytical methods (Wershaw and others, 1987; Fishman and Friedman, 1989; Fishman, 1993). The suspended-sediment samples were analyzed at the USGS Kentucky or Missouri District sediment laboratories using standard techniques (Guy, 1969; Sholar and Shreve, 1998).

Annual loads of suspended sediment were estimated using Graphical Constituent Loading and Analysis Software (GCLAS) where methods described by Porterfield (1972) are applied. A menu-driven interface is used in GCLAS to access computer algorithms that linearly interpolate between log-transformed, instantaneous suspended-sediment concentrations stored at unequal time intervals (Gary Johnson, U.S. Geological Survey, oral commun., 2001). Daily suspended-sediment loads then are estimated from the interpolated, log-transformed data. The amount of sediment deposited in Wonder Lake was estimated by subtracting the mass leaving in Nippersink Creek below Wonder Lake from the mass that entered the lake from Nippersink Creek above Wonder Lake.

Annual loads of total phosphorus, dissolved phosphorus, ammonia plus organic nitrogen, dissolved ammonia, and dissolved nitrite plus nitrate were calculated using a regression technique within the Estimator program (Cohn and others, 1989). The Minimum Variance Unbiased Estimator (MVUE) is used to correct for log-transformation biases (Cohn and others, 1989; Gilroy and others, 1990; Cohn and others, 1992a). Daily loads are calculated in the Estimator program using streamflow, time, and seasonality (expressed as sine and cosine transformations of time) as explanatory variables. In this analysis, one-half of the laboratory Method Reporting Level (MRL) was chosen to represent observed values reported as above zero yet below the MRL.

The regression equation for each constituent has the form

$$ln\ (CQ) = \beta_0 + \beta_1 * ln\ (Q) + \beta_2 * T + \beta_3 * (2*\pi*T) + \beta_4 * (2*\pi*T), \qquad (1)$$

where

C	=	concentration,
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$	=	empirical coefficients,
Q	=	daily mean streamflow,
T	=	time, and,
π	=	3.1416.

Water-column profiles for dissolved oxygen, water temperature, pH, and specific conductance were obtained by measuring at half-meter intervals from the surface to the lake bottom using a multiparameter meter. The meter was calibrated in the field with standard reference solutions for pH and specific conductance prior to measurement. The saturated air-calibration method was used for the dissolved-oxygen sensor (Robertson and others, 1999).

A Secchi disk was used to measure water clarity (Cole, 1994). This 20-centimeter-diameter disk has alternating quadrants of black-and-white, and is lowered through the water column until it disappears from sight. This depth of disappearance is recorded as the Secchi depth.

Grab samples of lake water were collected 1-2 ft below the water surface using a Van Dorn sampler (Field and others, 1995). Unfiltered samples were analyzed for total phosphorus and chlorophyll *a* concentrations. All lake samples were analyzed by the Wisconsin State Laboratory of Hygiene using the same techniques as utilized by the NWQL (Wisconsin State Laboratory of Hygiene, 1993).

One method of classifying the trophic state of a lake is by computing individual index values based on near-surface total P and chlorophyll *a* concentrations, and Secchi depths, as developed by Carlson (1977) and modified by Lillie and others (1993). These indices were developed to place these three water-quality characteristics on similar scales. TSI values for a lake can be calculated using the following equations (Lillie and others, 1993):

$$TSI_{SD} = 60.0 - 33.2\ (\log_{10} \text{Secchi depth, in meters}) \quad (2)$$

$$TSI_{C} = 34.82 + 17.41\ (\log_{10} \text{chlorophyll a concentrations, in micrograms per liter}) \quad (3)$$

$$TSI_{TP} = 28.24 + 17.81\ (\log_{10} \text{total phosphorus concentrations, in micrograms per liter}) \quad (4)$$

Acknowledgments

The authors wish to thank the Master Property Owner's Association of Wonder Lake, Ill., and specifically Richard Hilton and Tom Cooper of the Association. Peter Berrini of Cochran and Wilken, Inc. provided lake drawings and maps, as well as historical information. The following USGS personnel are noted for their assistance in the planning and execution of this study, and mentoring during the course of this study: Gary Johnson, Kevin Richards, George Groschen, and Mike Friedel.

HYDROLOGIC CONDITIONS

The annual mean streamflow in Nippersink Creek above Wonder Lake is 62.7 ft^3/s for the period of record from 1995 to 2001, which indicates annual runoff of about 10 in/mi^2 (Harris and others, 2002). The flow regime varied greatly between the monitored periods, 1994-97 and 1999-2001, as indicated by the annual runoff at the upstream monitoring site (table 2). The period from 1995 to 1997 was much drier than normal with each successive year slightly wetter than the preceding year. The wettest year during the study period was 1999, with 2000 also much wetter than normal. WY 2001 was close to the mean of 10.1 in/mi^2 or 62.7 ft^3/s. The combination of these hydrologic data from the two streamgaging periods should provide acceptable range for the constituent load estimates.

Based on the observed streamflow in Nippersink Creek below Wonder Lake, there are unmeasured inputs into Wonder Lake (table 2). The magnitude of these inputs is estimated to be no more than 12-15 percent of the volume exiting

Table 2. Annual runoff in Nippersink Creek above and below Wonder Lake, and ungaged lake inflow volumes by percentage of lake outflow in Nippersink Creek below Wonder Lake, McHenry County, Ill.

[nd, no data]

Water Years	Annual Runoff	
	Above Wonder Lake (inches per square mile)	Below Wonder Lake (inches per square mile)
1995	6.30	6.43
1996	8.78	8.69
1997	9.29	9.25
1998	[1]10.56	nd
1999	13.83	nd
2000	12.15	nd
2001	10.18	nd
Mean 1995-2001	10.09	8.12

Water Years	Estimated ungaged inflows (millions of cubic feet)	Percentage of outflow
1995	79,200	14.9
1996	88,100	12.3
1997	97,400	12.8

[1]Calculated value; not included in Mean.

the lake annually. There are three, small intermittent creeks (Galt Creek, Deep Spring Creek, and Wooded Shore Creek) that drain into Wonder Lake that may account for the majority of this volume (fig. 4). Other sources of flow and input to the lake not considered here are ground-water inflow (including septic fluxes), direct precipitation and evapotranspiration, and adjacent impervious areas. Wonder Lake has an additional 12.5 mi^2 (total area is 97.0 mi^2) of watershed area than does the gaging station above the lake (05548105, fig. 2). The Nippersink Creek station below the lake (05548110) has 0.3 mi^2 of drainage not contributing to the lake.

The flows in Nippersink Creek above and below Wonder Lake are shown in figures 5 and 6, respectively. These flows were used as model input for estimating sediment and nutrient loads in Nippersink Creek and Wonder Lake. These loads are discussed in the section Water Quality below.

WATER QUALITY

The discussion of water quality presented here is divided into three parts: water quality of Nippersink Creek above Wonder Lake, water quality of Wonder Lake, and water quality of Nippersink Creek below the lake. The creek-lake system then can be evaluated from an input-output viewpoint for those periods of time of concurrent observations.

Nippersink Creek above Wonder Lake

Descriptions of the observed concentrations and calculated loads of suspended sediment and nutrients are described below. These concentrations and loads represent the inputs to Wonder Lake.

Sediment

Daily-mean suspended-sediment concentrations in Nippersink Creek above Wonder Lake from July 1994 through July 2001 ranged from 1.2 mg/L to 808 mg/L, with a mean concentration of 89.3 mg/L (table 3). Suspended-sediment concentration generally is related to streamflow (fig. 7). Further discussion of sediment concentration is found in the section below on sediment loads in Wonder Lake. Mass loads were calculated from the concentration data. The load in Nippersink Creek was evaluated above and below Wonder Lake to estimate the amount trapped within the lake.

Nutrients

Total phosphorus concentrations ranged from 0.020 to 1.16 mg/L, with a mean concentration of 0.159 mg/L (table 3). The highest concentrations were observed in the spring; lower concentrations were observed throughout the year. Total phosphorus concentrations generally increased with increasing streamflow. Comparisons between observed constituent concentration and month of sample, and discharge at time of sampling for each nutrient collected in Nippersink Creek above Wonder Lake are shown in figures 8-13.

Dissolved phosphorus concentrations ranged from 0.005 to 0.188 mg/L, with a mean concentration of 0.044 mg/L (table 3, fig. 10). Eight values were below the MRL, 0.010 mg/L. Dissolved phosphorus concentrations were positively correlated to streamflow. There was no strong seasonality in dissolved phosphorus concentrations at this site (05548105).

The concentrations of dissolved ammonia as nitrogen (hereinafter referred to as “ammonia”) from March 1999 through August 2001 ranged from 0.010 to 0.228 mg/L (table 3, fig. 11). The NWQL’s MRL changed toward the end of the study to less than 0.041 mg/L that affected four samples being reported as less than the revised MRL. There were 16 of 37 water samples that were reported as below a MRL for ammonia. Ammonia concentrations had slight seasonality with highest concentrations in the spring. The concentrations of ammonia increased with increasing flow for flows less than 400 ft^3/s; however, above this flow there was a weak negative relation.

Concentrations of ammonia-plus-organic nitrogen as nitrogen (hereinafter referred to as “total organic nitrogen”) from March 1999 through August 2001 ranged from 0.31 to 4.2 mg/L, with a mean concentration of 1.1 mg/L (table 3, figure 12). Although the highest total organic nitrogen concentrations were observed in the spring, lower concentrations were observed throughout the period.

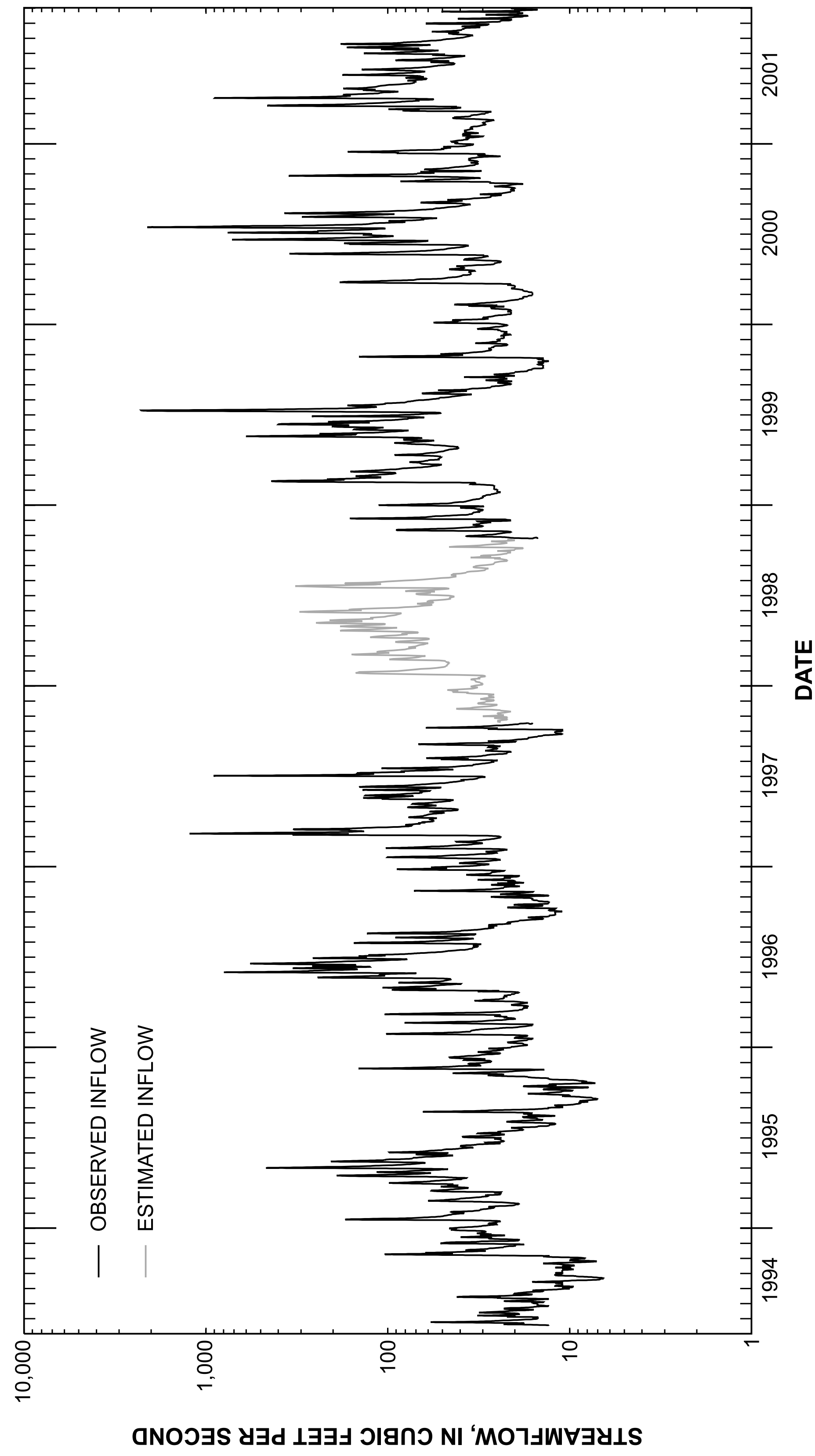

Figure 5. Daily mean streamflow in Nippersink Creek above Wonder Lake, McHenry County, Ill., June 1994 – September 2001.

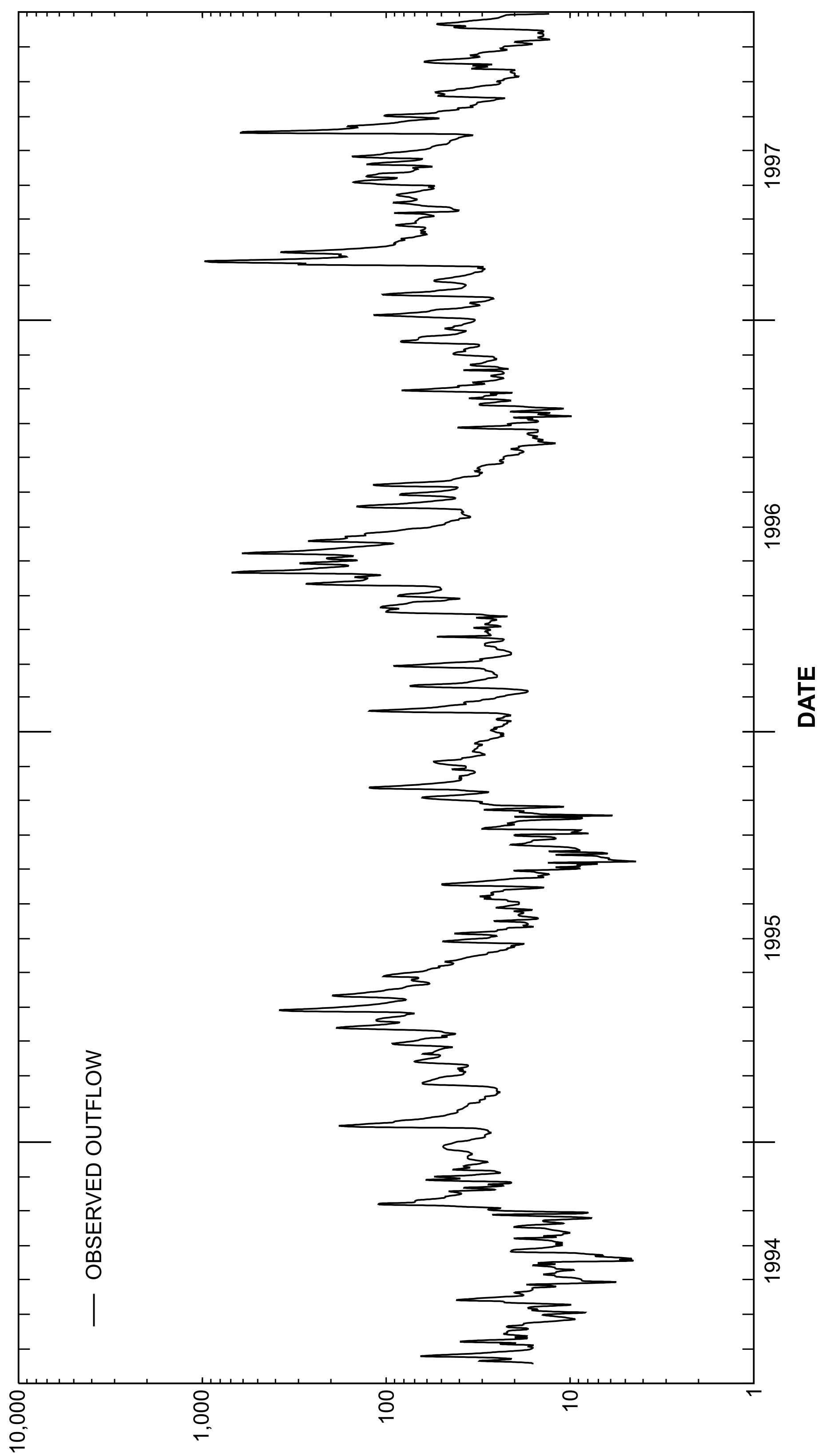

Figure 6. Daily mean streamflow in Nippersink Creek below Wonder Lake, McHenry County, Ill., June 1994 – September 1997.

Table 3. Suspended-sediment and nutrient concentration statistics for Nippersink Creek above Wonder Lake, McHenry County, Ill., 1994-2001.

[mg/L, milligrams per liter; min, minimum; MRL, method reporting level; max, maximum; Dev., deviation]

	Number of Samples	Mean	Min or one-half the MRL	Percentile					Max	Standard Dev.	Variance	Skewness
				10th	25th	50th	75th	90th				
Daily-Mean Suspended Sediment (mg/L)	1990	89.3	1.2	25.2	36.5	63.0	121	192	808	75.6	5,710	2.3
Dissolved Ammonia (NH_4 as N) (mg/L)	37	.066	.010	.010	.010	.036	.095	.193	.228	.068	.005	1.31
Total Ammonia + Organic N as N (mg/L)	37	1.1	.31	.39	.44	.66	1.3	2.4	4.2	1.0	1.0	2.1
Dissolved Nitrite (NO_2) + Nitrate (NO_3) as N (mg/L)	37	4.42	2.27	2.43	2.91	3.87	5.39	7.58	9.00	1.94	3.75	.862
Dissolved Nitrite (NO_2 as N) (mg/L)	37	.032	.010	.015	.020	.026	.044	.057	.067	.016	.000	.680
Total Phosphorus as P (mg/L)	114	.159	.020	.040	.060	.100	.208	.277	1.16	.177	.031	3.30
Dissolved Phosphorus as P (mg/L)	95	.044	.005	.010	.020	.034	.051	.090	.188	.039	.002	1.97

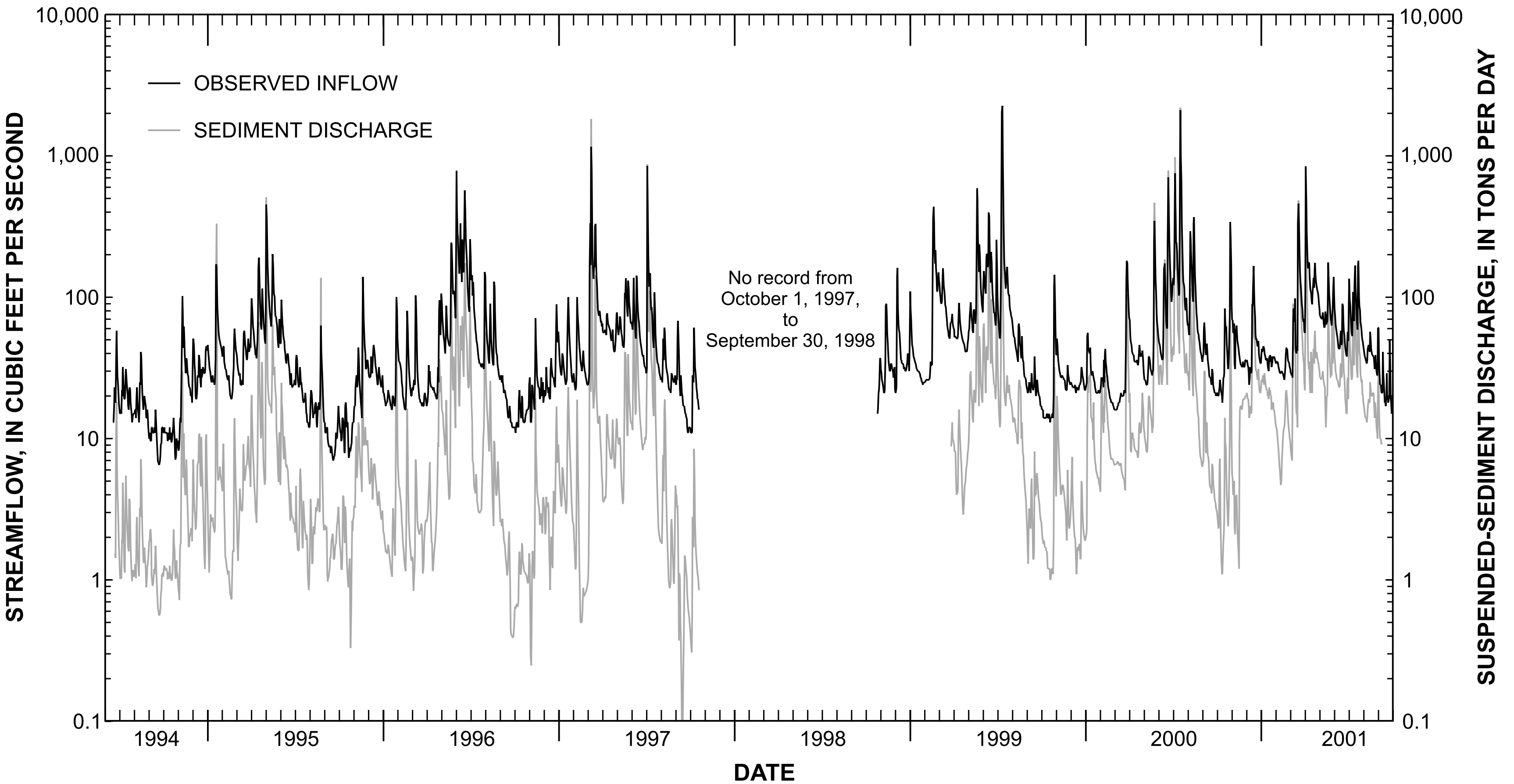

Figure 7. Daily mean streamflow and sediment discharge in Nippersink Creek above Wonder Lake, McHenry County, Ill., June 1994 – September 2001.

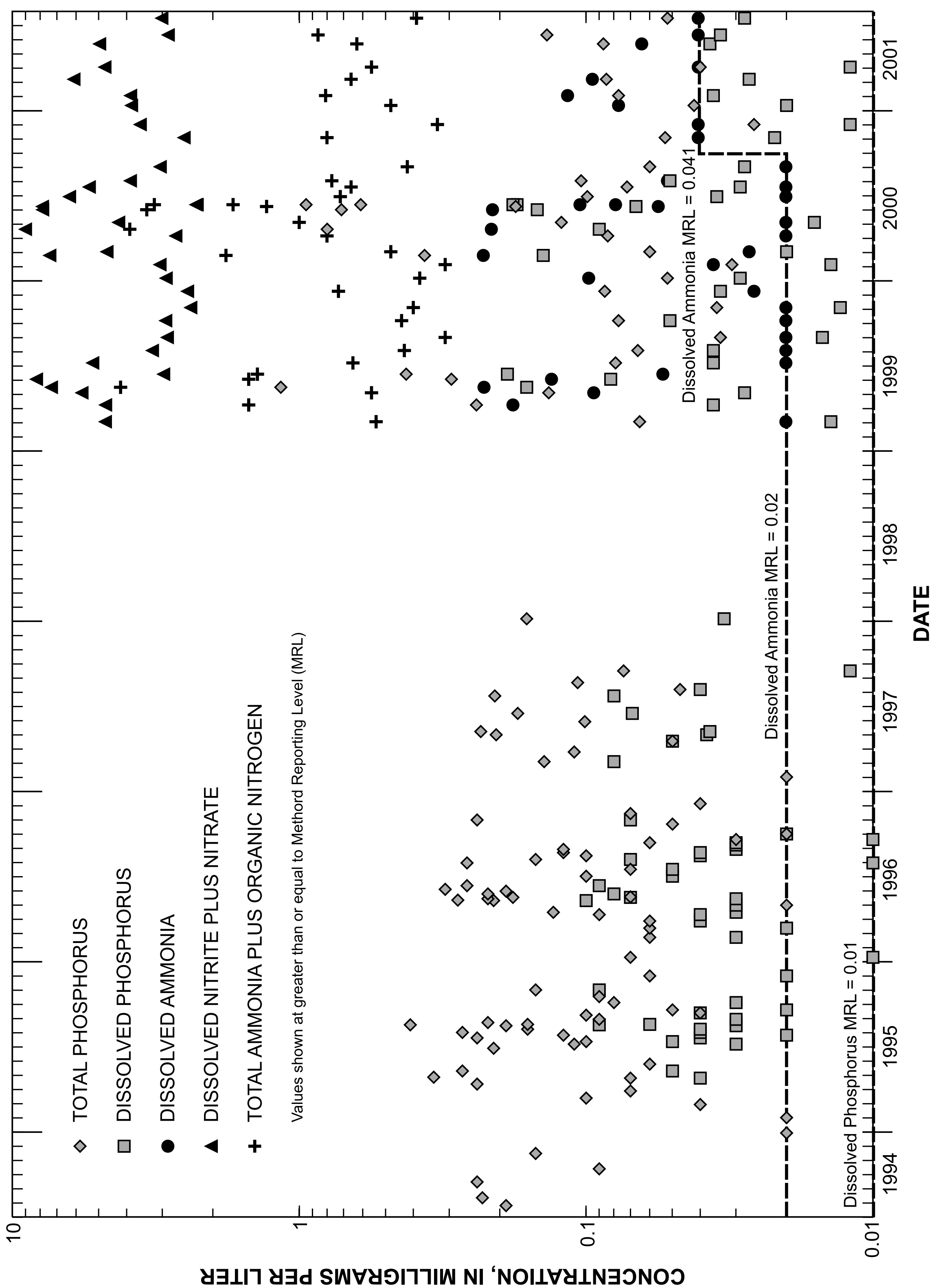

Figure 8. Nutrient concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill. July 1994 – August 2001.

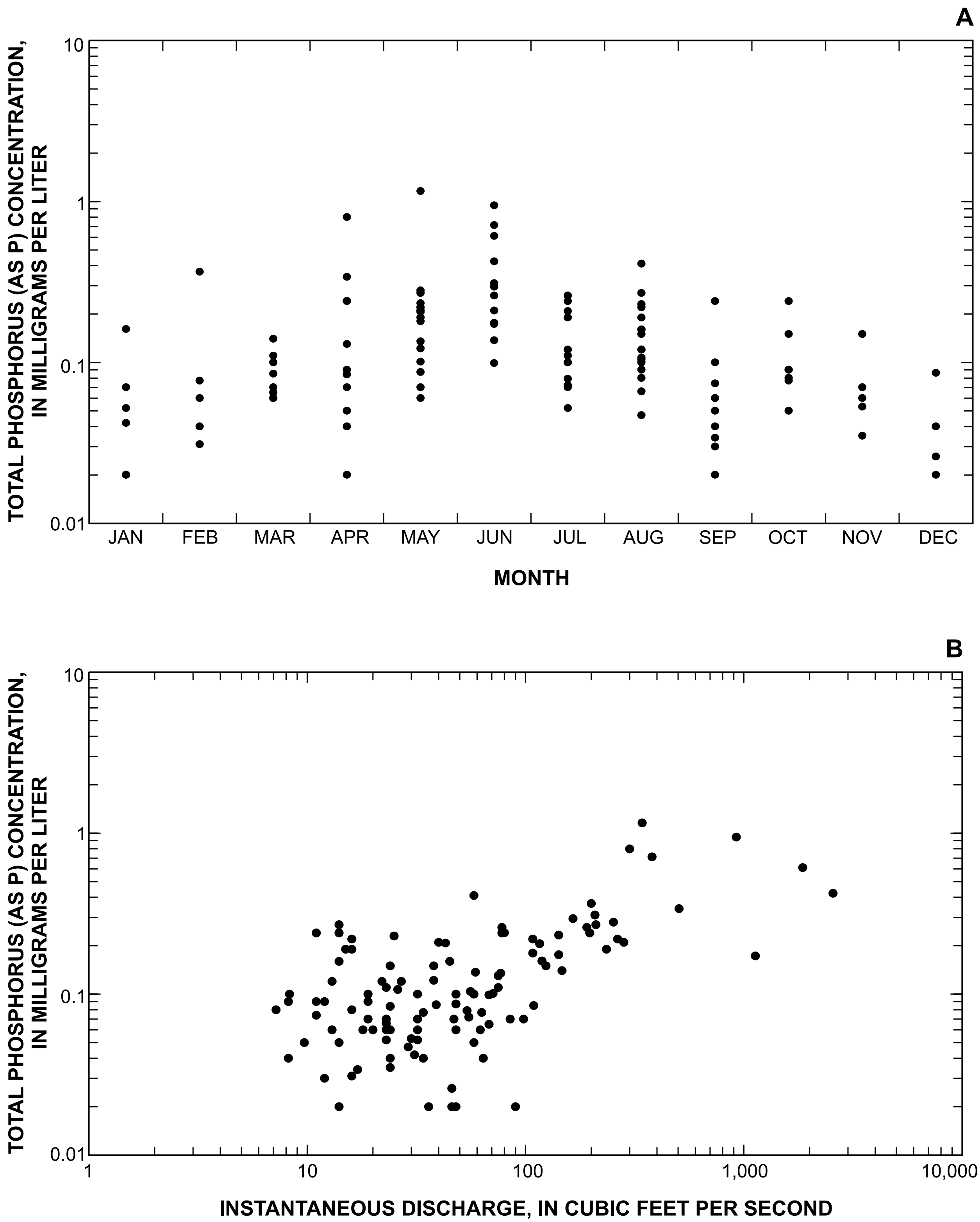

Figure 9. Total phosphorus (as P) concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

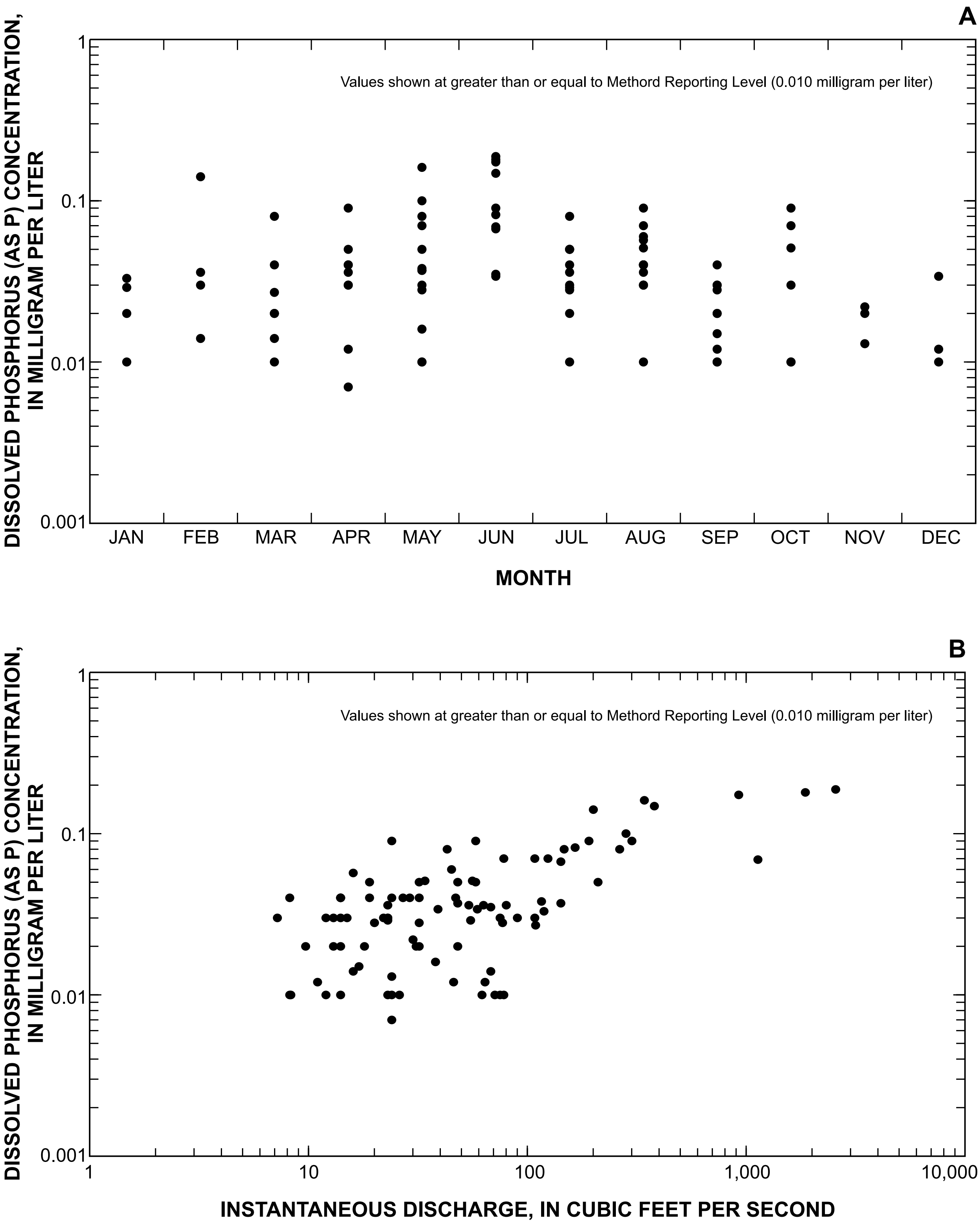

Figure 10. Dissolved phosphorus (as P) concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

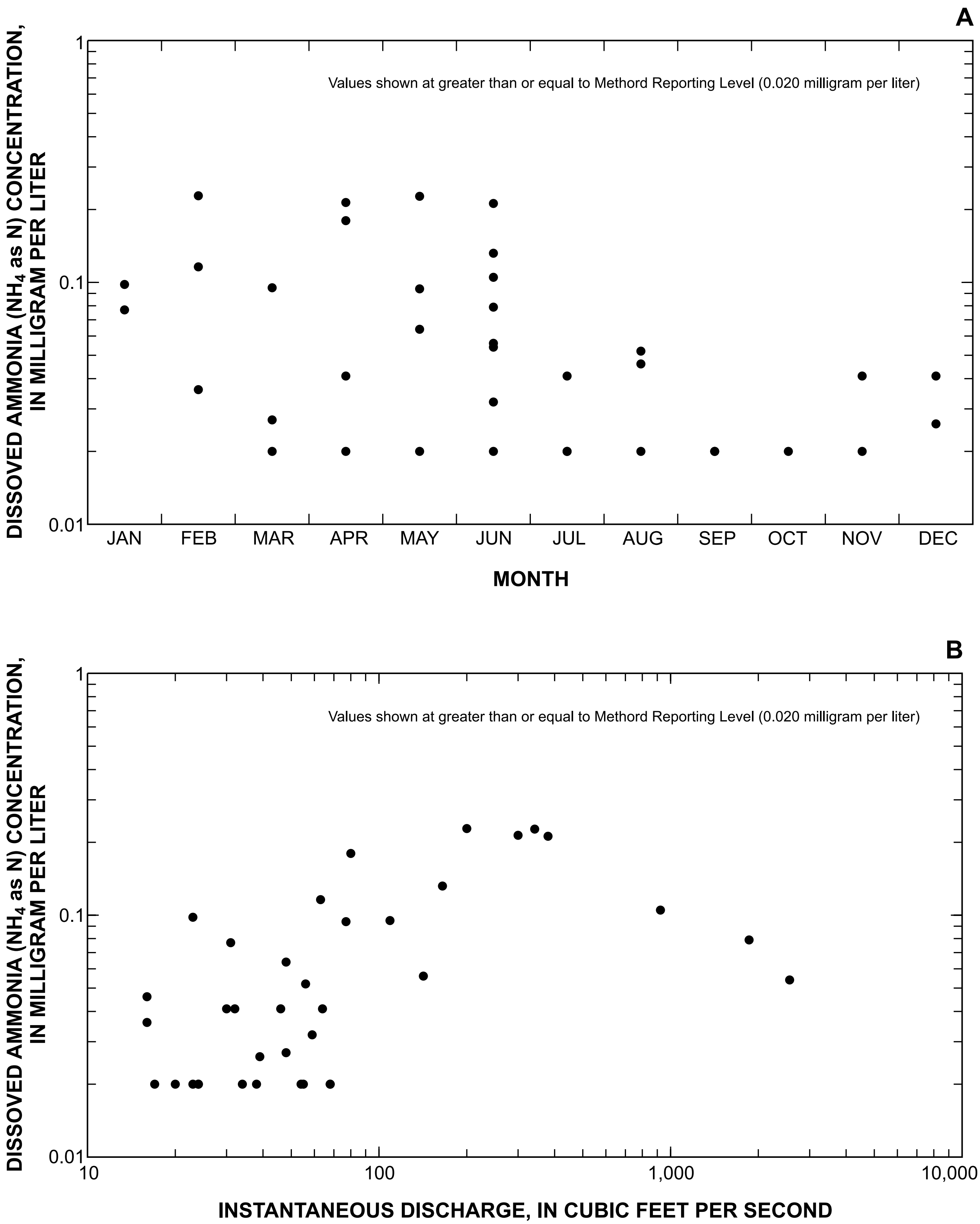

Figure 11. Dissolved ammonia (NH_4 as N) concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

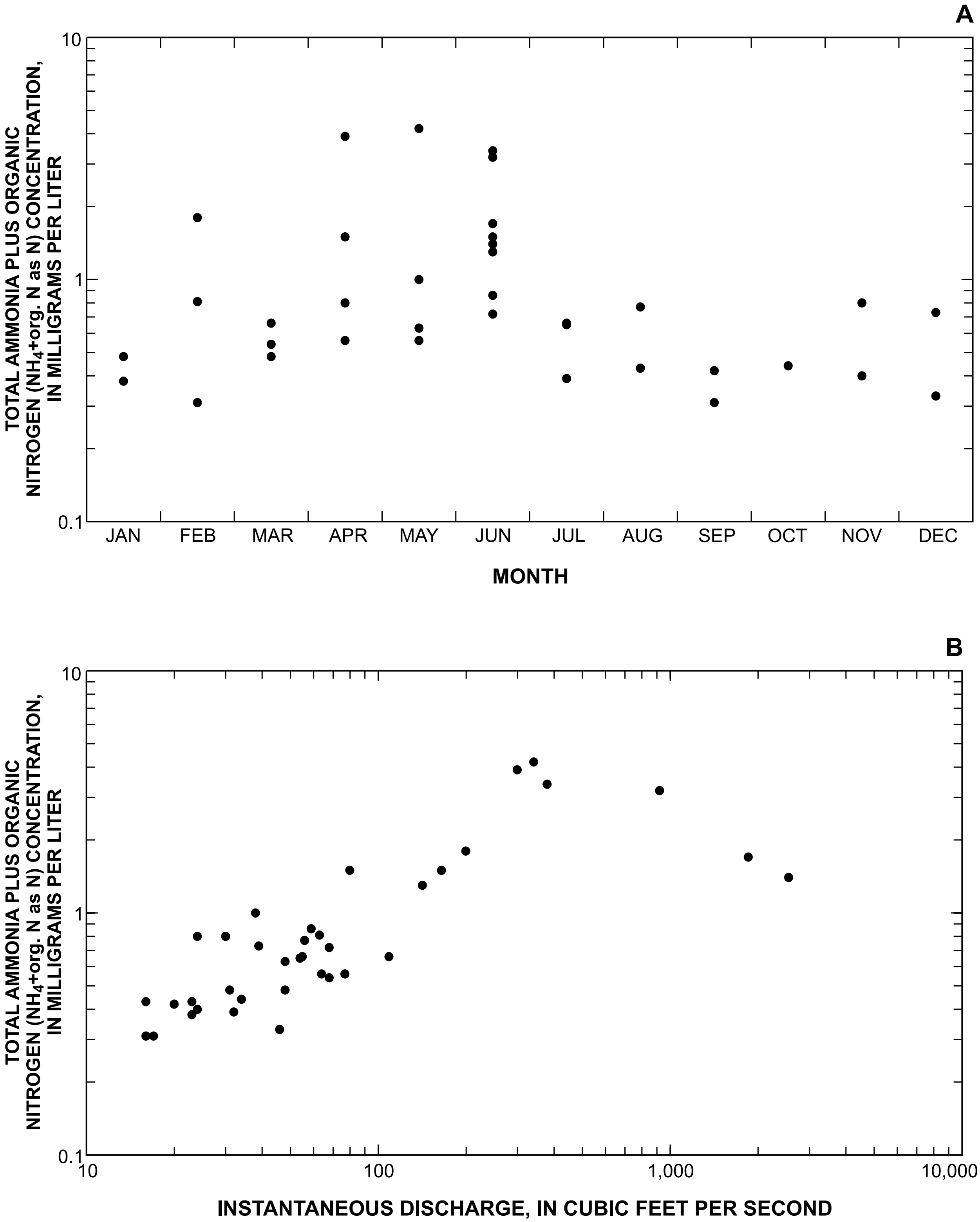

Figure 12. Total ammonia plus organic nitrogen (NH_4 + org. N as N) concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

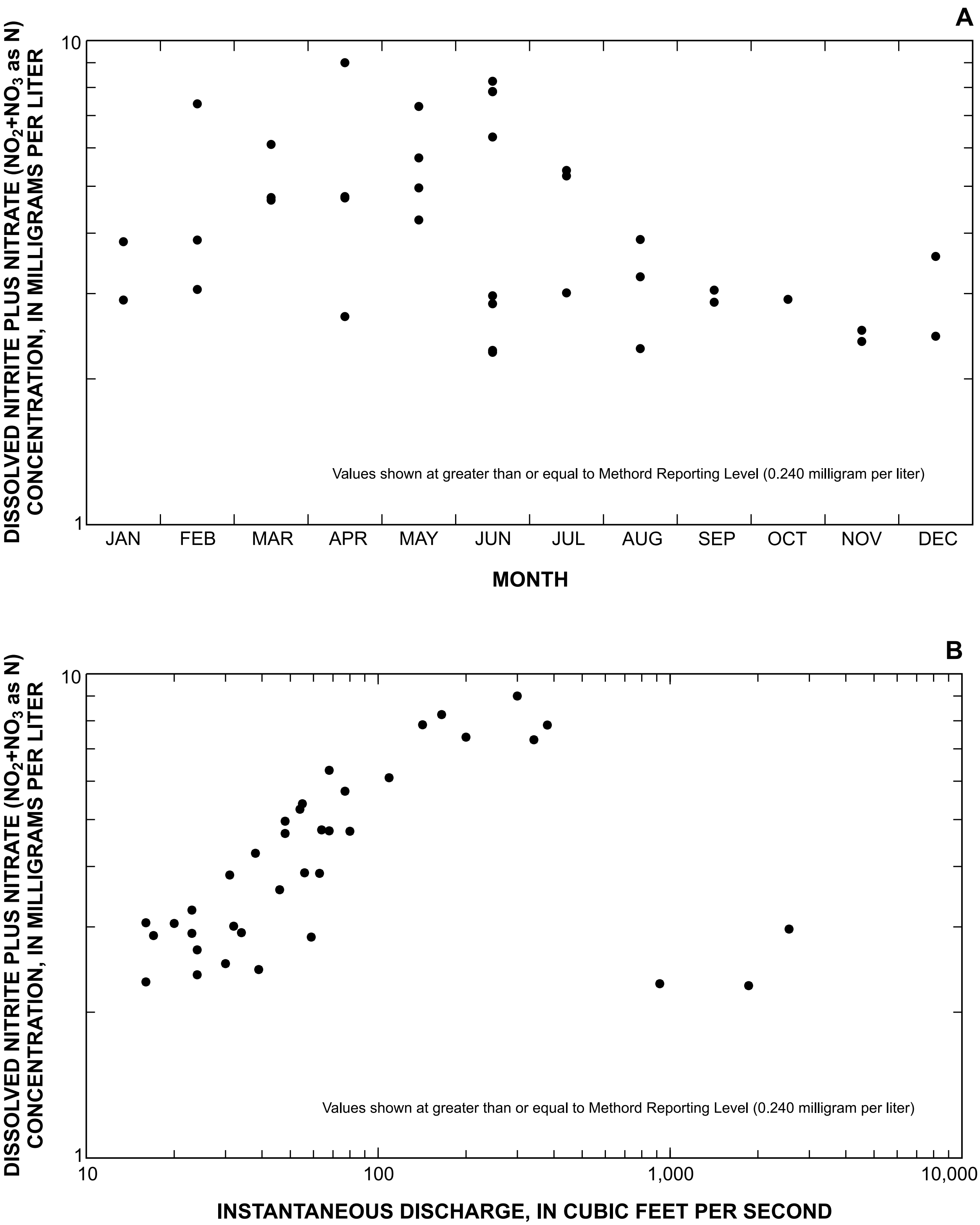

Figure 13. Dissolved nitrite plus nitrate ($NO_2 + NO_3$ as N) concentrations in Nippersink Creek above Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

Similar to ammonia concentrations, total organic nitrogen concentrations increased with increasing flow for flows less than 400 ft^3/s. For flows greater than 900 ft^3/s, there may be negative relation to concentration.

Concentrations of dissolved nitrite plus nitrate as nitrogen (hereinafter referred to as "nitrate") from March 1999 through August 2001 ranged from 2.27 to 9.00 mg/L, with a mean concentration of 4.42 mg/L (table 3, fig. 13). Although the highest nitrate concentrations were observed in spring, lower concentrations were observed throughout the period. Similar to ammonia and total organic nitrogen concentrations, nitrate concentrations increased with increasing flow up to 400 ft^3/s, and then decreased with higher flow.

The same water samples taken in Nippersink Creek above Wonder Lake were analyzed for nitrite as nitrogen (hereinafter referred to as "nitrite") concentrations. Generally, nitrite concentrations were two orders of magnitude lower than the nitrate concentrations and are, therefore, considered negligible (table 3).

Constituent concentrations and coinciding daily streamflow were used to develop multivariate models (described in equation 1 above) with time and streamflow regressors to estimate nutrient loads. Regression coefficients, p-values for statistically significant parameters, and goodness-of-fit measures, as well as the model-calibration period, are listed in table 4 for the Nippersink Creek load-prediction models. Each phosphorus parameter was calibrated twice.

It was necessary to calibrate two regression equations for phosphorus data to accurately compare the various study phases because of varying hydrologic conditions. This calibration was completed in an attempt to estimate an annual phosphorus load trapped in the lake. The equation that better explained observed variability was used to calculate loads. The annual nutrient loads estimated in Nippersink Creek above Wonder Lake based on the 1999-2001 calibration, and the corresponding 95-percent confidence intervals are listed in table 5.

The total phosphorus, dissolved phosphorus, and total organic nitrogen models better described the variability in loading than the nitrate and ammo-

Table 4. Regression coefficients, significance level, and goodness-of-fit parameters, by calibration period, for nutrients in Nippersink Creek above Wonder Lake, McHenry County, Ill.

[r^2, explained variability; %, percent; S, standard error; >, greater than]

Nutrient (Calibration period)	Model Coefficient (p-value)					r^2 (%)	S
	β_0	β_1	β_2	β_3	β_4		
Total Organic Nitrogen (1999-2001)	5.854 (0.000)	1.425 (0.000)	0 (>0.05)	0.212 (0.072)	-0.106 (0.298)	95.0	0.42
Dissolved Ammonia (1999-2001)	2.936 (0.000)	1.526 (0.000)	0 (>0.05)	.471 (0.048)	.349 (0.093)	84.1	.84
Dissolved Nitrate (1999-2001)	7.247 (0.000)	1.119 (0.000)	0 (>0.05)	0 (>0.05)	0 (>0.05)	77.9	.71
Total Phosphorus (1999-2001)	4.022 (0.000)	1.643 (0.000)	0 (>0.05)	.201 (0.151)	-.279 (0.026)	94.8	.50
Dissolved Phosphorus (1999-2001)	3.029 (0.000)	1.638 (0.000)	0 (>0.05)	-.337 (0.011)	-.157 (0.164)	94.8	.46
Total Phosphorus (1994-97)	2.554 (0.000)	1.342 (0.000)	0 (>0.05)	-.271 (0.030)	-.535 (0.000)	85.9	.59
Dissolved Phosphorus (1994-97)	1.365 (0.000)	1.342 (0.000)	0 (>0.05)	0 (>0.05)	0 (>0.05)	75.1	.82

nia models as indicated by the higher percentage of explained variability (r^2) and smaller standard errors (S) (table 4). Suspended material generally is better related to flow than dissolved constituents. Visual inspection of the data confirms this observation (figs. 7, 9, 12). Dissolved phosphorus, however, has a good fit for inputs to Wonder Lake in contrast to the poor fit for dissolved nitrogen forms. The dissolved phosphorus concentrations tended to increase with increasing flow, whereas the dissolved nitrogen forms did not (figs. 10, 11, 13).

WONDER LAKE

Wonder Lake was sampled nine times from April 1999 through August 2000 (Harris and others, 2002). Vertical depth profiles of water temperature, dissolved oxygen, pH, and specific conductance collected during each sampling are presented graphically in figures 14 and 15. These seasonal profiles indicate that Wonder Lake intermittently mixes throughout the year, and no appreciable stratification takes place for extended periods. The trophic state of Wonder Lake was evaluated along with the physical properties previously mentioned.

Trophic State

Spring (April-May) Secchi depth in Wonder Lake was about 2 ft in both 1999 and 2000. The mean summer (June-August), or growing season, Secchi depth was about 1.5 ft during the study. The mean chlorophyll *a* concentration during the study was 62 µg/L, with a growing-season mean of 69 µg/L. The mean near-surface, total phosphorus concentration during the study was 145 µg/L. The mean total phosphorus concentration for the growing season was 162 µg/L.

The lowest water-clarity measurement corresponded with the highest total phosphorus concentration observation in June 1999. This observation was on the day following the peak flow in Nippersink Creek for 1999. This observation may indicate that under large flow inputs, Wonder Lake becomes well mixed with a large amount of suspended sediment. These well-mixed lake conditions would disrupt or destroy any thermal stratification as well as dissolved-oxygen stratification for days to weeks. The depth profiles of the water column indicate periods of this lack of stratification (figs.14-15).

TSI index values were calculated to place these three characteristics on similar scales using equations 2, 3, and 4 as described above. Oligotrophic lakes (TSI values less than 40) have a limited supply of nutrients, typically are clear with low algal populations and P concentrations, and they typically contain oxygen throughout the year in their deepest parts. Mesotrophic lakes (TSI values between 40 and 50) have a moderate supply of nutrients, are not especially clear, and are prone to moderate algal blooms; occasional oxygen depletions in the deeper

Table 5. Estimated annual nutrient loads in tons from Nippersink Creek above Wonder Lake, McHenry County, Ill.

[All loads in tons; annual 95-percent confidence interval value in brackets]

Nutrient	Water Years (Oct. 1 – Sept. 30)						Mean	Median
	1996	1997	1998	1999	2000	2001		
Total Organic Nitrogen	62.97 [6.81]	67.41 [8.85]	66.82 [5.76]	135.8 [23.04]	114.7 [18.15]	63.88 [6.79]	85.26	67.11
Dissolved Ammonia	3.77 [0.91]	5.82 [2.11]	4.94 [0.99]	9.35 [3.25]	6.88 [2.36]	5.56 [1.61]	6.05	5.69
Dissolved Nitrate	264.4 [41.3]	281.2 [46.4]	313.8 [44.0]	445.3 [90.4]	388.1 [76.3]	303.0 [44.3]	332.6	308.4
Total Phosphorus	12.41 [1.89]	12.42 [2.36]	11.02 [1.21]	33.25 [8.83]	27.76 [6.64]	10.23 [4.74]	17.85	12.41
Dissolved Phosphorus	3.36 [0.43]	3.40 [0.57]	3.00 [0.28]	9.08 [2.18]	7.82 [1.65]	2.96 [0.36]	4.94	3.38

parts of the lake are possible. Eutrophic lakes (TSI values greater than 50) are nutrient rich with possible corresponding water-quality problems, such as frequent seasonal algal blooms; oxygen depletion is common in the deeper parts of the lake and clarity is poor.

The TSI values for Wonder Lake all fall in the range for eutrophic lakes (greater than 50), except for two chlorophyll *a* samples in June and July 1999, which indicate mesotrophic conditions (fig. 16). These two chlorophyll *a* samples may be considered data outliers, as the June and July samples from the following year (2000) were an order of magnitude higher in concentration, and close to the median value for all observations. Additionally, the June and July 1999 samples followed major flow events from Nippersink Creek (fig. 5). The lake likely was flushed with this incoming water, and flowing waters typically have lower chlorophyll *a* concentration than slower-moving lake waters. Wonder Lake is a highly eutrophic system based on these TSI values.

Sediment Load

The amount of sediment trapped in Wonder Lake was estimated by subtracting the mass leaving in Nippersink Creek below Wonder Lake from the mass that entered the lake from Nippersink Creek above Wonder Lake. These sediment discharge data

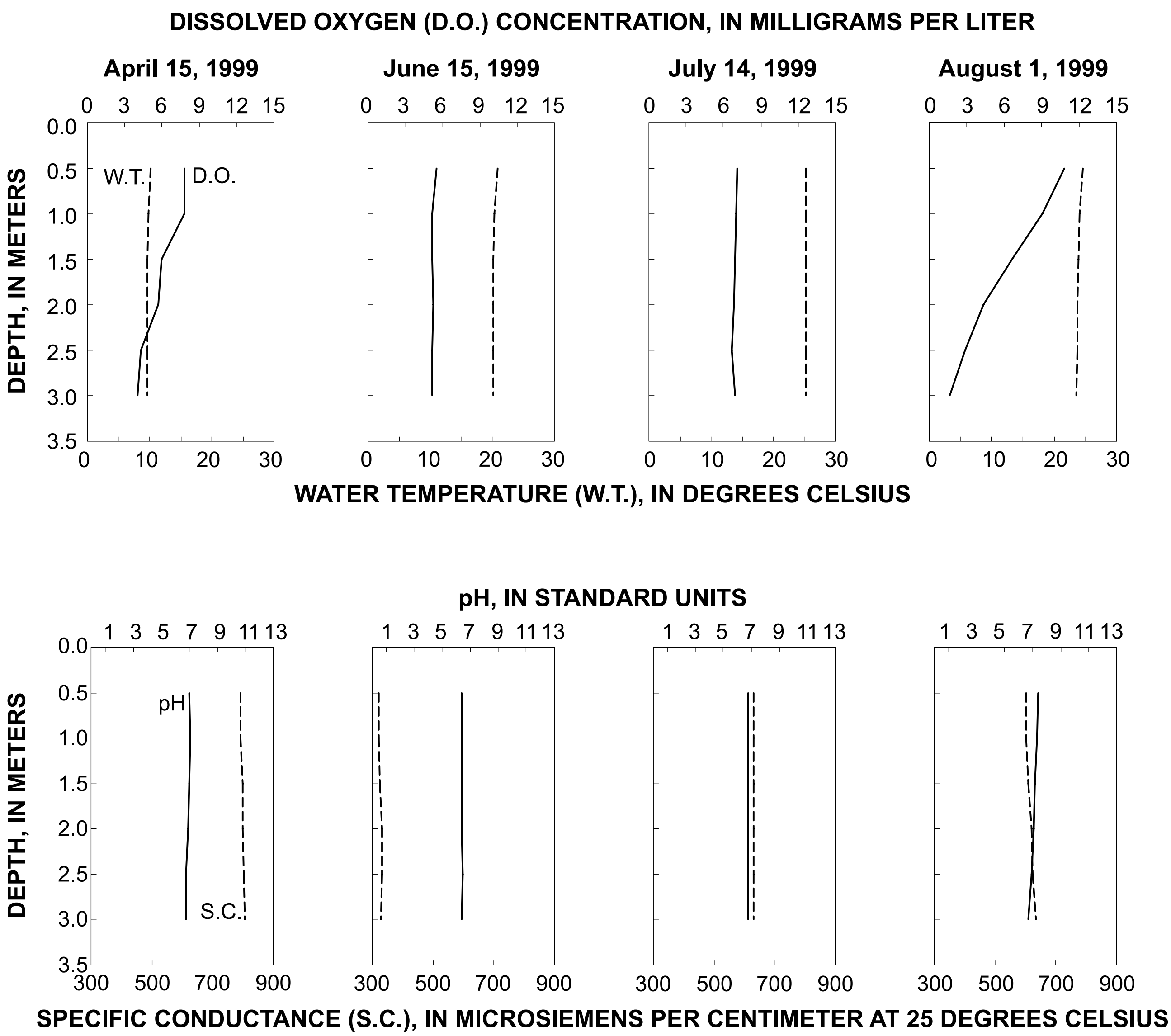

Figure 14. Water-quality data, Wonder Lake, McHenry County, Ill., April 15 – August 1, 1999.

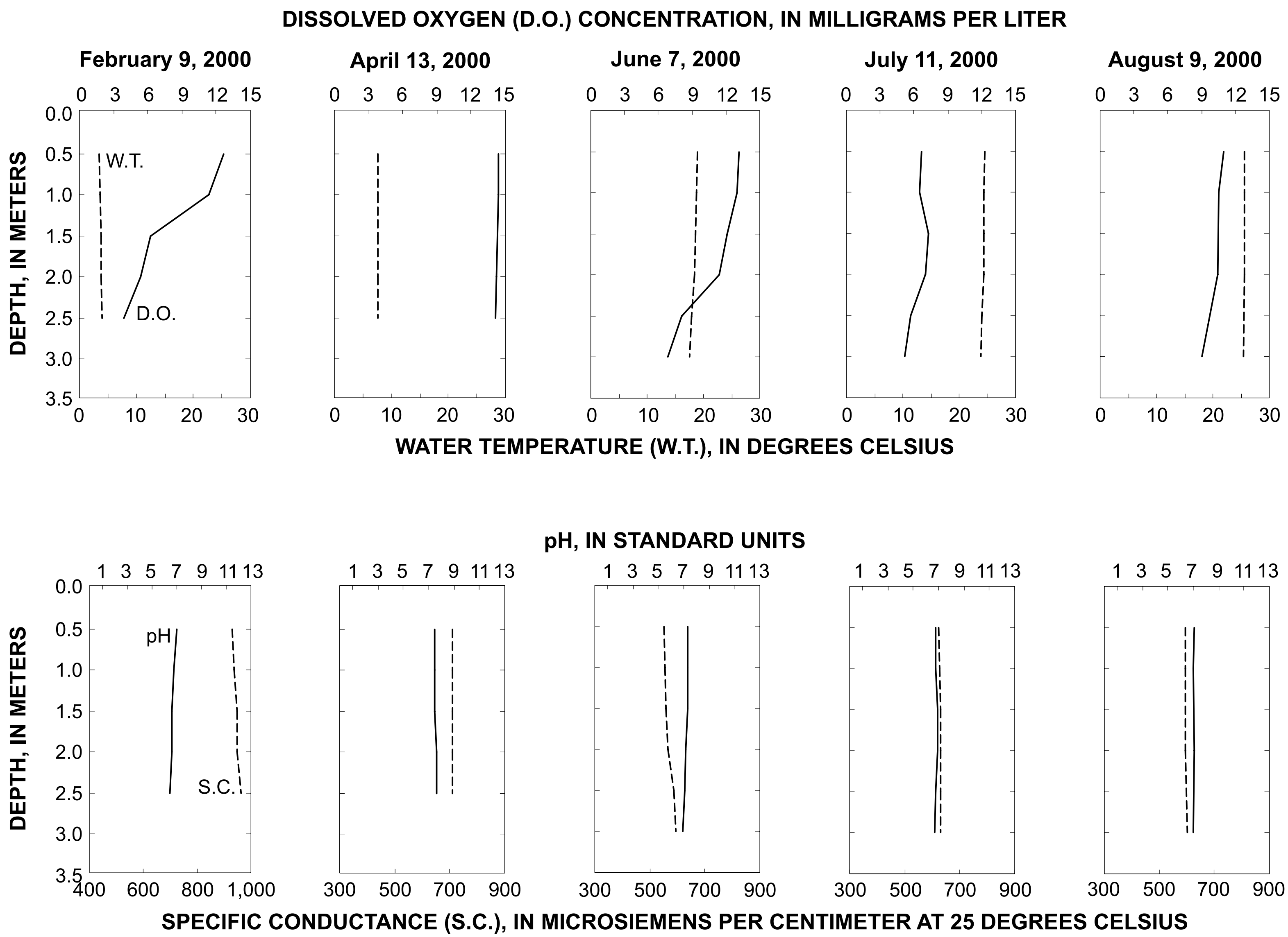

Figure 15. Water-quality data, Wonder Lake, McHenry County, Ill., February 9 – August 9, 2000.

were published by the USGS (LaTour and others, 2001; Harris and others, 2002). Annual sediment loads and retention are presented on a water-year basis (table 6).

Stream and sediment discharge graphs for each station on Nippersink Creek are shown in figures 7 and 17. Monthly sediment loads are given in table 7. Wonder Lake trapped almost 75 percent of the sediment delivered through Nippersink Creek from July 1994 through June 1997.

The 75-percent trapping efficiency of Wonder Lake follows the relation observed by Brune (1953) for many other normally ponded reservoirs. Trapping efficiency is calculated from the capacity (C) to inflow (I) ratio. The estimated 1994 volumetric capacity of Wonder Lake is 3,600 acre-ft (Cochran and Wilken, Inc., 1996). The mean daily inflow of 62.7 ft^3/s is equivalent to 124 acre-ft/d, which results in a C / I ratio of 0.079. Based on this Brune's curve ratio, the trapping efficiency of Wonder Lake should be from 70 to 90 percent. As a reservoir fills, its trapping efficiency decreases. The 74-year old Wonder Lake is approximately 33 percent filled from its 1929 volume (Cochran and Wilken, Inc., 1996). If Wonder Lake was dredged and its volume increased in the future, it is likely that it will trap a greater percentage of the delivered sediment load.

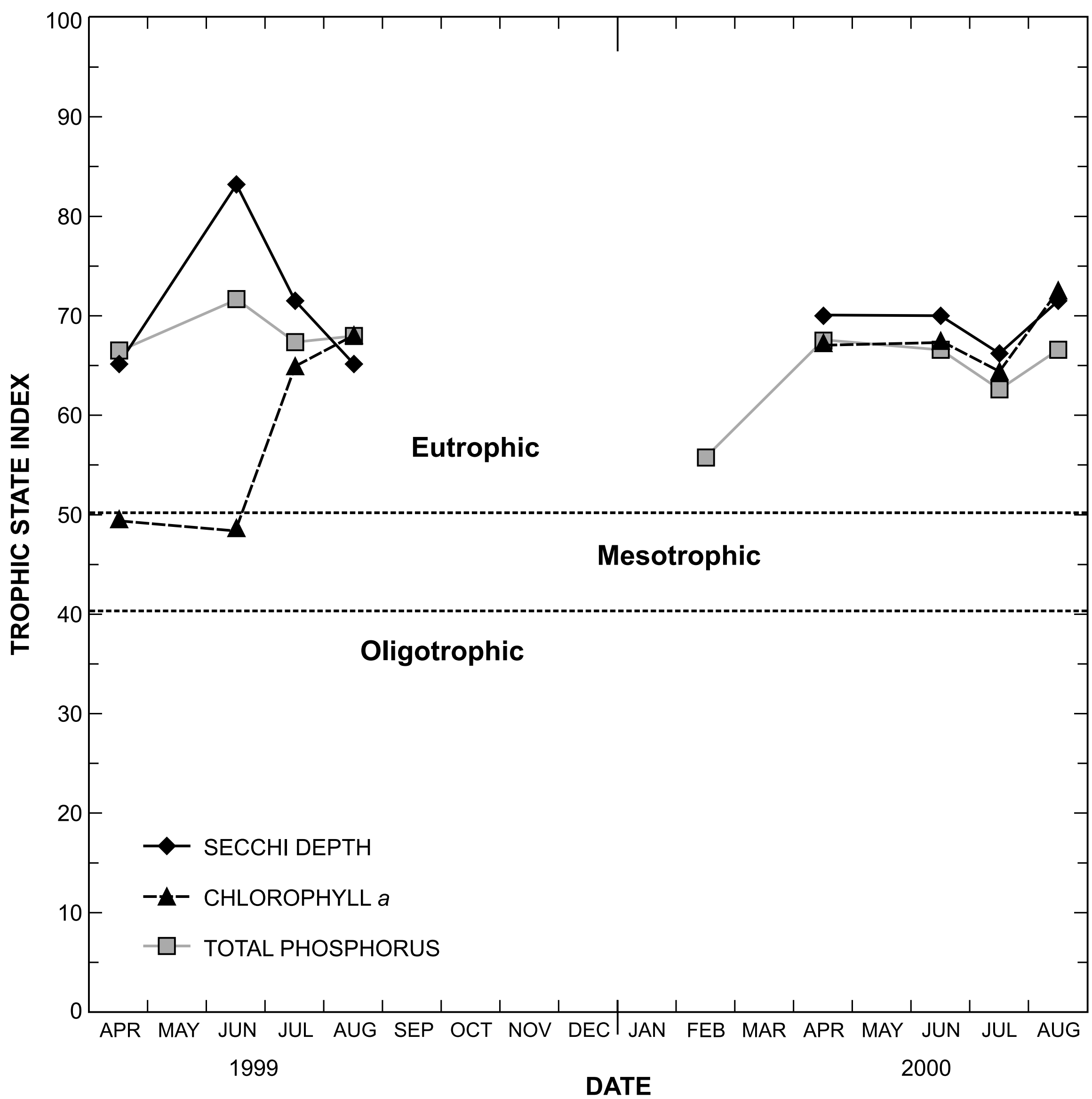

Figure 16. Trophic state indices of Wonder Lake, McHenry County, Ill., April – August 1999, and February – August 2000.

Table 6. Sediment load trapped within Wonder Lake, McHenry County, Ill., 1994-2001.

[%, percent; nd, no data.]

Water Year(s)	Number of days monitored	In (tons)	Out (tons)	Trapped = In - Out (tons)	Trapped (%)
1994	102	207.9	95	112.9	54.3
1995	365	3,568	786	2,781	78
1996	366	4,815	1,435	3,380	70.2
1997	273	7,336	1,738	5,598	76.3
1994-97	1,106	15,927	4,055	11,872	74.5
1998	0	nd	nd	nd	nd
1999	214	7,177	nd	nd	nd
2000	366	15,981	nd	nd	nd
2001	304	10,741	nd	nd	nd

It is estimated that a similar amount of sediment was delivered to Wonder Lake in WY 2000 alone as had been delivered between June 1994 and June 1997 (table 5). Throughout the study, which encompassed 1,990 days, the estimated average daily sediment load is 25 tons. This daily loading would indicate an average annual sediment load of 9,145 tons. If the 75-percent sediment-trapping rate applies in an average year, then about 6,800 tons of sediment would be trapped within Wonder Lake in a typical year.

Nippersink Creek below Wonder Lake

Descriptions of the observed concentrations and calculated loads of suspended sediment and nutrients at Nippersink Creek below Wonder Lake, approximately 0.5 mi downstream of the Wonder Lake dam, are described below. These concentrations and loads represent the outputs from Wonder Lake.

Sediment

Suspended-sediment concentrations in Nippersink Creek below Wonder Lake from July 1994 to June 1997 ranged from 3.1 to 90 mg/L, with a mean concentration of 19.1 mg/L (table 8). These concentrations correspond to those observed upstream of the lake during the same period, given the trapping effect, and relate positively to discharge (fig. 17).

Nutrients

The concentrations of total phosphorus ranged from 0.020 to 1.81 mg/L with a mean concentration of 0.152 mg/L (table 3, fig. 18). Total phosphorus concentrations were not strongly related to flow or season, however, the maximum observation occurred with the largest discharge sampled during the 1994-97 study period (fig. 19).

Dissolved phosphorus concentrations ranged from 0.005 to 0.541 mg/L with a mean concentration of 0.045 mg/L (table 3, fig. 18). Dissolved phosphorus concentrations had a weak positive relation to increasing flow but no seasonality. The maximum observed value occurred with the highest-sampled event as it did with total phosphorus (fig. 20).

The loading models (table 9) do not explain the variability in daily loads below the lake as they did above the lake. The models calibrated with the 1994-97 data for total phosphorus above and below Wonder Lake were reasonably accurate to estimate the amount of phosphorus retained in the lake during that time period. Similar comparisons for dissolved phosphorus would be highly variable, as model simulation only can account for 49 percent of the observed variability for that constituent.

Using the model calibrated with total phosphorus data in Nippersink Creek above and below Wonder Lake from 1994 to 1997, an estimate is made of the amount trapped within the lake (table 10). There was about 6 percent of the mean annual

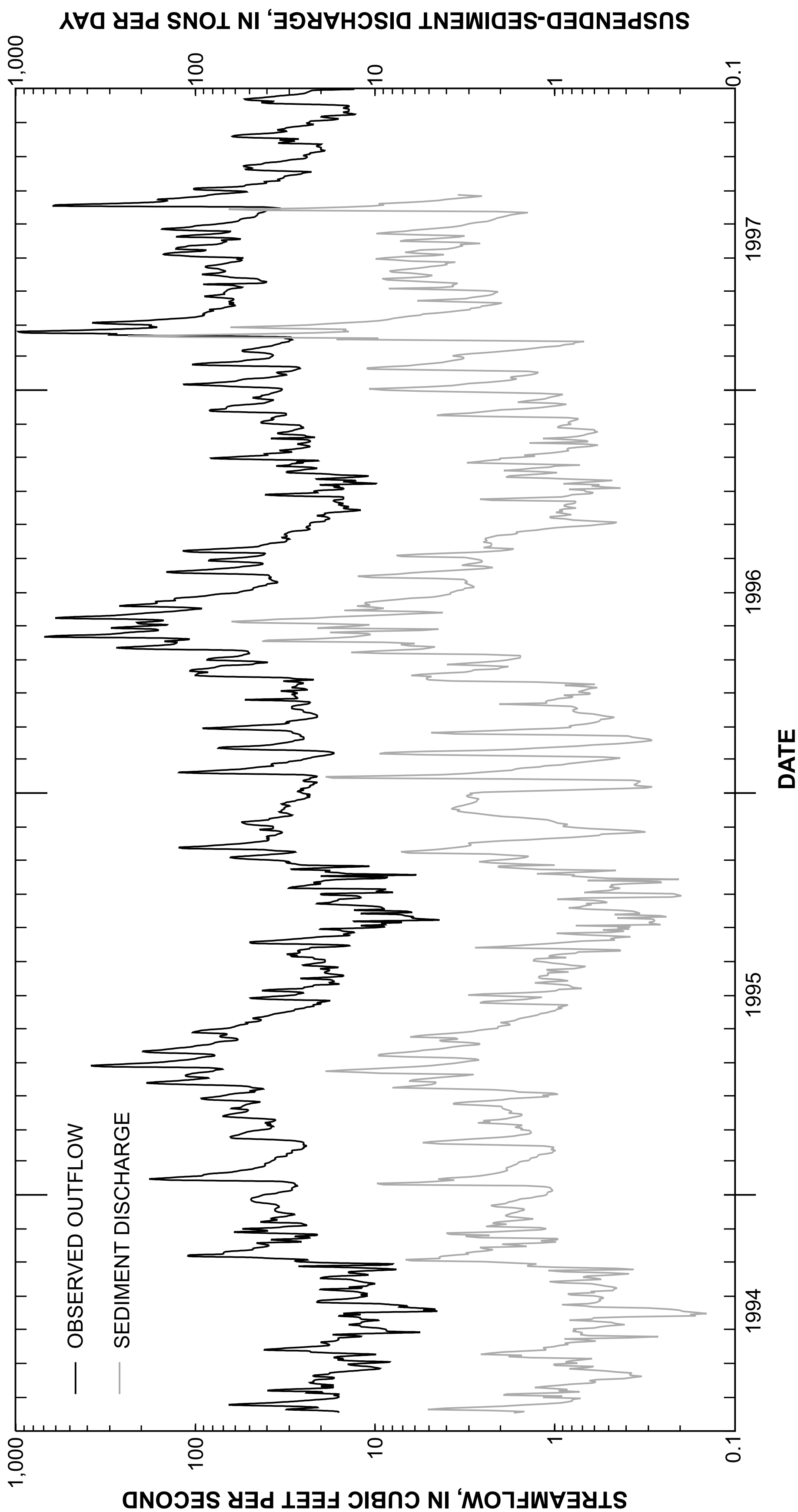

Figure 17. Daily mean streamflow and sediment discharge in Nippersink Creek below Wonder Lake, McHenry County, Ill., June 1994 – September 1997.

Table 7. Monthly suspended-sediment load in Nippersink Creek above and below Wonder Lake, McHenry County, Ill. 1994-2001.

[nd, no data]

Water Year	October	November	December	January	February	March	April	May	June	July	August	September
					Nippersink Creek above Wonder Lake (05548105)							
1994	nd	nd	nd	nd	nd	nd	nd	nd	nd	63.1	62.0	32.7
1995	36.4	162	152	650	72.9	207	1,190	579	137	75.0	254	53.3
1996	90.5	294	108	179	89.2	82.8	338	1,900	1,180	401	121	27.0
1997	64.8	89.8	160	178	3,020	590	246	942	2,050	232	47.4	45.0
1998	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1999	nd	nd	nd	nd	nd	227	1,080	1,830	3,400	417	105	114
2000	168	77.9	352	392	542	346	1,840	3,190	7,590	995	220	265
2001	392	993	566	499	3,360	1,060	1,140	970	1,260	516	nd	nd
					Nippersink Creek below Wonder Lake (05548110)							
Water Year	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
1994	nd	nd	nd	nd	nd	nd	nd	nd	nd	24.8	32.0	15.4
1995	19.7	78.8	56.8	79.5	54.1	61.2	159	147	51.0	36.2	29.7	14.3
1996	21.3	72.8	65.0	87.1	57.0	27.4	71.8	305	484	134	82.7	28.4
1997	34.3	29.8	45.4	133	617	308	153	173	246	nd	nd	nd

total phosphorus load retained in Wonder Lake using the earlier data set. This estimated trapping increases to 28 percent when the mean annual total phosphorus loading amount is used based on the latter calibration (tables 5 and 10). The difference in estimated total phosphorus trapping is attributable solely to the differences between the two models for Nippersink Creek above Wonder Lake.

Results for the percent retained for total phosphorus delivered to Wonder Lake were appreciably different for the two models. Based on the sediment-trapping efficiency, and the observed relation between flow and concentrations of particulate nutrients, it would be expected that a larger percentage of total phosphorus would be retained within the lake, similar to suspended sediment.

Three intermittent streams contribute directly to Wonder Lake (fig. 4). Because of study limitations, the flow magnitude and duration were not measured in these tributaries. Therefore, slightly more sediments and nutrients may be delivered and retained than are estimated here. Flow inputs are best estimated when both Nippersink Creek monitoring sites are in operation upstream and downstream of Wonder Lake.

SUMMARY AND CONCLUSIONS

Wonder Lake, McHenry County, Illinois was formed when an earthen dam was constructed across Nippersink Creek in 1929. The USGS, in cooperation with the McHenry County SWCD, operated two streamflow and water-quality monitoring sites from July 1994 through June 1997, and examined the water quality of Wonder Lake during 1999-2000. From 1999 through 2001, the USGS NAWQA Program operated the same upstream monitoring station to assess the streamflow, nutrients, sediments, and other chemical and physical characteristics of Nippersink Creek.

Table 8. Suspended-sediment and nutrient concentrations in Nippersink Creek below Wonder Lake, McHenry County, Ill., 1994-97.

[All data except number of samples in milligrams per liter; MRL, method reporting level]

Statistic	Daily mean suspended sediment	Total Phosphorus as P	Dissolved Phosphorus as P
Number of Samples	1106	73	53
Mean	19.1	0.152	0.045
Minimum or one-half MRL	3.1	.020	.005
10th-percentile	10.0	.060	.005
25th-percentile	14.0	.080	.020
Median	17.2	.120	.030
75th-percentile	22.1	.150	.040
90th-percentile	29.7	.204	.078
Maximum	90.2	1.81	.541
Standard Deviation	9.1	.215	.076
Variance	82.0	.046	.006
Skewness	2.1	6.80	5.64

Nutrient and sediment loading to Wonder Lake is strongly related to the hydrologic conditions of Nippersink Creek and the surrounding watershed. Suspended-sediment and nutrient loads were related to stream discharge. In years of greater streamflow, higher concentrations of nutrients and sediment were observed. Likewise, lower concentrations were observed in years when the mean annual flow was less than the average annual flow. Some of the dissolved forms of nitrogen were found in higher concentrations on a seasonal basis regardless of flow.

The median annual load of total phosphorus (during 1994-2001) in Nippersink Creek above Wonder Lake was 12.41 tons, whereas dissolved phosphorus was delivered at a median rate of 3.38 tons per year. The annual load of total organic nitrogen was 67.11 tons. Median annual dissolved ammonia loading was 5.7 tons. The median annual load of dissolved nitrate was 308.4 tons.

It was not possible to reliably estimate the mean annual amounts of total and dissolved phosphorus trapped in Wonder Lake. The flow and concentrations were highly variable at Nippersink Creek below Wonder Lake during 1994-97. Between 6 and 28 percent of the total phosphorus load was trapped in the lake based on regression model analysis. A large portion of the load variability could not be explained by the regression.

Wonder Lake is characterized as eutrophic based on a trophic state index. Three criteria were used in evaluating the lake: Secchi disk depth, total phosphorus concentration, and chlorophyll *a* concentration. These criteria are indexed such that each measure is placed on similar scales for comparison. The lake was characterized nine times during 1999-2000 (total of 27 trophic state evaluations). Twenty-five of the 27 evaluations placed Wonder Lake in the eutrophic index category. Two measurements of chlorophyll *a* concentration classified the lake as mesotrophic; however, the lake was classified as eutrophic based on the Secchi disk depth and total phosphorus concentration criteria.

The observed trapping efficiency of Wonder Lake is nearly 75 percent. As the lake fills with more sediment over time, this trapping efficiency will decrease. However, a decrease in the trapping efficiency usually is slow and gradual. If the lake were restored to its original capacity, the sediment-trapping efficiency likely would increase above the current rate. The data used in this calculation were collected during a period (1994-97) when the annual streamflow was less than the average flow for the period of record (1994-2001). The years of 1999 through 2001 did not have sufficient data coverage to estimate a

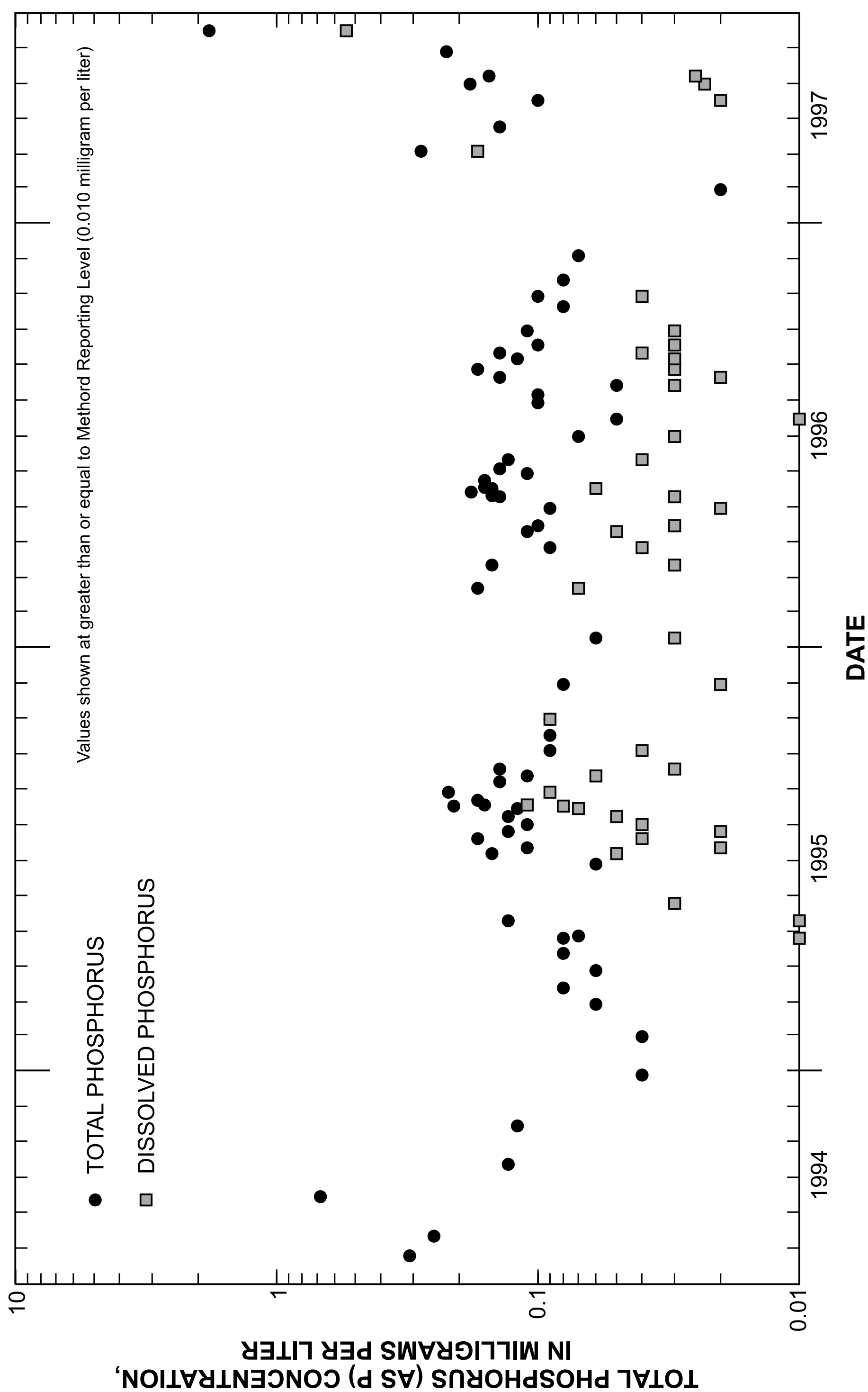

Figure 18. Total and dissolved phosphorus (as P) concentrations in Nippersink Creek below Wonder Lake, McHenry County, Ill., July 1994 – July 1997.

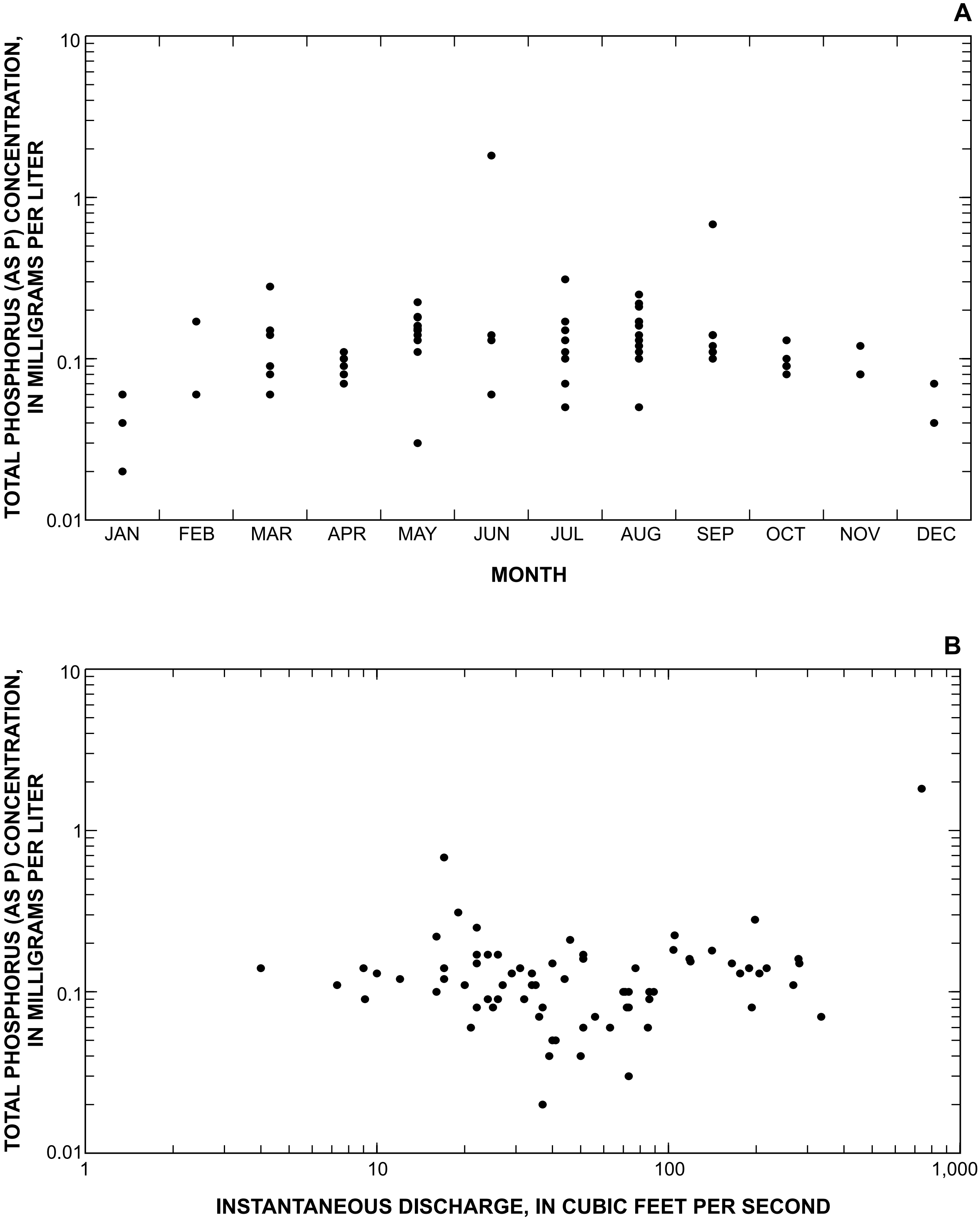

Figure 19. Total phosphorus (as P) concentrations in Nippersink Creek below Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

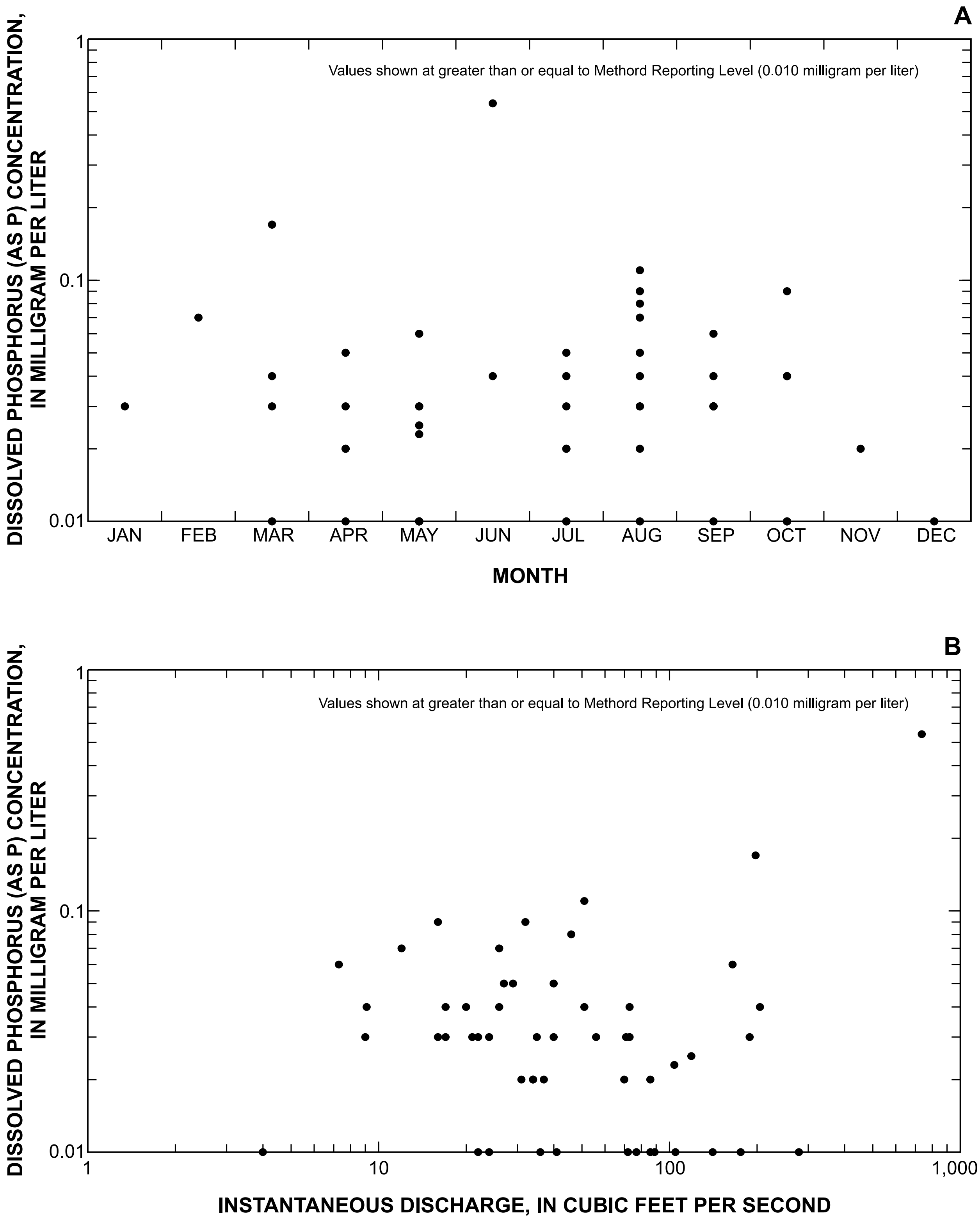

Figure 20. Dissolved phosphorus (as P) concentrations in Nippersink Creek below Wonder Lake, McHenry County, Ill., by A) month of sample and B) sampled flow.

Table 9. Regression coefficients, significance level, and goodness-of-fit parameters, by calibration period, for nutrients in Nippersink Creek below Wonder Lake, McHenry County, Ill.

[r^2, explained variability;%, percent; S, standard error; >, greater than]

Nutrient (Calibration Period)	Model Coefficient (p-value)					r^2 (%)	S
	β_0	β_1	β_2	β_3	β_4		
Total Phosphorus (1994-97)	2.593 (0.000)	1.108 (0.000)	0 (>0.05)	-0.183 (0.139)	-0.363 (0.002)	79.3	0.58
Dissolved Phosphorus (1994-97)	1.119 (0.000)	1.004 (0.000)	0 (>0.05)	0 (>0.05)	0 (>0.05)	49.3	1.04

Table 10. Estimated annual total phosphorus retention in Wonder Lake, McHenry County, Ill., by model-calibration period.

[%, percent; na, not applicable]

Total phosphorus model-calibration period and location	Load (tons), by Water Year (Oct. 1 – Sept. 30)			
	1996	1997	Mean	Retained (%)
1999-2001 Above Wonder Lake	12.41	12.42	12.41	28.0
1994-97 Above Wonder Lake	10.41	8.54	9.48	5.8
1994-97 Below Wonder Lake	9.35	8.51	8.93	na

trapping efficiency. Loads of sediment delivered to the lake will decrease the volume, water clarity, and navigable areas of the lake.

About 15,900 tons of suspended sediment was transported in Nippersink Creek above Wonder Lake during the 1994-97 observation period. It is estimated that a similar amount of sediment was delivered to Wonder Lake in WY 2000 alone as had been delivered between June 1994 and June 1997. During all observations from 1994 to 2001 (1,990 non-consecutive days), the estimated average daily sediment load was 25 tons. This daily loading indicates an average annual sediment load of 9,130 tons. If the 75-percent sediment-trapping rate applies in an average year, then about 6,800 tons of sediment is trapped within Wonder Lake in a typical year. If the lake could be restored to its original capacity, the sediment-trapping efficiency may be increased.

The water quality of lakes is affected greatly by their watershed. The amounts of water, sediment, and nutrients delivered to Wonder Lake through Nippersink Creek are affected by many natural processes and human factors, which are variable throughout time. The land uses in this study area have been changing over the last 30 years with increasing population and various agricultural practices, and these changes may affect future water-quality conditions in the lake. Estimating a typical condition, as well as simulating future conditions, may help watershed planners in addressing those variable conditions.

SELECTED REFERENCES

Allan, J.D., 1995, Stream Ecology: Structure and function of running waters: Kluwer Academic Publishers, Dordrecht, The Netherlands, 388 p.

Arnold, T.L., Sullivan, D.J., Harris, M.A., Fitzpatrick, F.A., Scudder, B.C., Ruhl, P.M., Hanchar, D.W., and Stewart, J.S., 1999, Environmental setting of the upper Illinois River Basin and implications for water quality: U.S. Geological Survey Water-Resources Investigations Report 98-4268, 67 p.

Brune, G.M., 1953, Trap Efficiency of Reservoirs, in Melching, C.S., and Avery, C.C., 1990, An introduction to watershed management for hydrologists: [Belgium] Vrije Universiteit Brussel – Hydrologie, 18, 128 p.

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

Cochran and Wilken, Inc., 1996, Wonder Lake Feasibility Study and Restoration Plan: prepared for the Master Property Owners Association of the Wonder Lake Area, 31 p. plus appendixes.

Cohn, T.A., 1988, Adjusted maximum likelihood estimation of the moments of lognormal populations from Type I censored samples: U.S. Geological Survey Open-File Report 88-350, 34 p.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937-942.

Cohn, T.A., Caulder, D.L., Gilroy, E.J., Zynjuk, L.D., and Summers, R.M., 1992a, The validity of a simple statistical model for estimating fluvial constituent loads; an empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 28, no. 9, p. 2353-2363.

Cohn, T.A., Gilroy, E.J., and Baier, W.G., 1992b, Estimating fluvial transport of trace constituents using a regression model with data subject to censoring: Proceedings of the Joint Statistical Meeting, Boston, Mass., August 9-13, 1992, p. 142-151.

Cole, G.A., 1994, Textbook of Limnology (4th ed.): Prospect Heights, Ill., Waveland Press, Inc., 412 p.

Coupe, R.H., 1998, Concentrations and loads of nitrogen and phosphorus in the Yazoo River, northwestern Mississippi, 1996-97: U.S. Geological Survey Water-Resources Investigations Report 98-4219, 17 p.

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

Field, S.J., Elder, J.F., Garn, H.S., Goddard, G.L., Kammerer, Jr., P.A., Olson, D.L., Robertson, D.M., and Rose, W.J., 1995, Water-Quality and lake-stage data for Wisconsin lakes, water year 1994: U.S. Geological Survey Open-File Report 95-190, 157 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fishman, M.J., and Friedman, L.C., eds, 1989, Methods for determination of inorganic substances in water and fluvial sediments (3rd ed.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Graf, J.B., 1983, Measurement of bedload discharge in nine Illinois streams with the Helley-Smith sampler: U.S. Geological Survey Water-Resources Investigations Report 83-4136, 70 p.

Gilroy, E.J., Hirsch, R.M., and Cohn, T.A., 1990, Mean square error of regression-based constituent transport estimates: Water Resources Research, v. 26, no. 9, p. 2069-2077.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Guy, H.P., 1970, Fluvial sediment concepts: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C1, 55 p.

Hack, J.T., 1960, Interpretation of erosional topography in humid-temperate regions, in Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in Geomorphology: W.H. Freeman & Company, San Francisco, 522 p.

Harris, M.L., Draper, P.J., Schrader, D.L., 2002, Water resources data, Illinois, water year 2001: U.S. Geological Survey Water-Data Report IL-01, CD-ROM.

Healy, R.W., 1979, River mileages and drainage areas for Illinois streams, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Resources Investigations Report 79-111, 302 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Elsevier Publishing, New York, 522 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 264 p.

Johnson, G., 1997, Instruction manual for U.S. Geological Survey sediment observers: U.S. Geological Survey Open-File Report 96-431, 36 p.

LaTour, J.K., Gioja, J.M., Maurer, J.C., Wicker, T.L., 2001, Water resources data, Illinois, water year 2000: U.S. Geological Survey Water-Data Report IL-00, CD-ROM.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in Geomorphology: W.H. Freeman & Company, San Francisco, 522 p.

Lillie, R.A., Graham, S., and Rasmussen, P., 1993, Trophic-State Index equations and regional predictive equations for Wisconsin Lakes: Wisconsin Department of Natural Resources Research Management Findings No. 35, 4 p.

Melching, C.S., and Avery, C.C., 1990, An introduction to watershed management for hydrologists: [Belgium] Vrije Universiteit Brussel – Hydrologie, 18, 128 p.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 66 p.

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

Robertson, D.M., J.F. Elder, H.S. Garn, G.L. Goddard, S.B. Marsh, D.L. Olson, and W.J. Rose, 1999, Water-Quality and lake-stage data for Wisconsin lakes, water year 1998: U.S. Geological Survey Open-File Report 99-98, 143 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Sholar, C.J., and Shreve, E.A., 1998, Quality-assurance plan for the analysis of fluvial sediment by the Northeastern Region, Kentucky District Sediment Laboratory: U.S. Geological Survey Open-File Report 98-384, 20 p.

U.S. Bureau of the Census, 1991, Census of population and housing, 1990 – Public law 94-171 data: Washington, D.C., U.S. Bureau of the Census.

U.S. Bureau of the Census: accessed April 4, 2003, at URL http://quickfacts.census.gov/qfd/states/17/17111.html

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and Van Driel N., 2001, Completion of the 1990s National land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering and Remote Sensing 67, p. 650-662.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p.

Westlake, D.F., 1975a, Macrophytes in Whitton, B.A., River Ecology: University of California Press, Berkeley, Calif., p. 81-105.

Wisconsin State Laboratory of Hygiene, 1993, Manual of analytical methods, inorganic chemistry: Wisconsin State Laboratory of Hygiene, revised November 1993, in Robertson, D.M., J.F. Elder, H.S. Garn, G.L. Goddard, S.B. Marsh, D.L. Olson, and W.J. Rose, 1999, Water-Quality and lake-stage data for Wisconsin lakes, water year 1998: U.S. Geological Survey Open-File Report 99-98, 143 p.

District Chief
U.S. Geological Survey
221 N. Broadway Ave.
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