Nitrate and Pesticides in Surficial Aquifers and Trophic State and Phosphorus Sources for Selected Lakes, Eastern Otter Tail County, West-Central Minnesota, 1993–96

By James F. Ruhl

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Conversion Factors and Vertical Datum

Multiply	By	To obtain
inch (in.)	25.4	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acres (ac)	4,047	square meter
pound (lb)	453.6	gram
acre-foot (ac-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	.02832	cubic meter per second
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second

Chemical concentration: Given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit that represents 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.

Median concentration: The central concentration value, or 50th percentile, of a distribution of concentrations ranked in order of magnitude. For an odd number of concentration values, the median is that value with an equal number of higher and lower values. For an even number of concentration values, the median is the mean of the two central values. Median concentrations have been rounded to the nearest even number for expression to the correct number of significant figures.

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

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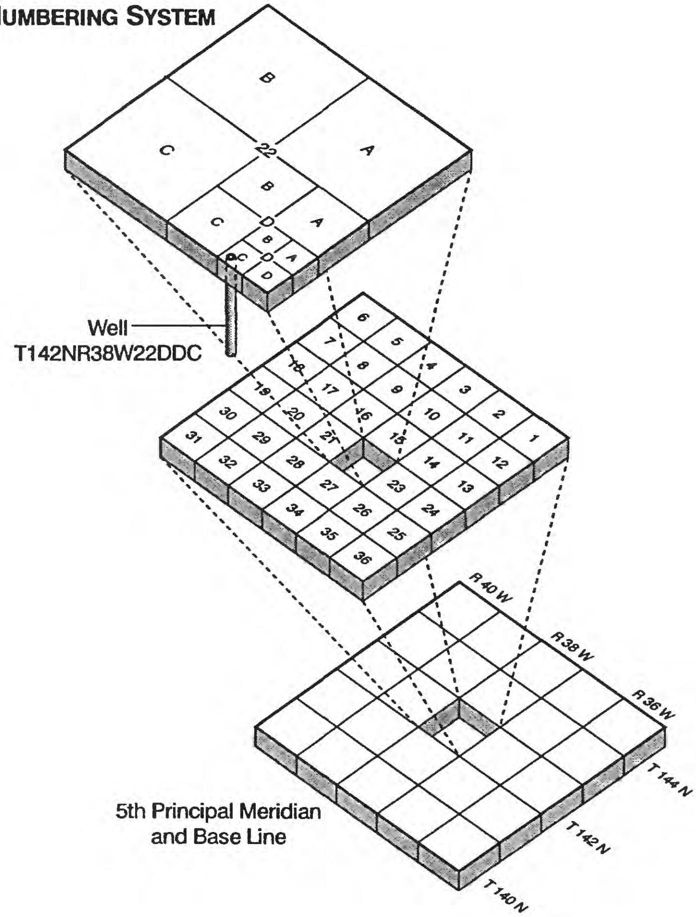
SITE LOCATION AND NUMBERING SYSTEM

The numbering system used to define the location of data collection sites is based on the Federal system of land subdivision (township, range, and section). The first number of the site location indicates the township (the N after the township number is an abbreviation for north); the second, the range (the W after the range number is an abbreviation for west); and the third the section. Uppercase letters after the section number indicate location within the section; the first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. The number of uppercase letters indicates accuracy of the location number. For instance, if a point can be located within a 10-acre tract, three uppercase letters are shown in the location number. The number T142NR38W22DDC indicates the site of a well in the SW 1/4 of the SE ¼ of the SE ¼, section 22, township 142 north, range 38 west, 5th principal meridian and base line.



Nitrate and Pesticides in Surficial Aquifers and Trophic State and Phosphorus Sources for Selected Lakes, Eastern Otter Tail County, West-Central Minnesota, 1993–96

By James F. Ruhl

Abstract

Nitrate concentrations (as nitrogen) were analyzed in water from 73 wells completed in surficial aquifers. Water from about one-third of the wells had concentrations greater than 10 mg/L (milligrams per liter), the regulatory limit for drinking water established by the U.S. Environmental Protection Agency. Nitrate concentrations: (1) were greater in water from wells in agricultural settings than in nonagricultural settings; (2) were not greater in water from shallow wells (25 feet deep or less) in settings with rapid soil permeability than with moderate soil permeability, probably because the effects of permeability were offset by the effects of land use and well depth; and (3) were greater in water from shallow wells (25 feet deep or less) than from deep wells (greater than 25 feet deep).

Triazine herbicides were detected in water from 23 of the 73 sampled wells by immunoassay tests. Most of these wells are in agricultural settings. Ten pesticides, which included seven triazine herbicide compounds, were detected in water from 19 of 25 wells analyzed by gas chromatography/mass spectrometry. Atrazine and deethylatrazine, a degradation product of atrazine, were detected in water from 18 and 16 wells, respectively. None of the detected pesticides had concentrations that exceeded their respective regulatory limits for drinking water established by the U.S. Environmental Protection Agency.

Four lakes in the Otter Tail River Basin, which in downstream order are Little Pine, Big Pine, Rush, and Otter Tail Lakes, ranged in trophic state from upper oligotrophic to lower eutrophic. The Secchi disk transparencies were 4.0 to 7.4 feet, chlorophyll *a* concentrations (epilimnetic) were 4.4 to 28 micrograms per liter, and total phosphorus concentrations (epilimnetic) were less than 0.010 to 0.022 mg/L (except one concentration of 0.060 mg/L). The trophic state of these lakes may have become less eutrophic from upstream to downstream lakes.

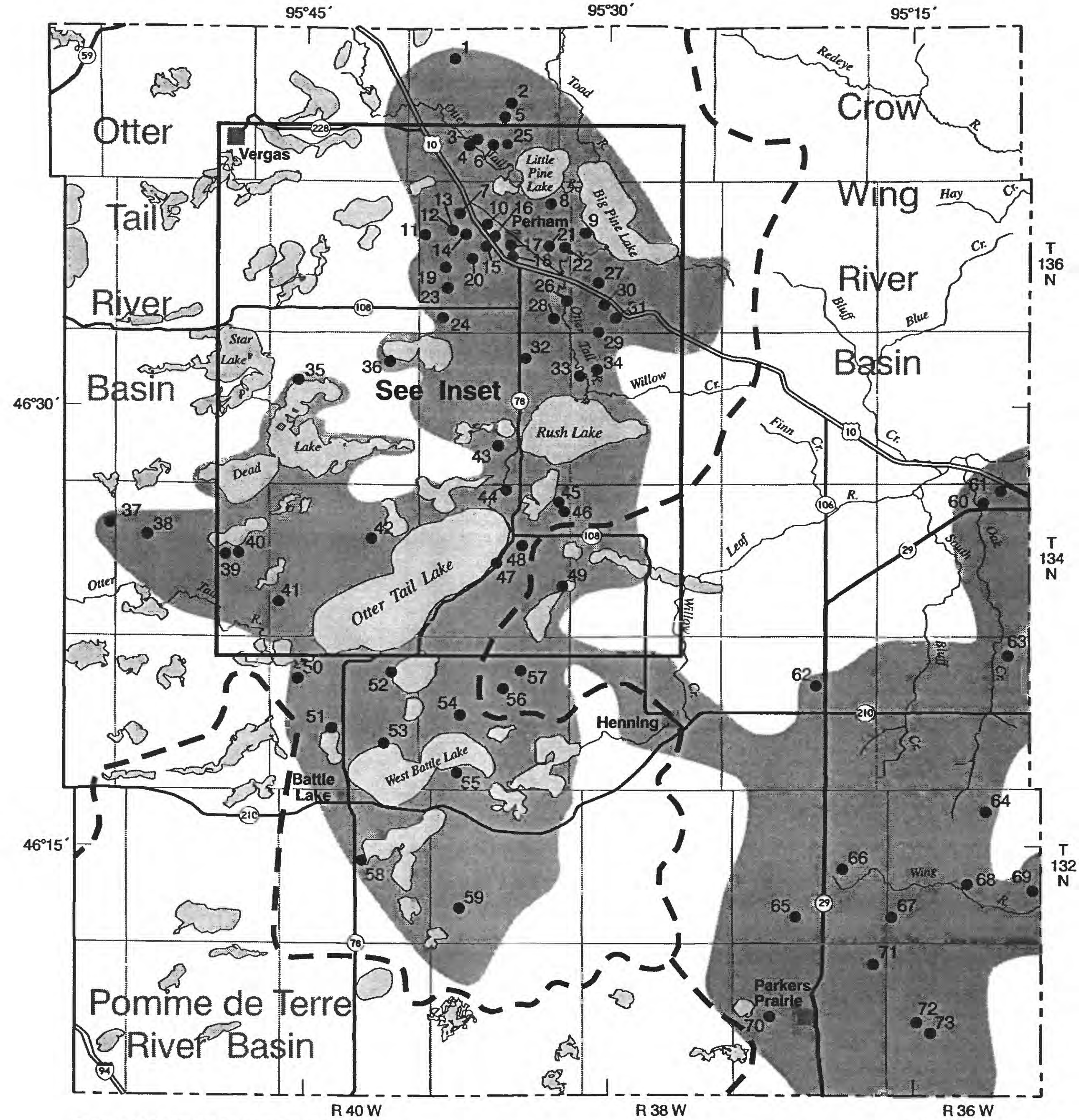
Major external sources of phosphorus to Big Pine Lake were the Otter Tail and Toad Rivers. The phosphorus load from these two streams during March 16, 1995, to March 15, 1996 was 10,400 pounds. The phosphorus load from the Toad River (5,730 pounds) was greater than from the Otter Tail River (4,670 pounds) even though streamflow from the Toad River was about 70 percent less than the Otter Tail River. Phosphorus removal from Big Pine Lake through the Otter Tail River outlet during the 1-year period was 8,460 pounds. The total annual accumulation of phosphorus, which includes an estimated 700 pounds from ground-water discharge, was 2,640 pounds. The accumulated phosphorus probably was utilized by phytoplankton or was absorbed by nonliving particulate matter that eventually settled into bottom sediments.

Bottom sediments were an internal source of phosphorus to Little Pine and Big Pine Lakes. Increased total phosphorus concentrations (hypolimnetic) of 0.037 to 0.120 mg/L at depth during August 9–10, 1995, indicated phosphorus release from bottom sediments. The increased phosphorus probably was associated with anoxic conditions in the hypolimnion during summer stratification.

Phosphorus at depth in Little Pine and Big Pine Lakes was mostly orthophosphate. During the fall turnover of the lakes, this orthophosphate may have circulated to near the lake surface and became an available nutrient for phytoplankton during the following growing season. The internal phosphorus load to Little Pine Lake may have been important because about three-fourths of the lake probably became stratified and anoxic in the hypolimnion. The internal phosphorus load to Big Pine Lake may not have been important because only a small portion of the lake became stratified and anoxic at depth.

Introduction

The U.S. Geological Survey (USGS) conducted a 4-year (1993–96) water-quality study of surficial sand and gravel aquifers (hereinafter, surficial aquifers) and selected lakes in the eastern two-thirds of Otter Tail County in west-central Minnesota (fig. 1). The East Otter Tail Soil and Water Conservation District and Minnesota Department of Natural Resources cooperated in the study. Concerns of local public officials and citizens about nitrate and pesticide



Base from U.S. Geological Survey digital data 1:100,000, 1972, Albers Equal-Area Conic Projection, standard parallels 29°30′ and 45°30′, Central meridian 95°30′

SCALE 1:400,000

0 5 10 15 MILES

0 5 10 15 KILOMETERS

Geology modified from Myette (1984a) and Cowdery (1997).

LOCATION MAP

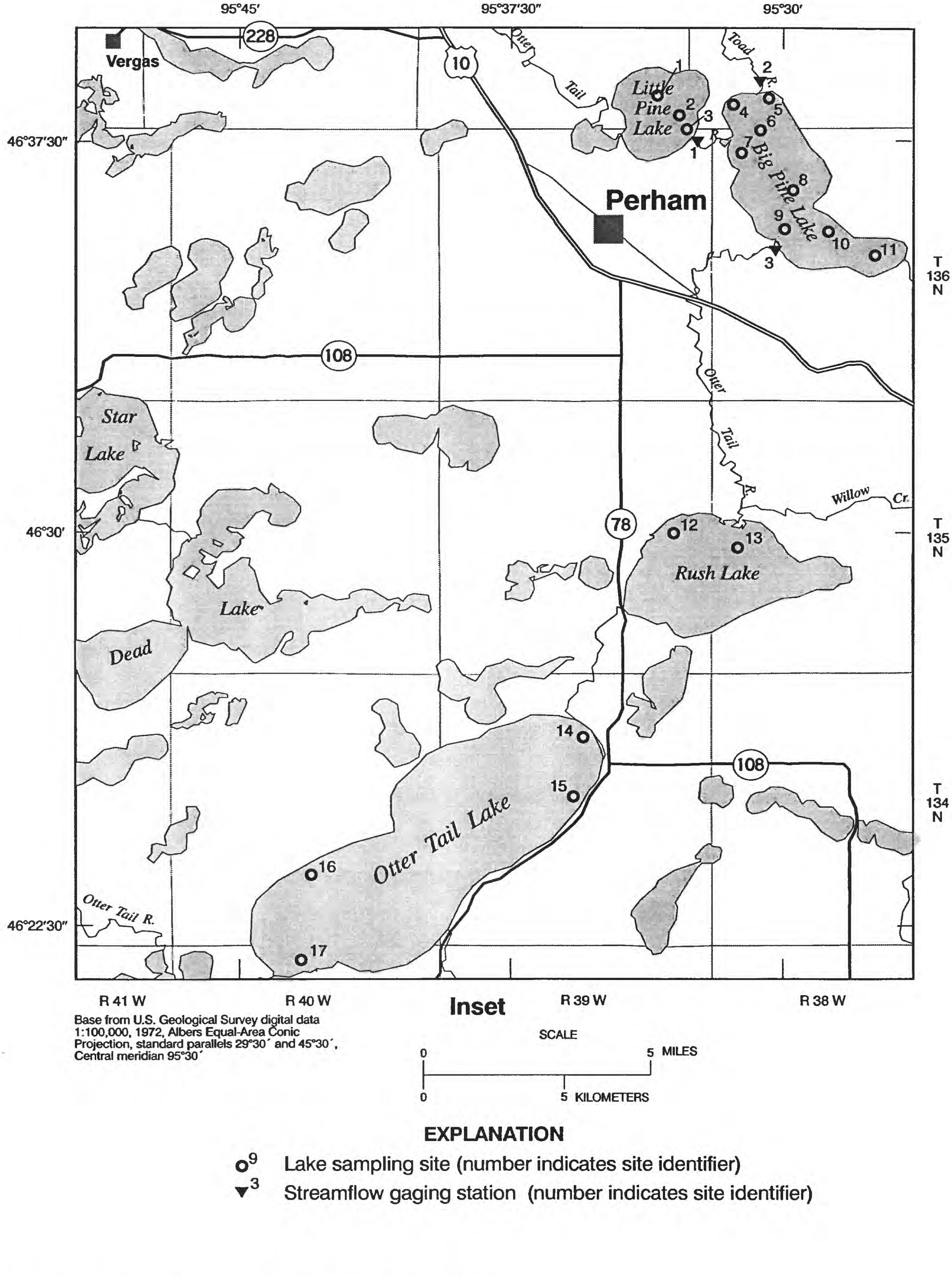
EXPLANATION

General extent of surficial aquifers

River basin boundary

●21 Well (number indicates site identifier)

Figure 1. Location of study area, river basins, and



data collection sites, eastern Otter Tail County, Minnesota.

contamination of the aquifers and about phosphorus enrichment of the lakes prompted the study.

Sources of nitrate, pesticides, and phosphorus in the study area may be from identifiable, widespread areas, which include: (1) fertilizers and pesticides applied to croplands and lawns; (2) animal manure stored in feedlots and applied to fields; and (3) leachates from domestic septic systems. This study evaluated the susceptibility of the surficial aquifers and selected lakes to increased nitrate, pesticides, and phosphorus from land use.

Water-Quality Concerns

In many areas, nitrogen and phosphorus nutrients and pesticides threaten the water quality of surficial aquifers and lakes. Nutrients are natural chemical substances required for plant and animal growth, and pesticides are synthetic organic compounds used to control pests. Increased amounts of nitrate and pesticides in surficial aquifers may result in ground water that is unsuitable for drinking. Increased amounts of phosphorus in lakes may result in eutrophication (nutrient enrichment of an aquatic ecosystem), a condition that typically degrades aesthetic and recreational values of the affected waters.

The movement of nutrients and pesticides from land-surface sources into ground and surface water depends on soil properties, climate, land-management practices, and the mobility and persistence of the nutrients and pesticides. Ground water is potentially vulnerable to contamination by nitrate and pesticides where the depth to the water table is shallow and the unsaturated zone above the water table is permeable. Surface water is vulnerable to phosphorus enrichment where runoff transports large nutrient loads into receiving lakes and streams.

Nitrogen and phosphorus nutrients

Nitrogen (N) occurs in natural waters over a range of oxidation states (Hem, 1985). Most nitrogen in surface waters is organic; most nitrogen in ground water is inorganic. Inorganic nitrogen occurs in natural waters as: (1) nitrite (NO_2^-) and nitrate (NO_3^-), which are the oxidized anionic forms; and (2) ammonium (NH_4^+), which is the reduced cationic form that can be volatilized into gaseous ammonia (NH_3). The nitrogen used by plants is primarily nitrate, which is both stable and mobile. Natural background levels of nitrate-nitrogen (hereinafter, nitrate) in ground water generally are less than 3 mg/L (Madison and Brunett, 1984). The levels of nitrite and ammonium in natural waters generally are small except in oxygen-depleted waters near sources of nitrogen contamination.

Nitrate concentrations in drinking water above 10 mg/L are considered unsafe for human consumption (U.S. Environmental Protection Agency, 1996). Infants that drink water with nitrate in excess of this concentration are at risk to incur methemoglobinemia, an anemic condition commonly known as "blue baby syndrome." Although the number of recently documented cases of methemoglobinemia is small, evidence of nitrate contamination of ground water has been reported for many areas in the Upper Midwest. A recent study of near-surface aquifers in agricultural areas of the midcontinental United States found that 6 percent of nearly 600 ground-water samples collected from about 300 wells had more than 10 mg/L nitrate (Kolpin and others, 1994).

Phosphorus is present in natural waters in organic and inorganic forms (Hem, 1985). Most phosphorus in surface waters is organic. Dissolved organic phosphorus occurs as soluble organic phosphates; suspended organic phosphorus occurs as cellular components of living and nonliving phytoplankton (open-water algae). Most phosphorus in ground water is inorganic. Dissolved inorganic phosphorus occurs as species of phosphoric acid (H_3PO_4), which are fully oxidized to orthophosphate (PO_4^{-3})—the most stable and biologically reactive species—and progressively reduced species (HPO_4^{-2}, $H_2PO_4^{-1}$, and H_3PO_4). All species of phosphate generally have low solubility and mobility; however, eroded soil may transport large amounts of phosphate to surface waters.

Larger-than-background concentrations of nutrients in surface waters may result in eutrophication. Under these conditions, nutrients are present in amounts greater than that needed to sustain normal populations of plants and animals. In many aquatic ecosystems, the availability of phosphorus nutrients limits biological productivity (Hem, 1985). Small increases in the phosphorus load to surface waters in these ecosystems, therefore, may result in significantly increased growth of phytoplankton and other aquatic plants.

Water-resource problems linked to eutrophication include: (1) restricted streamflows; (2) reduced clarity; (3) increased treatment costs; and (4) unpleasant tastes and odors. More importantly, decay of excess plant residues in lakes and streams may decrease dissolved oxygen to low levels and increase ammonium to toxic levels—conditions that may decrease fish populations.

Pesticides

Pesticide is a generic term for compounds that include herbicides. Little is known about the toxicity of most pesticides, particularly from long-term exposure at low levels. Safe levels of pesticides in drinking water have been established for only a small number of these chemicals (U.S. Environmental Protection Agency, 1996). Increased usage of pesticides, combined with increased capability to measure small amounts of these chemicals in water, has resulted in increased frequency of detection of these chemicals in natural waters. These detections, however, mostly have been of trace amounts at concentrations assumed to be safe for drinking (Kolpin and others, 1994).

Purpose and Scope

The purpose of this report is to describe the susceptibility of surficial aquifers to contamination by nitrate and pesticides and of selected lakes to enrichment of phosphorus in the eastern two-thirds of Otter Tail County of west-central Minnesota (fig. 1). The analysis of the aquifers addressed: (1) the areal distribution, temporal variation, and sources of nitrate; (2) factors that affect nitrate concentration; and (3) the areal distribution of pesticides. The analysis of the lakes addressed: (1) the trophic state of Little Pine, Big Pine, Rush, and Otter Tail Lakes; and (2) sources of phosphorus in Little Pine and Big Pine Lakes.

Data were collected from 1993 to 1996. These data included: (1) concentrations of nitrogen and phosphorus species, chloride, and triazine herbicides in water from 73 wells completed in the surficial aquifers; (2) concentrations of about 80 pesticides in water from 25 of these wells; (3) concentrations of nitrogen and phosphorus species, chlorophyll *a* and *b*, and triazine herbicides in water from 17 sites on Little Pine, Big Pine, Rush, and Otter Tail Lakes; and (4) concentrations of phosphorus species in stream water and discharge and stage at streamflow gaging stations on the Toad and Otter Tail Rivers near two inlets and one outlet for Big Pine Lake.

Environmental Setting

The study area extends over about a 1,500-mi^2 area of west-central Minnesota that typifies glaciated terrain of the Upper Midwest. The topography varies from hilly to gently rolling and flat. Soils vary from sandy, loamy, and well drained in most areas to silty and clayey and not well drained in a few areas. The summers are short and generally mild, the winters are long and severe. Normal precipitation ranges from about 25 to 27 in. per year based on a period of record from 1941 to 1970 (Baker and Kuehnast, 1978). About three-fourths of the annual precipitation is rain that falls from April through October.

Continental glaciation deposited sediments as much as 400 feet thick over crystalline bedrock in the study area. These sediments are comprised primarily of outwash and till. Glacial meltwater streams deposited the outwash, which consists of sorted and stratified sand and gravel, sometimes with small amounts of clay and silt. The surficial outwash, which varies in thickness from several to as much as 100 feet (Reeder, 1972), typically forms flat to gently rolling plains. Stationary glaciers that melted in place deposited the till, which consists of unsorted and unstratified clay, silt, sand, gravel, pebbles, and boulders. The surficial till typically forms hilly moraines. Post-glacial organic materials (peat) accumulated in poorly drained, scattered depressions to form wetlands.

The surficial outwash comprises the surficial aquifers, which extend over a large part of the study area (fig. 1). These aquifers are unconfined. The depth to the water table is from 0 feet at the shoreline of lakes, ponds, and streams to as much as 70 feet in upland areas, but generally is from 5 to 30 feet (Reeder, 1972). Yields from wells completed in the surficial aquifers may be as much as 1,200 gal/min (Reeder, 1972).

Surface-water drainage from the study area is primarily from the Otter Tail River Basin and, to a smaller extent, from the Crow Wing and Pomme de Terre River Basins (fig. 1). Most lakes in the study area are in outwash areas underlain by sand and gravel. These lakes generally have effective hydraulic connection to the ground-water system. The surface of these lakes reflects the surrounding water table, which generally is flat because of the high permeability and level terrain of the outwash.

Land use in the study area predominantly consists of cultivated croplands, but also includes livestock feedlots, lakes, wetlands, forests, residential development, and small municipalities. The principal crops are corn, beans, hay and, to a lesser extent, potatoes. Yields of these crops have increased in recent years because of changes in agricultural management practices. Pesticides have protected crops from diseases, predation, and displacement by unwanted plants. The moisture and nutritional needs of the crops have been met with increased efficiency because of irrigation and fertilization.

Previous Investigations

General appraisals of water resources of river basins in the region of the study area have been published as a series of atlases by Cotter and Bidwell (1966), Winter and others (1969), and Lindholm and others (1972). The hydrogeology and general quality of ground water in the region of the study area have been investigated by Lindholm (1970), Reeder (1972), Helgesen (1977), Myette (1982), Myette (1984b), and Stark and others (1994). Studies by Cowdery (1997), Myette (1984a), Ruhl (1995), and Stark and others (1991) addressed land-use effects on water quality. The quality of Big Pine Lake was assessed by the Minnesota Pollution Control Agency (1992).

Methods

Procedures used to collect, treat, and store water samples for this and other studies are described by Fishman and Friedman (1989) and Koterba and others (1995). Analyses were done at the USGS National Water Quality Laboratory in Arvada, Colorado. Immunoassay analyses for triazine herbicides were done at the USGS laboratory in Mounds View, Minnesota. Field measurements of temperature, specific conductance, pH (acidity), and dissolved oxygen concentration were made with a portable Hydrolab meter calibrated at the start of each sampling day.

Ground-water samples were collected from: (1) 45 privately owned wells used for household supply, livestock, or irrigation; and (2) 28 observation wells. All of these wells are completed in the surficial aquifers and are distributed throughout the study area (fig. 1). The observation wells consist of: (1) 21 wells installed by the USGS—16 under the Red River of the North National Water-Quality Assessment (NAWQA) Program and 5 under the present study; (2) 5 wells installed under contract with the Minnesota Department of Natural Resources as part of a long-term state-wide monitoring program; and (3) 2 privately owned wells installed under contract with the Land O' Lakes Company in Perham, Minnesota.

Detailed descriptions of the methods of construction for the 21 observation wells installed by the USGS are described by Menheer and Brigham (1997). These wells were drilled with a hollow-stem rotary hydraulic auger drill rig. The well casings were flush-threaded, 2-inch inside-diameter, polyvinyl chloride (PVC). The screens were 5-ft-long, flush-threaded, machine-slotted (0.010-slot) PVC. The tops of the screens were set at about 1–2 ft below the water table. Washed, medium to coarse sand was used to backfill the hole around the well screens. Bentonite grout was pumped into the annular space above the sand packs to within 3–4 ft of land surface. A 7-ft long protective steel casing was cemented in place around the well head to divert surface drainage.

Most wells (59) were sampled twice, two wells were sampled once, and the other wells were sampled from 3 to 14 times. Prior to collection of samples, water was pumped for about 20 minutes and monitored to determine temperature, pH, specific conductance, and dissolved oxygen concentration. When these properties stabilized, the quality of water from the well was assumed to be representative of the quality of ground water in the aquifer, and a sample was collected.

Samples from each well were analyzed to determine concentrations of: (1) ammonium-nitrogen (reported as ammonia-nitrogen), ammonium- plus organic-nitrogen, nitrite-nitrogen, and nitrite- plus nitrate-nitrogen; (2) orthophosphate; and (3) chloride. These samples also were analyzed to detect the presence of triazine herbicides by the immunoassay method (Millipore, Marlborough, Massachusetts) (Thurman and others, 1990). This method detects an aggregate of triazine herbicides, which include atrazine, cyanazine, propazine, simazine, deethylatrazine, deisopropylatrazine, metribuzin, prometon, prometryn, and ametryn. The combined concentration of these compounds is reported as μg/L of atrazine.

Samples from 25 wells were analyzed by gas chromatography/mass spectrometry (GC/MS), mostly under the NAWQA Program, to determine concentrations of about 80 pesticides, which included triazines, acidimides, acetanilides, organophosphates, organochlorines, and carbamates. These wells consist of 17 observation wells installed by the USGS, 2 observation wells installed by the Minnesota Department of Natural Resources, and 6 privately owned wells. The sampling techniques used to collect, treat, and store the samples are described by Menheer and Brigham (1997).

The method detection limits (minimum concentrations that can be reliably cited) for the nitrogen and phosphorus species generally were: (1) 0.020 mg/L for ammonium-nitrogen; (2) 0.010 mg/L for nitrite-nitrogen (hereinafter, nitrite); (3) 0.050 mg/L for nitrite plus nitrate; (4) 0.010 mg/L for orthophosphate; and (5) 0.010 mg/L for total phosphorus. The method detection limits for pesticides by GC/MS analyses were from 0.001 to 0.050 μg/L and by immunoassay analyses was 0.10 μg/L.

The nitrite concentration was negligible for these data; thus, the nitrite plus nitrate concentration is considered to be equivalent to the nitrate concentration. Unless indicated otherwise, descriptive statistics for water-quality properties and constituents were determined from the most recent analyses for the sampled wells. Concentrations of constituents less than their method detection limit were assumed to be equal to their limit for purposes of statistical data analysis.

Lake-water samples were collected from three sites on Little Pine Lake, eight sites on Big Pine Lake, two sites on Rush Lake, and four sites on Otter Tail Lake (fig. 1). Depth-integrated samples were collected from the lake surface to a depth of about 3 feet at each site. Point samples were collected at variable depths with a poly-carbonate Kemmerer sampler at two sites each on Little and Big Pine Lakes. Secchi disk transparency and vertical profiles of temperature, specific conductance, pH, and dissolved-oxygen concentration were measured at each site. Samples were chemically analyzed to determine concentrations of nitrogen and phosphorus species from all the sites and of chlorophyll *a* and *b* from all but one of the sites. Samples from one site each on Little Pine and Big Pine Lakes were analyzed for triazine herbicides by GC/MS.

Blank-water and replicate samples were analyzed for nitrogen and phosphorus species to verify quality of data in the field and in the analytical laboratory. The blank and replicate samples were subjected to the same processing, handling, and equipment as sample water. The quality-assurance analyses indicated that samples were not cross-contaminated by equipment between visits to sample sites and that analytical results for water samples reported by the National Water Quality Laboratory were reproducible to within 5 percent.

Streamflow into and out of Big Pine Lake was estimated from stage and discharge data collected at temporary streamflow gaging stations on the Otter Tail and Toad Rivers (fig. 1). The stream-discharge measurements were made at intervals of about 2 to 6 weeks. Stage readings were usually made from three to five times per week from the middle of March until freeze-up in early November. The stage data were converted to daily mean stream discharge based on streamflow measurements and their relation to stage. After freeze-up, stage readings were discontinued, and the daily mean stream discharge was assumed to gradually decrease to typical winter low-flow conditions.

Water samples from streamflow gaging stations 1 and 2 were collected by the equal-width increment method (Ward and Harr, 1990). This method ensured that the samples were representative of the stream discharge. Water samples from streamflow gaging station 3 were collected by depth integration near the stream bank. These samples were considered to be representative of the stream discharge because the suspended sediment at this site was small.

Acknowledgments

The author is grateful to Jerry Neseth of the Perham field office of the U.S. Department of Agriculture National Resources Conservation Service (NRCS), who was very helpful in the initial planning of the study. Jeff Norby of the East Otter Tail Soil and Water Conservation District and Mike Lieser of the Fergus Falls area office of the NRCS provided assistance in the compilation of land-use and soil-permeability data. Dale Steevens of the R.D. Offutt Co., Mike Hermanson of the Land O' Lakes Company, and many landowners granted permission to sample their wells. Leslie Gunderson of Perham assisted in the collection of lake-water samples by providing and operating his privately owned boat for USGS field personnel. Shannon Smith, formerly with the USGS and now with the East-Central Minnesota Soil and Water Conservation District, was a project team member during the first 2 years of the study.

The Little Pine and Big Pine Lake Associations supported a USGS study of phosphorus loads to Little Pine and Big Pine Lakes from the Otter Tail and Toad Rivers. Results from this study are presented in this report. Carl Annalora of the Big Pine Lake Association was particularly helpful to the success of this study, which was conducted by Greg Payne of the USGS.

Nitrate and Pesticides in Surficial Aquifers

The surficial aquifers are vulnerable to contamination by nitrate and pesticides because of the generally shallow depth to the water table and high permeability of unsaturated materials that overlie the water table. These conditions allow nitrate and pesticides to rapidly move downward from land-surface sources into the ground water.

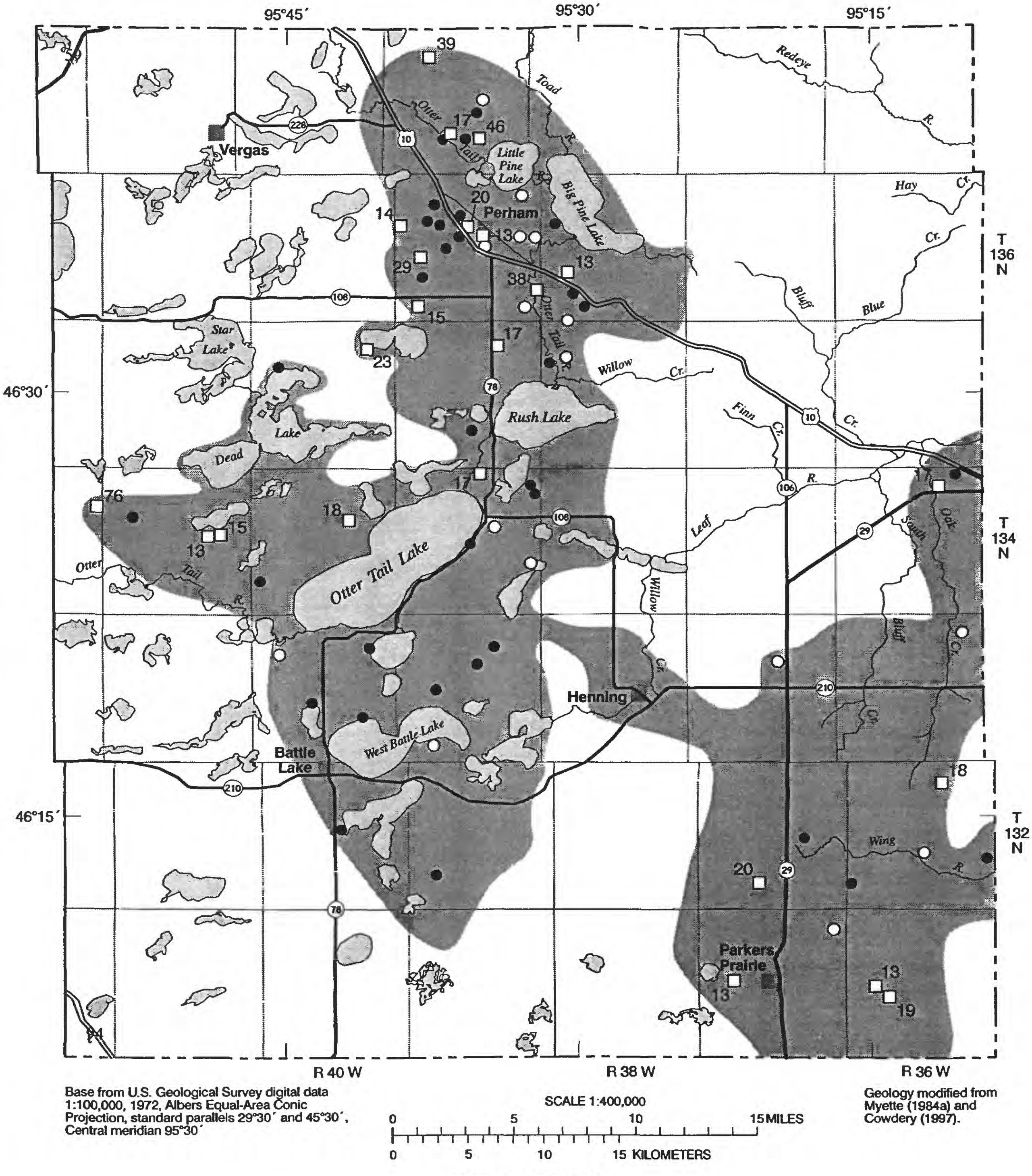
Ground water in the surficial aquifers has low dissolved-solids content, as indicated by the median dissolved solids concentration of 327 mg/L determined for water from the NAWQA Program wells. Calcium and bicarbonate, and to a lesser extent magnesium, are the major chemical constituents (Cowdery, 1997). Water from the sampled wells generally was oxygenated; the range and median of the dissolved-oxygen concentration were 0.10 to 13 mg/L and 2.9 mg/L (table 5, Supplemental Information Section).

Nitrate

The concentrations of nitrate in water from the 73 sampled wells ranged from less than the method detection limit of 0.050 mg/L to 76.0 mg/L (table 5, Supplemental Information Section). Ranges of nitrate concentrations are plotted by well location (fig. 2). The concentrations in samples from 39 wells, a little more than one-half of the total, were greater than 3 mg/L, the presumed natural background level. The concentrations in samples from 23 wells, about one-third of the total, were greater than 10 mg/L, the regulatory limit for drinking water (U.S. Environmental Protection Agency, 1996).

Locations where concentrations exceeded 3 mg/L are distributed throughout the surficial aquifers, however, the density of these locations appears to be relatively high north of Rush Lake. This high density may be attributable to the large number of observation wells in that part of the study area. Of the 20 wells north of Rush Lake that produced water with nitrate greater than 3 mg/L, 13 were observation wells. These observation wells (mostly NAWQA Program wells) were designed and constructed to study the quality of shallow ground near the water table. The nitrate concentrations in water from these wells are likely to be directly affected by overlying land use. South of Rush Lake most of the sampled wells are privately owned. The nitrate concentrations in water from these wells, because they typically are screened at greater depths below the water table , are less directly affected by overlying land use than is the case for the observation wells.

Potential sources of nitrate in water with nitrate concentrations greater than 3 mg/L are associated with



EXPLANATION

General extent of surficial aquifers

Nitrate concentration

● ≤ 3 mg/L

○ > 3 mg/L and < 10 mg/L

□ 13 ≥ 10 mg/L (number indicates concentration in mg/L)

Figure 2. Nitrate concentrations in water from wells completed in surficial aquifers, eastern Otter Tail County, Minnesota, 1993-95.

nitrogen fertilizer, animal manure, and septic system leachates. The study by Cowdery (1997), which analyzed water-quality data from NAWQA Program wells, identified tilled area, chemical application, irrigation, and cropland contiguity, as land-use factors linked to increased nitrate concentrations in shallow ground water of the surficial aquifers.

The short-term variation of nitrate, defined by the change in median concentration in water from 62 wells between April–August 1994 and April–September 1995, was negligible. The median concentration for each of the two sampling periods was about 6 mg/L (fig. 3). The short-term variation in water from a small number of individual wells (2, 3, 5, 22, 36, 46, 62, and 71; fig 1), however, ranged from an increase of about 11 mg/L to a decrease of about 33 mg/L.

The long-term variation of nitrate, defined by the change in median concentration in water from 14 wells sampled during a previous study (Myette, 1982) in 1979–81 and the present study, also was negligible. Although the concentration in water from one well increased since the previous study, the median concentrations for the two sampling periods were about the same (about 1 to 2 mg/L). Results of the long-term variation are suggestive rather than conclusive, however, because of the small number of wells analyzed in the previous study.

The seasonal variation of nitrate, defined by the change in concentration for well 3, sampled from early April 1994 to early September 1995, was substantial at times. Most of the variation was during two periods in spring and early summer when the concentration increased from 5.2 mg/L in mid-April 1994 to 12 mg/L in mid-June 1994 and from 14 mg/L in late May 1995 to 19 mg/L in mid-August 1995. These seasonal increases may have been attributable to nitrate from applications of fertilizer that was transported to the water table by rainfall recharge. These variations probably were most apparent in water from well 3 because it is an observation well screened near the water table. Cowdery (1997) concluded that seasonal variation in the nitrate concentration for shallow wells exists, but that consistent patterns of seasonal variation are not apparent in many cases.

Nitrate concentrations also were analyzed on the basis of three factors: (1) land use; (2) soil permeability; and (3) well depth (fig. 3). Well depth and soil permeability are physical factors that affect the travel time for water, and therefore nitrate, to move from the land surface into wells. The travel time is likely to decrease as well depth decreases and soil permeability increases. Land use is a source factor that affects the amount of nitrate available to enter wells. The amount may increase as the proportion of agricultural land use increases, particularly where nitrogen fertilizer and manure are applied to croplands.

The effects of these factors on nitrate concentration in water from the sampled wells were analyzed statistically by the Wilcoxon summed-ranks test. The following null hypotheses were tested: (1) the median concentrations in water from wells in agricultural and nonagricultural land use settings were equal; (2) the median concentrations in water from wells 25 feet deep or less in settings with moderate and rapid soil permeability were equal; and (3) the median concentrations in water from wells with depths 25 feet or less and greater than 25 feet were equal. Acceptance of the null hypotheses (p-value greater than or equal to 0.050) would indicate that the factors did not influence nitrate concentrations.

Land use within a 1-mile radius of the sampled wells was classified as either agricultural or nonagricultural. Agricultural land use consisted of pasture and croplands; nonagricultural land use mainly consisted of forests, wetlands, and residences. The classifications were made from photocopies of aerial photographs taken in 1992 that are on file at the NRCS offices in Perham and Fergus Falls, Minnesota. Soil permeability within a 0.5-mile radius of the sampled wells 25 feet deep or less was assigned one of two ratings based on minimum infiltration rates for soil horizons generally within the upper 5 feet of soil. These ratings were: (1) moderate—2 to 6 in. per hour; and (2) rapid—greater than 6 to 10 in. per hour. The ratings were compiled from soil surveys of Otter Tail County that are on file at the NRCS offices in Perham and Fergus Falls, Minnesota. Depths of the sampled wells were determined from: (1) well logs recorded by the driller; (2) a report published by Myette (1982); and (3) the well owners. Hand-driven sand point wells were assumed to have a depth of 25 feet or less.

The median concentration in water from wells in settings classified as agricultural was 7.15 mg/L, about four times higher than the median concentration (1.80 mg/L) in water from wells in settings classified as nonagricultural (p-value of 0.046). These results indicate that increased nitrate concentrations were associated with agricultural land use, a conclusion consistent with the study by Cowdery (1997).

The median nitrate concentration in water from shallow wells (depths of 25 feet or less) in settings with rapid soil permeability was 6.6 mg/L, not significantly different (p-value of 0.400) than the median concentration (7.9 mg/L) in water from shallow wells in settings with moderate soil permeability. The median concentration in water from shallow wells in settings with rapid soil permeability might be expected to be greater than in water from shallow wells in settings with moderate permeability. The difference in effects between rapid and moderate permeability rates, however, did not appear to be large enough to offset the effects of other factors, such as well depth and land use, on nitrate concentration in water from the shallow wells.

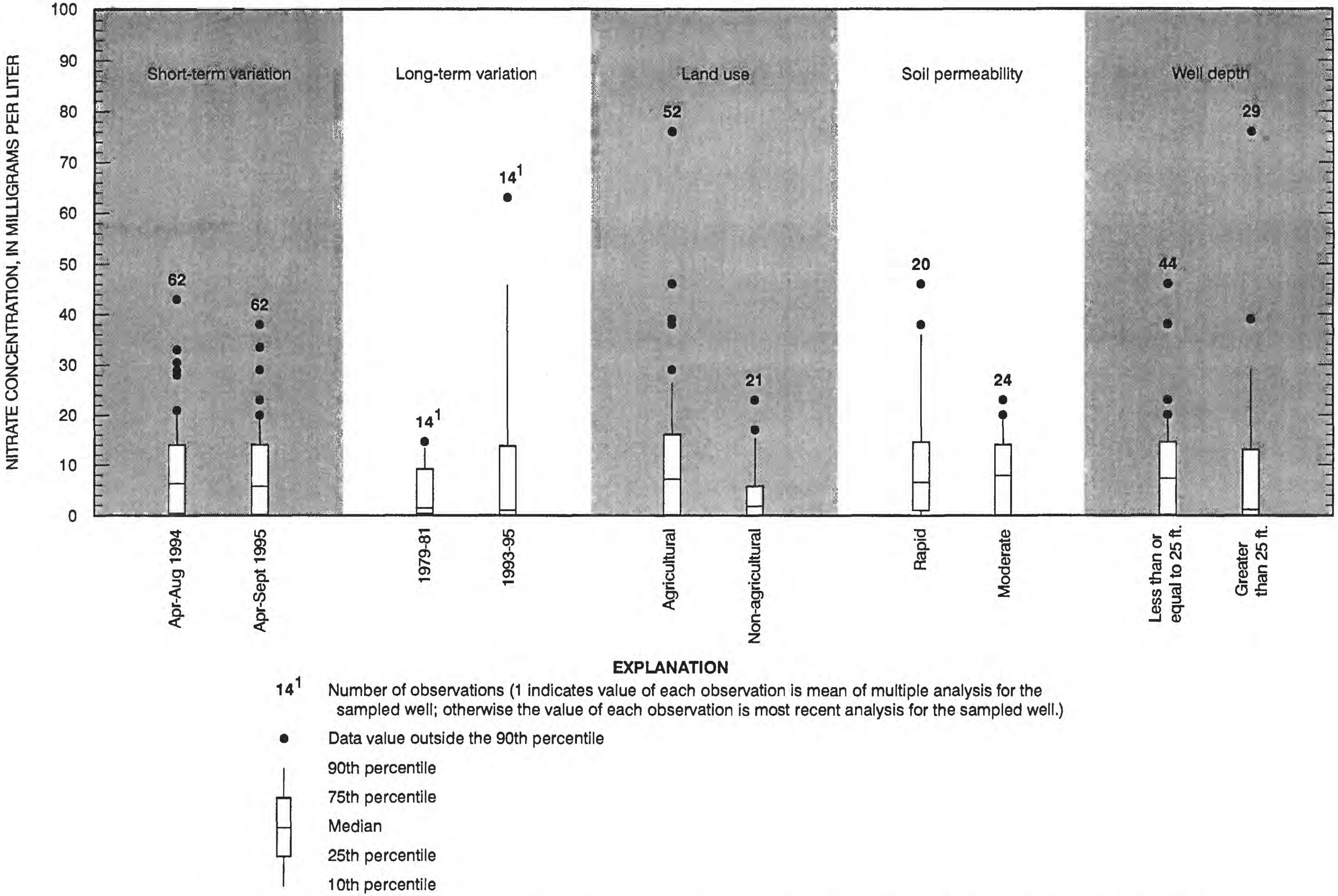


Figure 3. Distribution of nitrate concentrations in water from wells completed in surficial aquifers relative to short and long-term variation, land use, soil permeability, and well depth, eastern Otter Tail County, Minnesota.

The median concentration in water from wells with depths of 25 feet or less was 7.3 mg/L, about six times higher than the median concentration (1.1 mg/L) in water from wells greater than 25 feet deep. The difference in median concentrations was not statistically significant (p-value of 0.151) because of two large concentrations (39 and 76 mg/L) in water from wells greater than 25 feet deep. The concentration of 39 mg/L in water from well 1, which is 29 feet deep, was nearly part of the subset of nitrate concentrations in water from wells 25 feet deep or less. The concentration of 76 mg/L in water from well 37, which is 80 feet deep, is an anomalously large value. This large value indicates that the water may have been affected by surface leakage into the well. The large difference in median concentrations, therefore, even though not statistically significant, indicates that increased nitrate concentrations were associated with well depths of 25 feet or less.

Pesticides

Pesticide concentrations were determined by GC/MS in water from 25 wells (table 1). The concentrations of triazine herbicides from each sample were summed and compared to the concentration of triazine herbicides determined by immunoassay analyses. Comparison of the two methods was not made for 4 of the 25 wells because of nonmatching sampling dates. Results of the two methods were consistent with each other for 15 wells that had sample concentrations less than 0.100 µg/L. For wells that had sample concentrations greater than 0.100 µg/L, the two methods generally were consistent with each other for samples from wells 20, 27, 63, and 26 and slightly inconsistent with each other for samples from wells 37 and 71. The immunoassay method was reliable (based on GC/MS as the standard) for concentrations less than about 2 µg/L, which was the case for 70 of 73 sampled wells. The immunoassay method may have had a slight positive bias, however, for concentrations greater than about 2 µg/L.

Triazine herbicides were detected by immunoassay analyses in water from 23 (about 31 percent) of 73 wells at concentrations that ranged from 0.10 to 5.0 µg/L (table 5). The locations of these wells are distributed throughout the surficial aquifers (fig. 4). Most of these wells (19) are in agricultural land-use settings. More than half of these wells (14) had nitrate concentrations that exceeded 10 mg/L. The presence of triazine herbicides is associated with agricultural land use, where these chemicals were applied to croplands.

Ten pesticides were detected by GC/MS in water from 19 of 25 wells (table 1). All of the detected pesticides were herbicides. These herbicides consisted of five triazine herbicides (atrazine, simazine, cyanazine, propazine, and metribuzin), two degradation products of atrazine (deisopropylatrazine and deethylatrazine), two acetanilides (alachlor and metolachlor), and a degradation product of alachlor (2,6-diethylaniline). Atrazine and deethylatrazine were detected most frequently (in water from 18 wells for atrazine and in water from 16 wells for deethylatrazine). Atrazine, deethylatrazine, and deisopropylatrazine were the only pesticides that had concentrations greater than 1.00 µg/L. The pesticides not detected by GC/MS analysis are listed in table 2 with method detection limits.

Regulatory concentrations of pesticides in drinking water have been established for only three of the pesticides detected: (1) atrazine—3 µg/L; (2) simazine—4 µg/L; and (3) alachlor—2 µg/L (U.S. Environmental Protection Agency, 1996). The concentrations of atrazine, simazine, and alachlor were within their respective regulatory concentrations, although the concentration of atrazine for wells 26 and 37 (2.40 and 2.20 µg/L, respectively) approached the regulatory concentration.

Trophic State and Phosphorus Sources for Selected Lakes

Little Pine, Big Pine, Rush, and Otter Tail Lakes (located in the Otter Tail River Basin and listed in downstream order) are vulnerable to eutrophication from increased phosphorus. Sources of phosphorus to these lakes include runoff and lake bottom sediments. The pH of these lakes was within the range (6 to 9) (table 3) commonly observed for inland surface waters (Cole, 1983) and, except for a pH of 8.6 near the surface of Little Pine Lake, was within the range (6.5 to 8.5) deemed suitable for plant and animal aquatic habitat (Minnesota Pollution Control Agency, 1988). The specific conductance (median of 334 µS/cm at a depth of 3.0 feet) was lower than for ground water (median of 578 µS/cm). The dissolved oxygen concentration was suitable to support game fish, which generally require a minimum concentration of 5 mg/L (Minnesota Pollution Control Agency, 1992).

During August 9–10, 1995, Little Pine Lake was thermally stratified at sites 1 and 2 and Big Pine Lake was thermally stratified at site 8. Big Pine Lake was not stratified at site 10—although a partially formed thermocline (thin stratum where the rate of temperature change with depth is maximum) was evident—because the depth was too shallow (53 feet). The temperature, pH, specific conductance, and dissolved oxygen concentration were nearly constant with depth to about 23 feet at sites 1 and 2 and to about 50 to 55 feet at sites 8 and 10 (fig. 5). These depths represented the bottom of the epilimnion (upper stratum of water). Below the epilimnion in the thermocline and hypolimnion (lower stratum of water), the temperature, pH,

Table 1.--Pesticide concentrations determined by gas chromatography/mass spectrometry in water from wells completed in surficial aquifers, eastern Otter Tail County, 1994–95

[E, estimated; µg/L, micrograms per liter; <, less than; --not determined]

Site identifier for wells (fig. 1)	Date	Simazine, dissolved (µg/L)	Deiso-propyl-atrazine, dissolved (µg/L)	Deethyl-atrazine, dissolved (µg/L)	Cyanazine, dissolved (µg/L)	Propazine, dissolved (µg/L)	Metolachlor, dissolved (µg/L)	Atrazine, dissolved (µg/L)	Alachlor, dissolved (µg/L)	Metribuzin, dissolved (µg/L)	2,6-Diethyl-aniline, dissolved (µg/L)
1	06-21-94	<0.005	--	E0.005	<0.004	--	E0.001	0.011	<0.002	<0.004	<0.003
	06-20-95	<.005	--	E.026	<.004	--	<.002	.036	<.002	<.004	<.003
2	06-16-94	.008	--	<.002	<.004	--	.006	.035	<.002	<.004	<.003
3	06-14-94	<.005	--	E.051	<.004	--	<.002	.009	<.002	<.004	<.003
	06-20-95	<.005	--	E.073	<.004	--	<.002	E.014	<.002	<.004	<.003
4	06-16-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
5	06-02-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
8	06-29-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
9	07-25-94	<.005	--	E.018	<.004	--	<.002	.024	<.002	<.004	<.003
12	06-23-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
	07-14-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
20	07-12-94	<.005	--	E.026	.013	--	.003	.160	<.002	<.004	<.003
22	04-26-95	<.005	0.110	1.90	<.004	<0.050	<.002	.730	<.002	<.004	--
23	06-30-94	<.005	--	E.002	.019	--	<.002	.012	<.002	<.004	.007
24	07-14-94	<.005	--	E.013	<.004	--	<.002	.005	<.002	<.004	<.003
	06-21-95	<.005	--	E.024	<.004	--	<.002	E.005	<.002	<.004	<.003
25	07-25-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	.005	<.003
26	07-12-94	.012	--	E.640	<.004	--	.200	2.40	.014	.300	<.003
	06-21-95	<.005	--	E.620	<.004	--	.082	1.40	.011	.290	<.003
27	07-12-94	<.005	--	E.120	<.004	--	<.002	.190	<.002	<.004	<.003
28	06-28-94	<.005	--	E.014	<.004	--	<.002	.019	<.002	<.004	<.003
	07-26-94	<.005	--	E.012	<.004	--	<.002	.016	<.002	<.004	<.003
29	07-13-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
30	06-29-94	<.005	--	<.002	<.004	--	<.002	.003	<.002	<.004	<.003
32	07-11-94	.057	--	E.010	<.004	--	<.002	.018	<.002	<.004	<.003
33	07-13-94	<.005	--	<.002	<.004	--	<.002	<.001	<.002	<.004	<.003
34	07-13-94	<.005	--	E.020	<.004	--	<.002	.003	<.002	<.004	<.003
37	04-19-95	<.005	.200	E.960	<.004	.130	<.002	2.20	<.002	<.004	--
40	05-10-95	<.005	1.50	E1.20	<.004	<.050	<.002	.130	<.002	<.004	--
63	04-25-95	<.005	<.050	E.150	<.004	<.050	<.002	.250	<.002	<.004	--
71	05-09-95	<.005	.080	E.340	<.004	.120	<.002	1.80	<.002	<.004	--

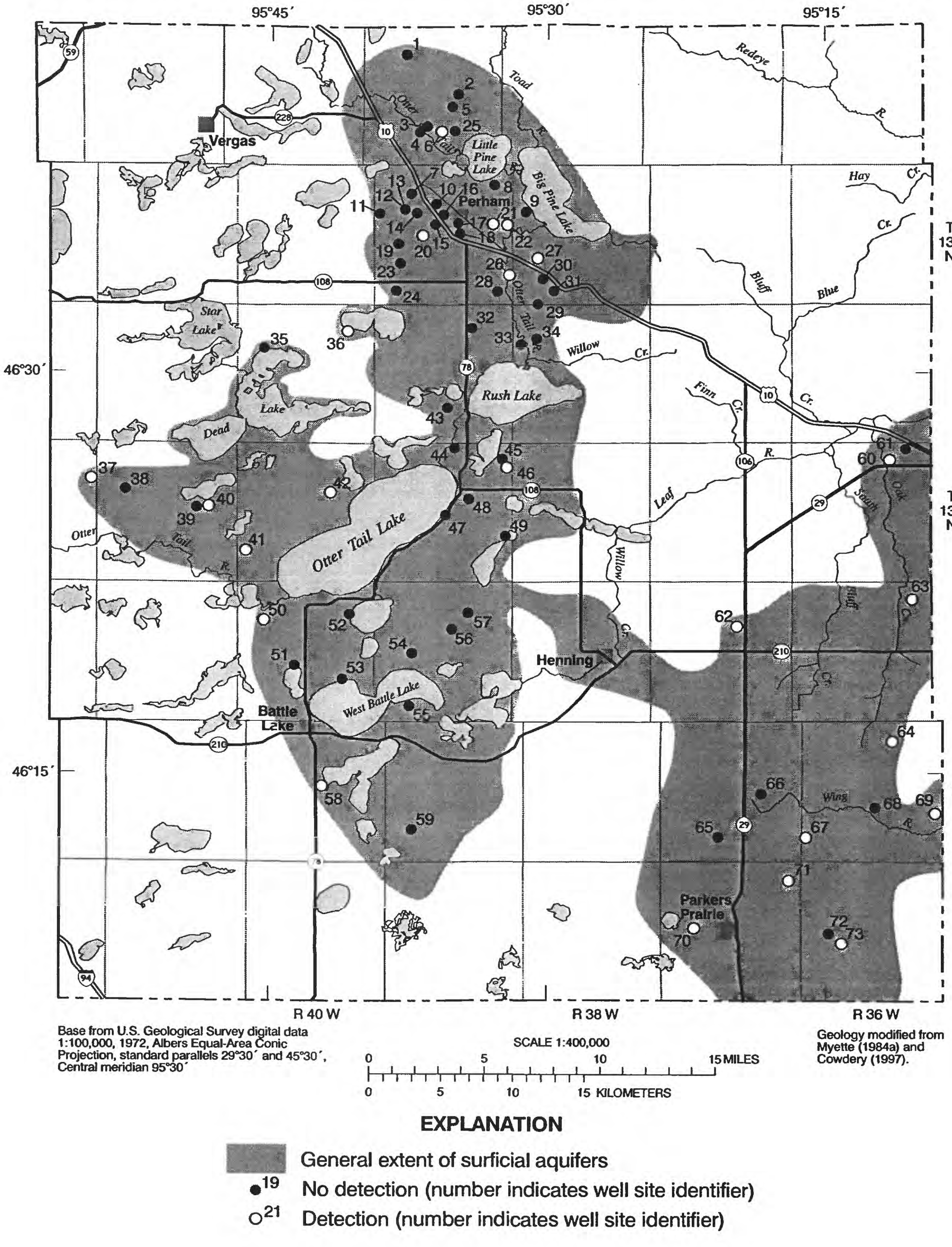


Figure 4. Detections by immunoassay test for triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, Minnesota, 1993-95.

Table 2--Pesticides not detected by gas chromatography/mass spectrometry in water from wells completed in surficial aquifers, eastern Otter Tail County, 1994–95

[MDL, method detection limit; mg/L, micrograms per liter]

Pesticide	MDL (µg/L)
Acetochlor	0.002
Acifluorfen	.035
Aldicarb	.016
Aldicarb sulfone	.016
Adicarb sulfoxide	.021
Benfluralin	.002
Bentazon	.014
Bromacil	.035
Bromoxynil	.035
Carbaryl	.008
Carbofuran	.028
Chloramben	.011
Chlorpyrifos	.004
Chlorthalonil	.035
Clopyralid	.050
p,p'-DDE	.006
2,4-D	.035
2,4-DB	.035
Dacthal (DPCA)	.017
Diazinon	.002
Dicamba	.035
Dichlobenil	.020
Dichlorprop	.032
Dieldrin	.001
Dinoseb	.035
Diuron	.020
Disulfoton	.017
Esfenvalerate	.019
EPTC	.002
Ethalfluralin	.004
Ethoprop	.003
Fenuron	.013
Fluometuron	.035
Fonofos	.003
3-Hydroxycarbofuran	.014

Pesticide	MDL (µg/L)
Lindane	.004
Linuron	.002
MCPA	.050
MCPB	.035
Malathion	.005
Methiocarb	.026
Methomyl	.017
Methyl azinphos	.001
Methyl, parathion	.006
Molinate	.004
1-Naphthol	.007
Napropamide	.003
Neburon	.015
Norflurazon	.024
Oryzalin	.019
Oxamyl	.018
Parathion	.004
Pebulate	.004
Pendimethalin	.004
Permethrin, cis	.005
Phorate	.002
Picloram	.050
Prometon	.018
Pronamide	.003
Propachlor	.007
Propargite	.013
Propanil	.004
Propoxur	.035
Silvex	.021
2,4,5-T	.035
Tebuthiuron	.010
Terbacil	.007
Terbufos	.013
Thiobencarb	.002
Triallate	.001
Trifluralin	.002

and dissolved oxygen concentration decreased with depth, and the specific conductance increased with depth to the lake bottom. Except for site 10 on Big Pine Lake, the concentrations of total phosphorus and dissolved ammonium-nitrogen were greater in the hypolimnion.

During August 9–10, 1995, the epilimnion of Little Pine and Big Pine Lakes ranged in temperature from 22 to 23° C, in pH from 8.1 to 8.6, in specific conductance from 322 to 340 µS/cm, and in dissolved-oxygen concentration from 5.2 to 8.8 mg/L. The concentration of total phosphorus was from 0.020 to 0.022 mg/L; the concentration of dissolved ammonium-nitrogen was from less than 0.010 to 0.030 mg/L. Similar values for these properties and constituents (except for a total phosphorus concentration of 0.060 mg/L at site 13 on Rush Lake) were observed in the epilimnion of Little Pine, Big Pine, Rush, and Otter Tail Lakes during September 20–22, 1994 (table 4).

Table 3.--Physical and chemical properties in Little Pine, Big Pine, Rush, and Otter Tail Lakes, eastern Otter Tail County, 1994-95

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; °C, degrees Celsius; <, less than]

Site identifier for lake sites (fig. 1)[1]	Date	Lake depth at sample location, total (feet)	Sample depth (feet)	Specific conductance, field (µS/cm)	pH, field (standard units)	Temperature, field (°C)	Oxygen, dissolved, field (mg/L)
3 (Little Pine Lake)	09-21-94	12	3.0	336	8.4	19.5	9.5
4 (Big Pine Lake)	09-21-94	10	3.0	332	8.4	20.0	9.1
5 (Big Pine Lake)	09-21-94	11	3.0	339	8.3	19.5	9.0
6 (Big Pine Lake)	08-09-95	24	0.5	331	8.4	23.0	8.1
			1.0	330	8.4	23.0	8.0
			2.0	329	8.4	23.0	8.0
			3.0	330	8.4	23.0	7.9
			4.0	331	8.4	23.0	7.9
			10	333	8.4	23.0	7.8
			15	332	8.4	23.0	7.9
			20	334	8.3	23.0	7.9
			23	334	8.3	23.0	7.7
7 (Big Pine Lake)	09-21-94	11	3.0	334	8.2	19.5	7.3
9 (Big Pine Lake)	09-21-94	20	3.0	330	8.3	19.5	8.0
11 (Big Pine Lake)	08-09-95	18	.5	334	8.4	23.5	8.4
			3.0	335	8.4	23.5	8.4
			8.0	334	8.4	23.5	8.3
			12	335	8.3	23.0	8.1
			15	335	8.3	23.0	8.0
			16	335	8.3	23.0	7.8
12 (Rush Lake)	09-20-94	7.5	3.0	314	8.5	20.5	9.6
13 (Rush Lake)	09-20-94	22	3.0	306	8.5	20.0	9.7
14 (Otter Tail Lake)	09-22-94	14	3.0	347	8.3	19.0	7.7
15 (Otter Tail Lake)	09-22-94	4.3	3.0	344	8.5	19.0	8.2
16 (Otter Tail Lake)	09-22-94	4.7	3.0	346	8.4	17.0	8.3
17 (Otter Tail Lake)	09-22-94	8.5	3.0	345	8.4	18.0	8.2

[1] Data from lake sites 1, 2, 8, and 10 are shown on fig. 5.

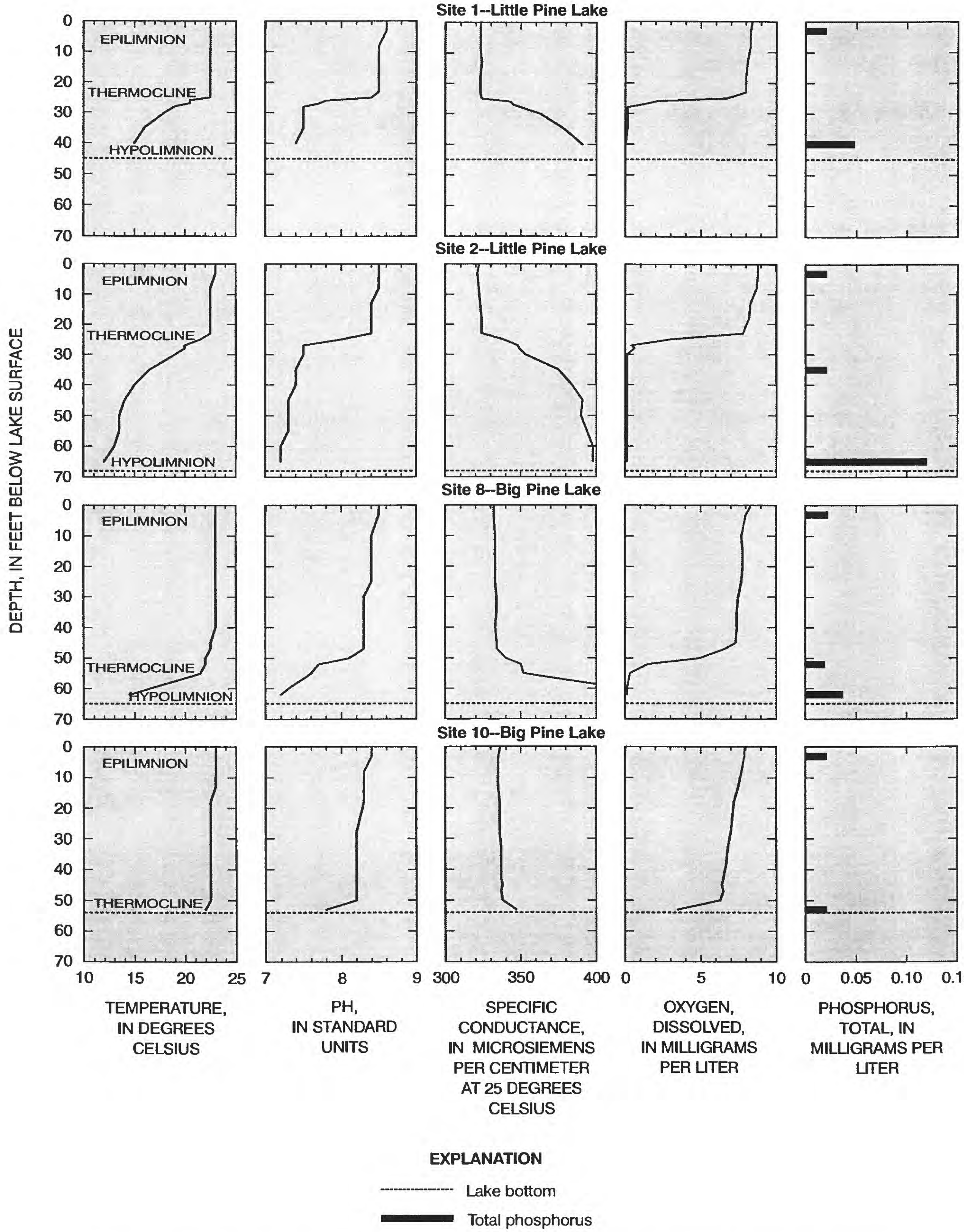


Figure 5. Vertical profiles of temperature, pH, specific conductance, dissolved oxygen, and total phosphorus in Little Pine and Big Pine Lakes, eastern Otter Tail County, Minnesota, August 9-10, 1995.

Table 4.--Secchi disk transparency, nutrients, chlorophyll, and Carlson's trophic state indicies in Little Pine, Big Pine, Rush, and Otter Tail Lakes, eastern Otter Tail County, 1994–95

[mg/L, milligrams per liter; µg/L, micrograms per liter; TSI, trophic state index; <, less than; --, not determined]

Site identifier for lake sites (fig. 1)	Date	Lake depth at sample location, total (feet)	Secchi disk trans-parency (feet)	Sample depth (feet)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Phos-phorus, ortho, dissolved (mg/L as PO_4)	Phos-phorus, dissolved (mg/L as P)	Phos-phorus, total (mg/L as P)	Chloro-phyll *a* phyto-plankton (µg/L)	Chloro-phyll *b* phyto-plankton (µg/L)	Chloro-phyll TSI	Phos-phorus TSI	Secchi disk TSI
1 (Little Pine Lake)	08-10-95	45	5.5	0-3	<0.015	<0.01	<0.005	<0.01	--	0.02	9.0	<0.10	52	47	53
				40	.390	<.01	<.050	.04	--	.048	--	--	--	--	--
2 (Little Pine Lake)	08-10-95	68	5.5	0-3	<.015	<.01	<.050	<.01	--	.021	11	.20	54	48	53
				35	.160	<.01	<.050	<.01	--	.021	--	--	--	--	--
				65	.880	<.01	<.050	.13	--	.12	--	--	--	--	--
3 (Little Pine Lake)	09-21-94	12	4.1	0-3	.010	<.01	<.050	<.01	<0.01	<.01	28	.50	63	37	57
4 (Big Pine Lake)	09-21-94	11	4.0	0-3	.010	<.01	<.050	<.01	.01	.01	12	.30	55	37	57
5 (Big Pine Lake)	09-21-94	11	4.8	0-3	.010	<.01	<.050	<.01	.01	.02	12	.20	55	47	55
6 (Big Pine Lake)	08-09-95	24	5.5	0-3	.020	<.01	<.050	<.01	--	.019	7.8	.30	51	47	53
7 (Big Pine Lake)	09-21-94	11	5.4	0-3	.030	<.01	<.050	<.01	<.01	<.01	11	.30	54	37	53
8 (Big Pine Lake)	08-09-95	65	5.4	0-3	.020	<.01	<.050	<.01	--	.022	6.6	.20	49	49	53
				52	.150	<.01	<.050	<.01	--	.019	--	--	--	--	--
				63	1.50	<.01	<.050	.02	--	.037	--	--	--	--	--
9 (Big Pine Lake)	09-21-94	20	5.4	0-3	.020	<.01	<.050	<.01	<.01	<.01	8.0	.20	51	37	53

Table 4.--Secchi disk transparency, nutrients, chlorophyll, and Carlson's trophic state indicies in Little Pine, Big Pine, Rush, and Otter Tail Lakes, eastern Otter Tail County, 1994–95--(Continued)

Site identifier for lake sites (fig. 1)	Date	Lake depth at sample location, total (feet)	Secchi disk trans-parency (feet)	Sample depth (feet)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Phos-phorus, ortho, dissolved (mg/L as PO_4)	Phos-phorus, dissolved (mg/L as P)	Phos-phorus, total (mg/L as P)	Chloro-phyll *a* phyto-plankton (µg/L)	Chloro-phyll *b* phyto-plankton (µg/L)	Chloro-phyll TSI	Phos-phorus TSI	Secchi disk TSI
10 (Big Pine Lake)	08-09-95	54	5.5	0-3	.030	<.01	<.050	<.01	--	.021	--	--	--	48	53
				52	.080	<.01	<.050	<.01	--	.021	--	--	--	--	--
11 (Big Pine Lake)	08-09-95	18	5.5	0-3	.040	<.01	<.050	<.01	--	.018	7.1	.40	50	46	53
12 (Rush Lake)	09-20-94	7.5	5.0	0-3	<.010	<.01	<.050	<.01	<.01	.01	6.0	.50	48	37	54
13 (Rush Lake)	09-20-94	22	4.4	0-3	<.010	<.01	<.050	<.01	<.01	.06	4.4	.20	45	63	56
14 (Otter Tail Lake)	09-22-94	14	7.4	0-3	.020	<.01	<.050	<.01	<.01	<.01	4.9	.30	46	37	48
15 (Otter Tail Lake)	09-22-94	4.3	--	0-3	.010	<.01	<.050	<.01	<.01	<.01	5.5	.30	47	37	--
16 (Otter Tail Lake)	09-22-94	4.7	--	0-3	.020	<.01	<.050	<.01	<.01	<.01	4.4	.20	45	37	--
17 (Otter Tail Lake)	09-22-94	8.5	5.7	0-3	.020	<.01	<.050	<.01	<.01	.02	6.4	.30	49	47	52

During August 9–10, 1995, epilimnetic water in Little Pine and Big Pine Lakes (sites 2 and 6, respectively) was analyzed by GC/MS for the triazine herbicides atrazine, deethylatrazine, deisopropylatrazine, simazine, cyanazine, propazine, metribuzin, prometryn, prometon, ametryn, metolachlor, and alachlor. None of these herbicides were detected by the analyses.

During August 9–10, 1995, the hypolimnion of Little Pine and Big Pine Lakes had temperatures as low as 12.5°C, pH as low as 7.2, specific conductance as high as 400 µS/cm, dissolved-oxygen concentrations as low as 0.0 mg/L, total phosphorus concentrations as high as 0.120 mg/L, and dissolved ammonium-nitrogen concentrations as high as 1.5 mg/L. The absence of dissolved oxygen in the hypolimnion is characteristic of stratified, eutrophic lakes (Cole, 1983).

The minimum depths required for stratification appeared to be about 30 feet for Little Pine Lake and 60 feet for Big Pine Lake. About 75 percent of Little Pine Lake is deeper than 30 feet, but only about 5 to 10 percent of Big Pine Lake is deeper than 60 feet. Therefore, three-fourths of Little Pine Lake probably stratified and became anoxic, but only a small portion of Big Pine Lake probably stratified and became anoxic during the summer of 1995.

Trophic State

Lakes commonly are classified by the following trophic states: (1) oligotrophy—clear lakes with small amounts of nutrients and phytoplankton; (2) mesotrophy—moderately clear lakes with moderate amounts of nutrients and phytoplankton; and (3) eutrophy—turbid lakes with large amounts of nutrients and phytoplankton. Trophic state is related to: (1) the Secchi disk transparency; (2) total epilimnetic phosphorus concentration; and (3) chlorophyll *a* concentration.

TSI (trophic-state indices) are measures of phytoplanktonic biomass on a scale of 0 to 100 in surface waters (Carlson, 1977). Each 10-unit increase (decrease) in TSI represents a doubling (halving) of phytoplanktonic biomass. TSI were computed from the Secchi disk transparency, total epilimnetic phosphorus concentration, and concentration of chlorophyll *a*, with the following equations:

$$\text{Secchi disk TSI} = 60 - 14.41 (\ln SD); \quad (1)$$

$$\text{Total phosphorus TSI} = 14.42 (\ln TP) + 4.15; \quad (2)$$

$$\text{Chlorophyll TSI} = 9.81 (\ln CHL) + 30.6; \quad (3)$$

where

Secchi disk TSI = trophic-state index based on Secchi disk transparency (SD), in meters;

Total phosphorus TSI = trophic-state index based on total epilimnetic phosphorus concentration (TP), in µg/L;

Chlorophyll TSI = trophic-state index based on chlorophyll *a* concentration (CHL), in µg/L.

The chlorophyll TSI indicates trophic state because the concentration of chlorophyll *a* is a measure of phytoplanktonic biomass. The total phosphorus TSI indicates trophic state because the total epilimnetic phosphorus concentration is a measure of the amount of phosphorus nutrients available for phytoplankton. The Secchi disk TSI indicates trophic state because the Secchi disk transparency is a measure of light attenuation by phytoplankton. Interpretation of the TSI, however, must be made with regard to the following assumptions: (1) the chlorophyll *a* content of the phytoplanktonic biomass is fairly constant for each species of phytoplankton; (2) phosphorus is the nutrient that limits the growth of phytoplankton; and (3) light attenuation attributable to causes other than phytoplankton, such as chemical coloration and suspended inorganic particulate matter, is negligible.

Reckhow (1979) developed the following ranking system for TSI: (1) less than 40—oligotrophic; (2) from 40 to 50—mesotrophic; and (3) greater than 50—eutrophic. (The TSI values for this classification system are for each of the three bases of TSI, not sums).

The TSI determined for Little Pine, Big Pine, Rush, and Otter Tail Lakes indicated that the trophic state of these lakes ranged from upper oligotrophic to lower eutrophic according to the system developed by Reckhow (1979) (fig. 6). The Secchi disk transparencies of 4.0 to 7.4 feet, chlorophyll *a* concentrations of 4.4 to 28 µg/L, and total epilimnetic phosphorus concentrations from less than 0.010 to 0.022 mg/L except for one concentration of 0.060 mg/L, indicated these trophic states (Vollenweider, 1976). The TSI indicated that the trophic state of these lakes generally varied very little, but may have become less eutrophic from upstream to downstream lakes based on the chlorophyll TSI, possibly because phosphorus retention in the upstream lakes reduced phosphorus loads to the downstream lakes.

Phosphorus Sources

The major external sources of phosphorus to Big Pine Lake were the Otter Tail and Toad Rivers. Other sources of external phosphorus were from ground-water discharge and eroded soil particles from direct runoff and airborne deposition. The phosphorus load to Big Pine Lake from the Otter Tail and Toad Rivers and ground-water discharge was estimated from March 16, 1995, to March 15, 1996.

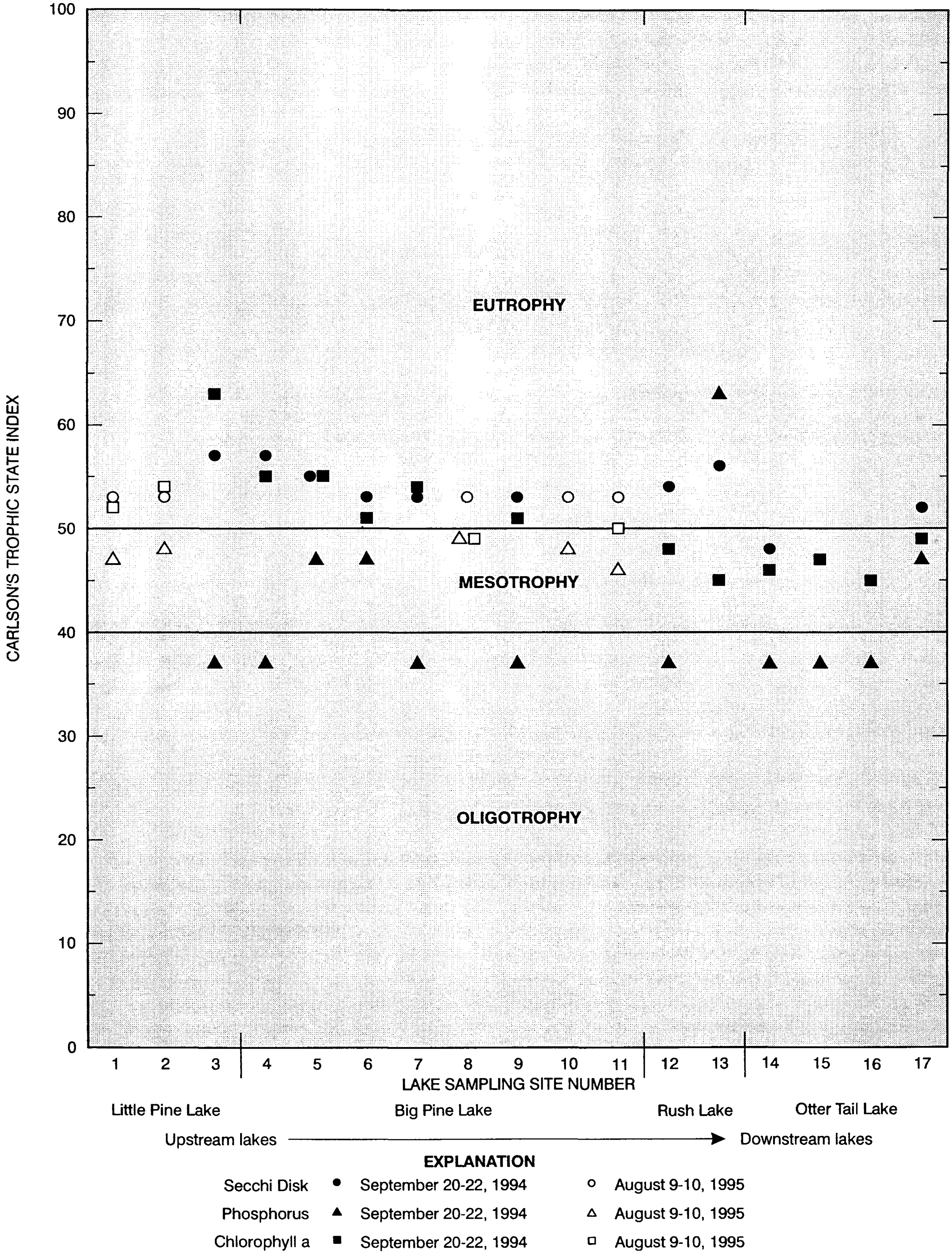


Figure 6. Carlson's trophic state indices for Little Pine, Big Pine, Rush, and Otter Tail Lakes, eastern Otter Tail County, Minnesota, 1994-95.

Streamflow transport of phosphorus into Big Pine Lake was estimated from discrete measurements made at the Otter Tail and Toad River inlets (streamflow gaging stations 1 and 2) and at the Otter Tail River outlet (streamflow gaging station 3) (table 6). Figure 7 shows the daily streamflow and phosphorus loads for these stations and the net daily streamflow and phosphorus loads for Big Pine Lake. The net daily values are the summation of daily streamflows and phosphorus loads for the inlets minus the daily streamflows and phosphorus loads for the outlet. (Positive net daily values indicate streamflows and phosphorus loads to the lake exceeded streamflows and phosphorus loads from the lake; negative net daily values indicate streamflows and phosphorus loads from the lake exceeded streamflows and phosphorus loads to the lake.)

The cumulative streamflows and phosphorus loads for each of the streamflow gaging stations were determined from summations of the daily values. The net cumulative streamflow and phosphorus load for Big Pine Lake are the summation of cumulative streamflows and phosphorus loads for the inlets minus the cumulative streamflow and phosphorus load for the outlet. (Positive net cumulative values represent accumulation of water and phosphorus in the lake; negative net cumulative values represent removal of water and phosphorus from the lake.)

The annual phosphorus load from the Otter Tail and Toad Rivers to Big Pine Lake was about 10,400 pounds. The load from the Toad River (about 5,730 pounds) was greater than from the Otter Tail River (about 4,670 pounds), even though streamflow from the Toad River was about 70 percent less than the Otter Tail River. The median total phosphorus concentration at the Toad River inlet was 0.063 mg/L, which was much greater than the median concentration of 0.016 mg/L at the Otter Tail River inlet.

The annual total phosphorus loss from Big Pine Lake through the Otter Tail River outlet was about 8,460 pounds. Thus, Big Pine Lake accumulated a total of 1,940 pounds of phosphorus from streamflow transport to and from the lake. Big Pine Lake initially accumulated phosphorus during spring runoff and then started to lose phosphorus during late spring. All of the accumulated phosphorus was removed by mid-May. Accumulation of phosphorus resumed during early July and continued until late winter.

The total annual accumulated phosphorus load to Big Pine Lake from ground-water discharge was estimated to be about 700 pounds. This phosphorus load is based on an estimate of ground-water discharge to Big Pine Lake of 12,570 ac-ft/yr (discussed below) with an assumed dissolved phosphorus concentration of 0.020 mg/L. (The assumed dissolved phosphorus concentration is based on the dissolved phosphorus concentrations for wells 8, 9, 22, and 27 near Big Pine Lake, which ranged from less than 0.010 to 0.240 mg/L (table 5). The median dissolved phosphorus concentration for all of the sampled wells was 0.010 mg/L.)

The annual ground-water discharge to Big Pine Lake was estimated from the following water-balance equation for a lake:

$$\text{(surface inflow - surface outflow) + net seepage = change in storage.} \qquad (4)$$

Surface inflow is cumulative streamflow into the lake and precipitation; surface outflow is cumulative streamflow out of the lake and evaporation. Surface inflow minus surface outflow, therefore, is net cumulative streamflow plus the gain from precipitation minus the loss from evaporation. The net seepage is either ground-water discharge into the lake (net seepage is positive), or lake-water recharge into the ground-water system (net seepage is negative). The change in storage is the change in volume associated with the net change in lake stage.

Based on the period March 16, 1995, to March 15, 1996, the annual net cumulative streamflow for Big Pine Lake was a loss of -16,200 ac-ft (fig. 7). Precipitation for the period was estimated to be 28 in. (equivalent to an annual gain of 11,825 ac-ft to the lake); evaporation for the period was estimated to be 22.4 in. (equivalent to an annual loss of -9,460 ac-ft from the lake) (National Oceanic and Atmospheric Administration, 1995 and 1996; and Winter and others, 1969). Surface inflow minus surface outflow for the period, therefore, was -13,835 ac-ft. The net change in lake stage for the period at the Otter Tail River outlet was -0.25 feet, which was equivalent to a loss in storage of -1,265 ac-ft. Therefore, the net seepage (ground-water discharge to the lake) for the period was 12,570 ac-ft.

The estimated load from ground-water discharge is sensitive to the assumed dissolved phosphorus concentration in the discharge. If the assumed concentration were increased by an order of magnitude to an unreasonably large value of 0.20 mg/L, the estimated phosphorus load from ground-water discharge would be 7,000 pounds, still less than the load of 10,400 pounds from the Otter Tail and Toad Rivers. The phosphorus load from ground-water discharge is a small portion of the total phosphorus load to the lake.

The total annual accumulation of phosphorus in Big Pine Lake from streamflow transport (1,940 pounds) and ground-water discharge (700 pounds) is estimated to be 2,640 pounds. The accumulated phosphorus probably was incorporated into phytoplanktonic cellular material or absorbed onto nonliving particulate matter that eventually settled into lake bottom sediments.

Internal sources of phosphorus to Little Pine and Big Pine Lake were bottom sediments. Phosphorus release from bottom sediments in the two lakes was indicated by the large concentrations measured in the hypolimnetic zone.

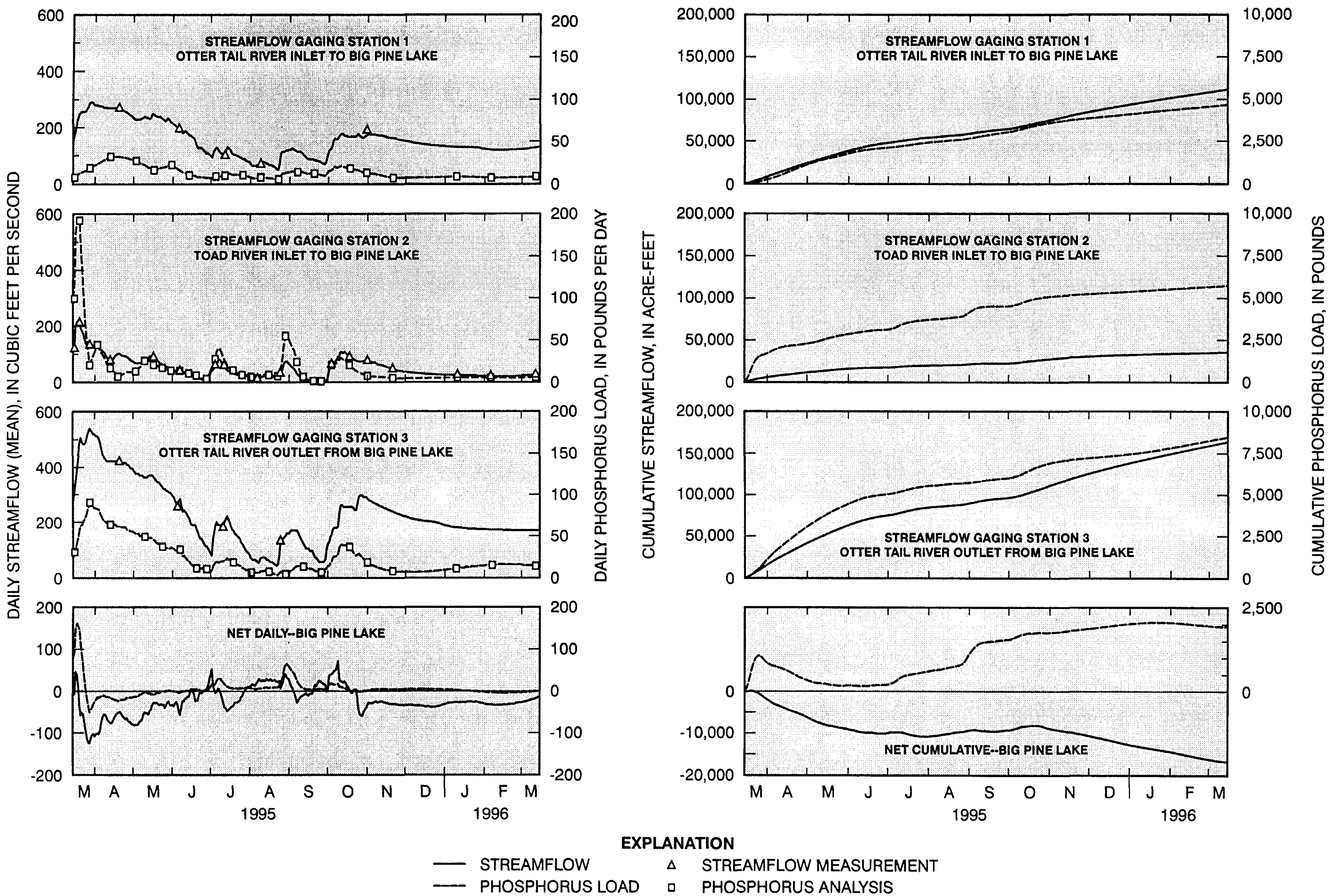


Figure 7. Daily and cumulative streamflow and phosphorus load in the Otter Tail and Toad Rivers at streamflow gaging stations located near two inlets and one outlet for Big Pine Lake, eastern Otter Tail County, Minnesota, March 15, 1995 to March 14, 1996.

These concentrations were 0.048 and 0.120 mg/L at depths of 40 and 65 feet at sites 1 and 2 on Little Pine Lake, respectively, and 0.037 mg/L at a depth of 63 feet at site 8 on Big Pine Lake during August 9–10, 1995 (fig. 5). The epilimnetic concentrations of total phosphorus at these sites ranged from 0.020 to 0.022 mg/L. This internal phosphorus load probably was linked to at-depth anoxic conditions in the hypolimnion during summer stratification. These conditions typically favor oxidation-reduction reactions at the sediment-water interface that release phosphorus into the water column (Wetzel, 1975).

The hypolimnetic phosphorus was mostly orthophosphate, which is the biologically reactive form. The at-depth concentration of orthophosphate ranged from less than 0.020 to 0.130 mg/L (table 4). During fall turnover—when the hypolimnion and epilimnion mix—the orthophosphate at depth may have circulated into the trophogenic zone (photosynthetic region) of the epilimnion, where the orthophosphate became an available nutrient for the growth of phytoplankton during the following growing season.

The internal phosphorus load to Little Pine Lake during 1995 may have had an important effect on its trophic state. As much as three-fourths of Little Pine Lake probably stratified during the summer and became anoxic in the hypolimnion. The internal phosphorus load to Big Pine Lake may not have had an important effect on its trophic state because the portion of Big Pine Lake that stratified and became anoxic in the hypolimnion was small.

Summary

This study analyzed nitrate and pesticides in the surficial aquifers and the trophic state and sources of phosphorus for selected lakes in the eastern two-thirds of Otter Tail County in west-central Minnesota. Land use in this area is mostly agriculture, but includes forests, wetlands, residential development, and small municipalities. In recent years, local public officials and citizens have become concerned about contamination of these aquifers by nitrate and pesticides and eutrophication of the lakes from increased phosphorus.

The concentration of nitrate (as nitrogen) in water from 73 wells (45 wells installed for private use and 28 wells installed for observation) completed in the surficial aquifers ranged from less than the detection limit of 0.050 mg/L to 76.0 mg/L. The concentration in water from 23 wells (about one-third of the total) was greater than 10 mg/L, the regulatory limit established by the U.S. Environmental Protection Agency for drinking water. The nitrate concentration in water from 39 wells, a little more than half of the total, was greater than 3 mg/L, the presumed natural background level. The density of wells with nitrate greater than 3 mg/L was slightly greater in the northern part of the study area where most of the observation wells were located. The nitrate concentrations in water from the observation wells, because they were screened at or within a few feet of the water table, were more directly affected by land use than the private-use wells, which typically were screened at greater depths below the water table.

Nitrate concentrations: (1) were greater in water from wells in agricultural settings than in water from wells in nonagricultural settings; (2) were not greater in water from shallow wells (25 feet deep or less) in settings with rapid soil permeability than in water from shallow wells in settings with moderate soil permeability, probably because the effects of permeability were offset by the effects of land use and well depth; and (3) were greater in water from shallow wells (25 feet deep or less) than in water from deep wells (greater than 25 feet deep).

Triazine herbicides were detected in water from 23 (about 31 percent) of the 73 sampled wells by immunoassay tests. Most of these wells are in areas of agricultural land use at locations distributed throughout the surficial aquifers. Ten pesticides, which included seven triazine herbicide compounds, were detected in water from 19 of these 25 wells. Atrazine, a triazine herbicide, and deethylatrazine, a degradation product of atrazine, were detected in water from 18 and 16 wells, respectively. None of the pesticides detected by GC/MS had concentrations that exceeded their respective regulatory limit for drinking water established by the U.S. Environmental Protection Agency.

The trophic state of four lakes in the Otter Tail River Basin, which in downstream order are Little Pine, Big Pine, Rush, and Otter Tail Lakes, ranged from upper oligotrophic to lower eutrophic. These trophic states were indicated by the Secchi disk transparencies (4.0 to 7.4 feet), chlorophyll *a* concentrations (4.4 to 28 µg/L), and total epilimnetic phosphorus concentrations (less than 0.010 to 0.022 mg/L except for one concentration of 0.060 mg/L). Carlson's trophic state indices indicated that the trophic state of these lakes generally varied very little, but may have become less eutrophic from upstream to downstream lakes based on the chlorophyll *a* index, possibly because phosphorus retention in the upstream lakes reduced phosphorus loads to the downstream lakes.

Major external sources of phosphorus to Big Pine Lake were the Otter Tail and Toad Rivers. The phosphorus load during March 16, 1995, to March 15, 1996 from these two streams was 10,400 pounds. The annual load from the Toad River (5,730 pounds) was greater than from the Otter Tail River (4,670 pounds) even though streamflow from the Toad River was about 70 percent less than the Otter Tail River. This difference was attributable to larger phosphorus concentrations in the Toad River.

The Otter Tail River removed 8,460 pounds of phosphorus through its outlet from Big Pine Lake during the

1-year period; thus, Big Pine Lake accumulated 1,940 pounds of phosphorus from streamflow transport to and from the lake. The annual phosphorus load to Big Pine Lake from ground-water discharge was estimated to be 700 lbs. Therefore, the total annual accumulation of phosphorus in Big Pine Lake was 2,640 lbs. The accumulated phosphorus probably was taken up by phytoplankton, or was absorbed by nonliving particulate matter that eventually settled into lake bottom sediments.

Bottom sediments were internal sources of phosphorus to Little Pine and Big Pine Lakes. The total phosphorus concentrations were increased at depths of 40 and 65 feet at two sites in Little Pine Lake and at a depth of 63 feet at one site in Big Pine Lake during August 9–10, 1995. The greater at-depth concentrations (0.037 to 0.120 mg/L) for these sites probably were associated with the small amount of dissolved oxygen in the hypolimnion during summer stratification.

Phosphorus at depth in Little Pine and Big Pine Lakes was mostly orthophosphate that ranged in concentration from less than 0.020 to 0.130 mg/L. During the fall turnover of the lakes, the at-depth orthophosphate may have circulated to near the lake surface where the orthophosphate became an available nutrient for the growth of phytoplankton during the following growing season. The internal phosphorus load to Little Pine Lake during 1995 may have had an important effect on its trophic state because about three-fourths of the lake probably stratified and became anoxic in the hypolimnion. The internal phosphorus load to Big Pine Lake may not have had an important effect on its trophic state because the portion of the lake that stratified and became anoxic in the hypolimnion was small.

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SUPPLEMENTAL INFORMATION

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[2]1	T137NR39WS08AAC	29	06-21-94	20.38	866	7.5	9.1	138
			08-09-94	20.53	891	7.4	8.3	199
			05-23-95	21.11	936	7.5	7.9	--
			06-20-95	21.20	950	7.5	9.7	--
			07-11-95	21.34	960	7.5	11	--
			09-06-95	21.59	957	7.4	10	--
[2]2	T137NR39WS15DDA	14	06-16-94	5.71	532	7.7	0.30	228
			04-11-95	5.64	952	--	--	--
			08-03-95	6.95	906	7.4	.20	--
[2]3	T137NR39WS28ACA	11	04-14-94	4.15	718	7.1	.10	314
			06-14-94	4.30	731	7.8	.10	296
			07-05-94	4.06	735	7.2	.10	292
			08-09-94	3.70	706	7.3	.10	255
			08-30-94	4.12	605	7.2	.80	260
			11-01-94	3.28	623	7.2	1.3	--
			03-22-95	4.11	701	7.2	.10	--
			04-18-95	4.22	739	7.2	.20	--
			05-23-95	4.31	741	7.2	.10	--
			06-20-95	4.47	753	7.3	.20	--
			07-10-95	4.41	755	7.4	.80	--
			08-04-95	4.51	754	7.2	1.2	--
			08-21-95	4.63	736	7.2	1.1	--
			09-05-95	4.45	726	7.2	1.1	--
[2]4	T137NR39WS28CAB	12	06-16-94	2.39	513	7.6	.10	255
			04-11-95	2.14	506	--	--	--
			08-04-95	2.88	532	7.5	.10	--
[3]5	T137NR39WS22ACC	24	06-02-94	6.69	832	7.6	.60	219
			04-11-95	8.54	787	--	--	--
[4]6	T137NR39WS27BDD	68	12-15-93	--	645	--	0.20	--
			05-11-95	--	651	--	.10	--
[4]7	T136NR39WS05DDC	90	12-15-93	--	488	--	.20	--
			04-19-95	--	503	--	.10	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[2]1	06-21-94	56	<0.01	0.02	<0.20	<0.01	29	<0.10
	08-09-94	60	<.01	.02	.30	<.01	32	--
	05-23-95	61	.01	.02	<.20	<.01	37	--
	06-20-95	59	.01	.02	.20	<.01	38	--
	07-11-95	61	.01	.02	<.20	<.01	38	--
	09-06-95	59	<.01	<.02	<.20	<.01	39	--
[2]2	06-16-94	4.2	.04	.02	.30	.04	<0.05	<.10
	04-11-95	84	.05	<.02	--	.04	17	<.10
	08-03-95	47	.05	<.02	<.20	.07	9.5	--
[2]3	04-14-94	16	.02	.01	.20	<.01	5.2	--
	06-14-94	17	.03	.02	.20	<.01	12	<.10
	07-05-94	17	<.01	.01	<.20	<.01	13	--
	08-09-94	17	<.01	.02	<.20	<.01	15	--
	08-30-94	16	.02	.01	<.20	<.01	13	--
	11-01-94	18	.03	<.02	<.20	<.01	14	--
	03-22-95	19	.02	.04	<.20	<.01	15	--
	04-18-95	18	.02	<.02	<.20	<.01	15	--
	05-23-95	17	.02	.03	<.20	<.01	14	--
	06-20-95	18	.03	.02	.20	<.01	16	--
	07-10-95	19	.03	<.02	<.20	<.01	17	--
	08-04-95	19	.02	<.02	<.20	<.01	18	--
	08-21-95	19	.02	.03	<.20	<.01	19	--
	09-05-95	17	.02	<.02	<.20	<.01	17	--
[2]4	06-16-94	2.8	.02	.30	.40	<.01	.39	<.10
	04-11-95	4.0	.01	.35	--	<.01	<.05	<.10
	08-04-95	3.6	.04	.33	.30	<.01	<.05	--
[3]5	06-02-94	51	<.01	<.01	.30	.09	13	--
	04-11-95	41	<.01	.02	--	.04	1.8	<.10
[4]6	12-15-93	3.1	0.07	2.6	--	0.02	0.14	<0.10
	05-11-95	3.7	.02	2.6	--	<.01	.08	.10
[4]7	12-15-93	4.9	<.01	0.04	--	.03	3.0	<.10
	04-19-95	2.3	<.01	<.02	--	<.01	.64	<.10

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[4]8	T136NR39WS01CCB	9	06-29-94	--	440	7.7	7.0	174
			04-26-95	--	434	--	7.3	--
[2]9	T136NR38WS07CDD	31	07-25-94	27.87	374	7.9	9.8	179
			04-13-95	--	356	--	--	--
[4]10	T136NR39WS09DDC	80	06-17-94	--	449	--	1.7	--
			04-19-95	--	457	--	.10	--
[4]11	T136NR39WS18BBB	<25	06-16-94	--	525	--	5.1	--
			04-19-95	--	549	--	5.2	--
[4]12	T136NR39WS08CCD	50	06-23-94	--	609	7.6	.10	204
			07-14-94	--	612	7.5	.10	206
[4]13	T136NR39WS08CCD	91	06-14-94	--	574	--	.20	--
			04-24-95	--	587	--	.20	--
[4]14	T136NR39WS17ABA	25	06-15-94	--	497	--	.10	--
			04-24-95	--	497	--	.10	--
[4]15	T136NR39WS16ADC	30	06-14-94	--	559	--	10	--
			04-19-95	--	593	--	13	--
[2]16	T136NR39WS16AAA	34	07-18-94	--	468	--	9.5	--
			04-12-95	27.03	507	--	9.6	--
[2]17	T136NR39WS15BDD	33	07-20-94	26.31	407	--	9.9	--
			04-10-95	26.50	432	--	12	--
[4]18	T136NR39WS15CAA	<25	06-09-94	--	508	--	6.0	--
			04-19-95	--	499	--	4.5	--
[4]19	T136NR39WS19ADC	90	06-17-94	--	784	--	6.1	--
			04-25-95	--	792	--	5.6	--
[2]20	T136NR39WS17DDD	9	07-12-94	7.34	559	7.3	3.1	265
			04-12-95	--	610	--	2.9	--
[5]21	T136NR39WS13CBB	32	06-15-94	--	395	--	10	--
			04-11-95	--	407	--	9.4	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[4]8	06-29-94	5.6	.02	.02	<.20	<.01	6.7	<.10
	4/26/95	6.3	.02	<.02	--	<.01	7.4	<.10
[2]9	07-25-94	.70	<.01	.03	.30	<.01	3.2	<.10
	04-13-95	--	<.01	<.02	--	<.01	2.0	<.10
[4]10	06-17-94	4.7	.01	.03	--	<.01	2.3	<.10
	04-19-95	1.2	<.01	.11	--	<.01	<.05	<.10
[4]11	06-16-94	7.4	.04	<.01	--	<.01	14	<.10
	04-19-95	13	.05	<.02	--	<.01	14	<.10
[4]12	06-23-94	39	.05	.01	<.20	<.01	.95	<.10
	07-14-94	44	.06	.01	<.20	<.01	1.5	<.10
[4]13	06-14-94	37	.06	.01	--	<.01	.84	<.10
	04-24-95	36	.05	<.02	--	<.01	1.0	<.10
[4]14	06-15-94	16	.07	.03	--	<.01	<.05	<.10
	04-24-95	16	.03	.03	--	<.01	<.05	<.10
[4]15	06-14-94	14	<.01	.02	--	.01	.37	<.10
	04-19-95	9.6	<.01	<.02	--	<.01	<.05	<.10
[2]16	07-18-94	1.7	.01	.02	--	.01	14.0	<.10
	04-12-95	4.9	<.01	<.02	--	.01	20.0	<.10
[2]17	07-20-94	1.9	<.01	.02	--	.03	14.0	<.10
	04-10-95	2.1	<.01	<.02	--	<.01	13.0	<.10
[4]18	06-09-94	13	<.01	.02	--	<.01	9.90	<.10
	04-19-95	7.8	<.01	<.02	--	<.01	7.30	<.10
[4]19	06-17-94	28	<.01	<.01	--	<.01	28.0	<.10
	04-25-95	31	.01	<.02	--	<.01	29.0	<.10
[2]20	07-12-94	14	<.01	.03	.200	<.01	0.12	.30
	04-12-95	14	.02	<.02	--	<.01	<.05	<.10
[5]21	06-15-94	4.9	<.01	<.01	--	<.01	5.6	.70
	04-11-95	7.3	.01	<.02	--	<.01	6.4	.50

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[5]22	T136NR39WS13DBB	30	06-15-94	--	1930	--	9.3	--
			04-11-95	--	493	--	7.0	--
[2]23	T136NR39WS29BBB	9	06-30-94	2.94	575	6.9	0.9	300
			04-12-95	5.24	360	--	--	--
[2]24	T136NR39WS31ADC	25	06-30-94	11.57	585	7.5	3.3	198
			07-14-94	11.68	584	7.5	3.2	196
			08-09-94	11.60	587	7.7	3.6	194
			05-23-95	12.61	593	7.5	3.3	--
			06-21-95	12.13	594	7.5	3.5	--
			07-11-95	11.95	597	7.8	4.3	--
			09-06-95	11.83	596	7.4	4.1	--
[2]25	T137NR39WS22DDD	18	07-25-94	14.73	943	7.6	7.7	177
[2]26	T136NR39WS25DAD	25	07-12-94	15.14	877	7.4	9.3	159
			08-10-94	15.86	907	7.6	7.7	162
			05-23-95	15.81	845	7.5	6.8	--
			06-21-95	16.19	840	7.4	6.8	--
			07-12-95	16.70	841	7.5	8.1	--
			09-06-95	17.28	803	7.4	8.0	--
[2]27	T136NR38WS29BBB	33	07-12-94	27.81	537	7.4	6.7	199
			04-12-95	31.18	478	--	9.5	--
[2]28	T136NR39WS36BCD	29	06-28-94	22.48	733	7.4	9.2	300
			07-26-94	22.37	744	7.5	9.2	306
			04-13-95	20.07	665	--	11	--
[2]29	T136NR38WS32DDD	14	07-13-94	9.00	524	7.6	8.9	209
			04-12-95	13.63	443	--	9.8	--
[2]30	T136NR38WS29CCA	24	06-29-94	14.26	568	7.5	1.0	269
			04-12-95	18.72	572	--	1.2	--
[4]31	T136NR38WS32ABA	20	12-15-93	--	655	--	0.70	--
			04-18-95	--	659	--	.10	--
[3]32	T135NR39WS11BBB	41	07-11-94	22.05	857	7.4	6.4	264
			04-13-95	26.97	861	--	7.4	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[5]22	06-15-94	240	0.01	<0.01	--	<0.01	35	3.0
	04-11-95	32	.24	<.02	--	<.01	4.6	1.0
[2]23	06-30-94	3.8	.05	.14	.600	<.01	<.05	<.10
	04-12-95	4.1	.05	.07	--	.01	.13	<.10
[2]24	06-30-94	15	<.01	.04	<.200	.02	13	<.10
	07-14-94	15	.12	.02	<.200	<.02	14	--
	08-09-94	16	<.01	.04	<.200	.02	15	--
	05-23-95	16	.03	<.02	<.200	.01	13	--
	06-21-95	16	.03	<.02	<.200	.01	14	--
	07-11-95	16	.02	<.02	<.200	.02	14	--
	09-06-95	16	.03	<.02	<.020	.02	15	--
[2]25	07-25-94	50	<.01	.02	.30	<.01	46	<.10
[2]26	07-12-94	41	<.01	.04	<.20	<.01	43	3.0
	08-10-94	44	<.01	.02	<.20	<.01	43	--
	05-23-95	35	<.01	.02	<.20	<.01	40	--
	06-21-95	35	.02	.02	<.20	<.01	19	--
	07-12-95	35	.01	.04	<.20	<.01	37	--
	09-06-95	33	<.01	.02	<.20	<.01	38	--
[2]27	07-12-94	10	<.01	.02	<.20	<.01	11	.20
	04-12-95	6.1	.02	<.02	--	<.01	13	.10
[2]28	06-28-94	15	.01	.02	<.20	<.01	12	<.10
	07-26-94	17	.02	.01	<.20	<.01	13	--
	04-13-95	--	.02	<.02	--	<.01	7.0	<.10
[2]29	07-13-94	1.0	<.01	<.01	<.20	<.01	13	<.10
	04-12-95	.70	<.01	<.02	--	<.01	7.3	<.10
[2]30	06-29-94	16	<.01	.02	<.20	<.01	<.05	<.10
	04-12-95	20	<.01	<.02	--	<.01	.12	<.10
[4]31	12-15-93	21	.04	.12	--	.02	<.05	<.10
	04-18-95	24	.03	.11	--	<.01	<.05	<.10
[3]32	07-11-94	53	<.01	.01	.20	<.01	16	<.10
	04-13-95	54	<.01	<.02	--	<.01	17	<.10

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[2]33	T135NR38WS07CBD	9	07-13-94	4.43	470	6.8	1.1	179
			04-13-95	7.47	439	--	3.5	--
[2]34	T135NR38WS07ADC	10	07-13-94	4.50	360	7.0	3.8	113
			04-13-95	8.57	226	--	--	--
[4]35	T135NR40WS08CCC	<25	06-13-94	--	511	--	0.20	--
			05-30-95	--	--	--	--	--
[4]36	T135NR40WS02DDC	<25	06-13-94	--	705	--	7.2	--
			05-11-95	--	--	--	--	--
[4]37	T134NR42WS12DDA	80	12-17-93	--	1,730	--	.30	--
			04-19-95	--	1,800	--	3.8	--
[3]38	T134NR41WS08CCC	43	06-17-94	--	207	--	6.9	--
			04-19-95	--	262	--	.40	--
[4]39	T134NR41WS14CAC	16	12-16-93	--	582	--	10	--
[4]40	T134NR41WS14DAB	23	06-14-94	--	611	--	6.8	--
			05-10-95	--	513	--	--	--
[4]41	T134NR40WS30CAB	70	12-16-93	--	744	--	.10	--
			05-10-95	--	763	--	--	--
[4]42	T134NR40WS15AAA	37	06-09-94	--	537	--	3.0	--
			05-10-95	--	532	--	3.4	--
[2]43	T135NR39WS28ADD	13	07-20-94	10.12	244	--	4.8	--
			04-14-95	10.26	195	--	9.2	--
[4]44	T134NR39WS03BAD	25	12-15-93	--	545	--	3.7	--
			07-20-94	--	536	--	2.5	--
			04-18-95	--	661	--	3.9	--
[4]45	T134NR39WS01ABC	60	12-15-93	--	631	--	0.1	--
			04-18-95	--	621	--	.10	--
[3]46	T134NR39WS01ACD	53	06-16-94	--	908	--	.10	--
			04-18-95	--	894	--	.10	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[2]33	07-13-94	39	0.04	0.03	<0.20	<0.01	<0.05	<0.1
	04-13-95	--	.03	.02	--	<.01	.16	<.10
[2]34	07-13-94	2.3	.20	.01	.30	<.01	15	<.10
	04-13-95	--	.25	<.02	--	<.01	5.8	<.10
[4]35	06-13-94	1.0	.06	.29	--	<.01	.11	<.10
	05-30-95	1.1	.02	.25	--	<.01	<.05	--
[4]36	06-13-94	26	<.01	<.01	--	<.01	2.7	.30
	05-11-95	21	.01	<.02	--	<.01	23.	.40
[4]37	12-17-93	160	<.01	1.0	--	.04	50.	4.0
	04-19-95	100	<.01	.31	--	.43	76.	5.0
[3]38	06-17-94	12	<.01	.11	--	.10	5.9	<.10
	04-19-95	5.3	<.01	1.1	--	.04	.46	<.10
[4]39	12-16-93	19	.02	.04	--	<.01	13	<.10
[4]40	06-14-94	10	<.01	.02	--	<.01	20	.30
	05-10-95	7.3	.01	<.02	--	<.01	15	--
[4]41	12-16-93	4.8	.04	.28	--	<.01	<.05	<.10
	05-10-95	--	.02	.20	--	<.01	<.05	.10
[4]42	06-09-94	22	.08	.02	--	<.01	16	<.10
	05-10-95	13	.08	<.02	--	<.01	18	.10
[2]43	07-20-94	1.0	.04	.03	--	<.01	4.9	<.10
	04-14-95	.50	.02	.02	--	<.01	2.5	<.10
[4]44	12-15-93	6.8	.02	.03	--	.02	6.5	<.10
	07-20-94	7.7	.01	.01	--	<.01	7.6	<.10
	04-18-95	11	.01	<.02	--	<.01	17	<.10
[4]45	12-15-93	17	<.01	.27	--	.02	.14	<.10
	04-18-95	14	<.01	.23	--	<.01	<.05	<.10
[3]46	06-16-94	29	<.01	.02	--	.30	33	.30
	04-18-95	37	<.01	.08	--	.07	.53	.30

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[4]47	T134NR39WS15CCA	<25	07-20-94	--	851	--	3.2	--
			04-20-95	--	889	--	1.4	--
[4]48	T134NR39WS15AAC	<25	06-10-94	--	575	--	.40	--
			04-18-95	--	584	--	.10	--
[4]49	T134NR39WS24DCC	<25	07-20-94	--	449	--	4.5	--
			04-18-95	--	458	--	3.9	--
[4]50	T133NR40WS08CBC	<25	06-14-94	--	619	--	3.8	--
			05-10-95	--	567	--	--	--
[4]51	T133NR40WS21CAD	<25	06-08-94	--	460	--	.60	--
			05-31-95	--	402	--	1.0	--
[4]52	T133NR40WS11ADC	<25	06-14-94	--	586	--	.10	--
			04-18-95	--	592	--	.10	--
[4]53	T133NR40WS26BDA	<25	07-20-94	--	406	--	0.10	--
			04-20-95	--	362	--	.10	--
[4]54	T133NR39WS17CDD	38	07-19-94	--	511	--	.	--
			04-20-95	--	510	--	.10	--
[2]55	T133NR39WS32BDA	35	07-19-94	--	439	--	1.1	--
			04-20-95	33.21	502	--	9.1	--
[3]56	T133NR39WS10CCD	42	06-16-94	--	544	--	.90	--
			04-20-95	--	441	--	.30	--
[4]57	T133NR39WS10ADC	83	12-16-93	--	427	--	.20	--
[4]58	T132NR40WS15CCD	32	06-08-94	--	568	--	5.7	--
			05-10-95	--	583	--	--	--
[4]59	T132NR39WS29CBB	45	12-16-93	--	328	--	.10	--
			04-20-95	--	439	--	.10	--
[4]60	T134NR36WS03DCD	20	12-15-93	--	672	--	10	--
			07-21-94	--	639	--	8.5	--
			04-17-95	--	778	--	8.3	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[4]47	07-20-94	70	<.01	.03	--	<.01	3.8	<.10
	04-20-95	82	<.01	<.02	--	<.01	1.8	<.10
[4]48	06-10-94	19	.01	.03	--	.02	7.0	<.10
	04-18-95	19	.02	.02	--	.05	3.1	<.10
[4]49	07-20-94	3.0	<.01	.02	--	<.01	5.0	<.10
	04-18-95	3.3	<.01	<.02	--	<.01	4.7	<.10
[4]50	06-14-94	15	<.01	.01	--	<.01	13	<.10
	05-10-95	12	<.01	<.02	--	<.01	8.1	.20
[4]51	06-08-94	6.4	.02	.19	--	<.01	<.05	<.10
	05-31-95	5.2	.01	.11	--	<.01	<.05	--
[4]52	06-14-94	9.3	.01	.13	--	<.01	.13	<.10
	04-18-95	8.4	.01	.13	--	.01	<.05	<.10
[4]53	07-20-94	10	.05	.03	--	<.01	.07	<.10
	04-20-95	4.7	.05	.03	--	<.01	<.05	<.10
[4]54	07-19-94	--	.07	1.0	--	<.01	<.05	<.10
	04-20-95	.60	.23	1.1	--	<.01	<.05	<.10
[2]55	07-19-94	1.8	.01	.01	--	<.01	1.1	<.10
	04-20-95	10	<.01	<.02	--	<.01	5.7	<.10
[3]56	06-16-94	1.0	<.01	.13	--	<.01	<.05	<.10
	04-20-95	1.0	<.01	.07	--	<.01	<.05	<.10
[4]57	12-16-93	.90	.07	.16	--	<.01	<.05	<.10
[4]58	06-08-94	4.4	<.01	.02	--	<.01	1.20	<.10
	05-10-95	5.5	<.01	<.02	--	<.01	1.10	.10
[4]59	12-16-93	3.9	.03	1.2	--	<.01	<.05	<.10
	04-20-95	6.6	.04	.40	--	<.01	<.05	<.10
[4]60	12-15-93	46	<.01	.03	--	.02	16	.30
	07-21-94	48	<.01	.03	--	<.01	15	.20
	04-17-95	71	<.01	<.02	--	<.01	17	.20

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Location	Well depth (feet below land surface)	Date	Water-level depth (feet below land surface)	Specific conductance, lab (µS/cm at 25°C)	pH, lab (standard units)	Oxygen, dissolved, field (mg/L)	Alkalinity, total, field (mg/L as $CaCO_3$)
[4]61	T134NR36WS01BBA	39	06-17-94	--	565	--	.10	--
			04-17-95	--	539	--	.10	--
[2]62	T133NR37WS10CDD	14	07-19-94	--	744	--	6.4	--
			04-26-95	--	512	--	6.3	--
[4]63	T133NR36WS01CBC	17	07-19-94	--	699	--	0.60	--
			04-25-95	--	578	--	.10	--
[4]64	T132NR36WS03DCA	<25	06-09-94	--	647	--	5.5	--
			04-25-95	--	647	--	5.5	--
[4]65	T132NR37WS28CDC	<25	06-08-94	--	579	--	8.8	--
			04-26-95	--	595	--	7.9	--
[4]66	T132NR36WS23BBA	<25	06-07-94	--	509	--	.10	--
			04-26-95	--	523	--	.10	--
[4]67	T132NR36WS30CCC	<25	06-09-94	--	634	--	.10	--
			05-09-95	--	671	--	--	--
[4]68	T132NR36WS22CBB	<25	06-09-94	--	470	--	8.2	--
			04-27-95	--	524	--	8.3	--
[4]69	T132NR36WS24DDD	28	06-07-94	--	679	--	.30	--
			04-27-95	--	788	--	.30	--
[4]70	T131NR37WS17BDB	<25	06-09-94	--	620	--	2.3	--
			05-09-95	--	676	--	--	--
[4]71	T131NR37WS01CDB	<25	06-10-94	--	817	--	.10	--
			05-09-95	--	769	--	--	--
[4]72	T131NR36WS19AAA	18	12-16-93	--	655	--	.70	--
			06-07-94	--	702	--	1.6	--
			05-09-95	--	638	--	--	--
[4]73	T131NR36WS20ACC	<25	06-07-94	--	702	--	.80	--
			04-27-95	--	753	--	1.0	--

Table 5.--Selected properties, phosphorus and nitrogen nutrients, and triazine herbicides in water from wells completed in surficial aquifers, eastern Otter Tail County, 1993–95--(Continued)

Site identifier for wells (fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, ammonium + organic, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	Triazine herbicide compounds[1], dissolved (µg/L as atrazine)
[4]61	06-17-94	7.7	0.07	0.62	--	<0.01	<0.05	<0.10
	04-17-95	7.9	.03	.67	--	<.01	<.05	<.10
[2]62	07-19-94	16	<.01	.03	--	.04	29	.10
	04-26-95	5.4	<.01	<.02	--	<.01	8.0	.80
[4]63	07-19-94	7.1	0.01	0.02	--	<0.01	5.6	0.40
	04-25-95	3.9	<.01	<.02	--	<.01	4.5	.90
[4]64	06-09-94	17	<.01	.01	--	<.01	19	.10
	04-25-95	16	<.01	<.02	--	<.01	18	.20
[4]65	06-08-94	13	.01	<.01	--	<.01	18.0	<.10
	04-26-95	13	.01	<.02	--	<.01	20.0	<.10
[4]66	06-07-94	1.2	.06	.43	--	<.01	<0.05	<.10
	04-26-95	.90	.02	.40	--	<.01	<.05	<.10
[4]67	06-09-94	5.1	.04	.13	--	.01	.44	<.10
	05-09-95	5.2	<.01	.11	--	<.01	.05	.10
[4]68	06-09-94	5.6	<.01	.02	--	<.01	9.0	<.10
	04-27-95	6.0	<.01	<.02	--	<.01	8.9	<.10
[4]69	06-07-94	16	.07	.56	--	<.01	.66	.10
	04-27-95	27	.04	.84	--	<.01	<.05	.10
[4]70	06-09-94	12	.01	.02	--	<.01	9.9	.20
	05-09-95	15	.01	<.02	--	<.01	13	.30
[4]71	06-10-94	8.2	.20	.03	--	.08	21	3.0
	05-09-95	4.4	.85	.02	--	.04	7.7	5.0
[4]72	12-16-93	23	<.01	.04	--	<.01	15	<.10
	06-07-94	22	<.01	.02	--	<.01	13	<.10
	05-09-95	20	<.01	<.02	--	<.01	13	<.10
[4]73	06-07-94	22	<.01	.01	--	<.01	15	.20
	04-27-95	25	<.01	<.02	--	<.01	19	.20

[1] Results determined by immunoassay method.
[2] Indicates U.S. Geological Survey observation well.
[3] Indicates Minnesota Department of Natural Resources observation well.
[4] Indicates private-use well.
[5] Indicates private observation well.

Table 6.--Selected properties, phosphorus and nitrogen nutrients, and stream discharge at streamflow gaging stations on the Otter Tail and Toad Rivers near two inlets and one outlet for Big Pine Lake, eastern Otter Tail County, 1994–95

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

Site identifier for stream-flow gaging stations (fig. 1)	Date	Discharge, instantaneous (cubic feet per second)	Specific conductance, field (µS/cm at 25°C)	pH, field (standard units)	Phosphorus, ortho, dissolved (mg/L)	Phosphorus, total (mg/L)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)
1 (Otter Tail River inlet to Big Pine Lake)	03-15-95	--	397	7.8	<0.010	0.008	0.030	<0.01	0.31
	03-28-95	--	412	8.0	<.01	.012	.100	<.01	.33
	04-13-95	--	390	8.1	<.010	.022	.020	.02	.20
	04-20-95	269	--	--	--	--	--	--	--
	05-03-95	--	588	8.0	.01	.022	<.015	<.01	.17
	05-17-95	--	417	8.5	<.01	.012	<.015	<.01	.08
	05-31-95	--	374	8.7	<.01	.019	.030	<.01	<.05
	06-06-95	195	--	--	--	--	--	--	--
	06-14-95	--	364	8.7	<.01	.011	.020	<.01	<.05
	07-05-95	--	353	8.4	<.01	.013	.020	<.01	<.05
	07-12-95	100	331	8.7	<.01	.017	.020	<.01	<.05
	07-26-95	--	310	8.8	<.01	.022	<.015	<.01	<.05
	08-09-95	69	323	8.6	<.01	.018	.020	<.01	<.05
	08-23-95	--	321	8.5	<.01	.019	<.015	<.01	<.05
	09-07-95	--	312	8.2	<.01	.023	.040	<.01	<.05
	09-20-95	--	325	8.1	<.01	.027	<.015	<.01	<.05
	10-18-95	--	296	7.7	<.01	.020	.040	<.01	.07
	10-31-95	190	391	8.3	<.01	.014	.040	<.01	<.05
	11-21-95	--	325	8.3	<.01	.008	.020	<.01	.07
	01-10-96	--	373	8.0	.01	.012	.070	.01	.19
	02-06-96	--	390	8.6	<.01	.011	<.015	<.01	.28
	03-12-96	--	410	6.7	.01	.012	.050	<.01	.52

Table 6.--Selected properties, phosphorus and nitrogen nutrients, and stream discharge at streamflow gaging stations on the Otter Tail and Toad Rivers near two inlets and one outlet for Big Pine Lake, eastern Otter Tail County, 1994–95—Continued

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

Site identifier for stream-flow gaging stations (fig. 1)	Date	Discharge, instantaneous (cubic feet per second)	Specific conductance, field (µS/cm at 25°C)	pH, field (standard units)	Phosphorus, ortho, dissolved (mg/L)	Phosphorus, total (mg/L)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)
2 (Toad River inlet to Big Pine Lake)	03-15-95	120	263	7.8	0.12	0.160	0.750	0.03	0.60
	03-20-95	212	305	7.8	.06	.170	.310	.02	.42
	03-28-95	132	401	8.0	.02	.029	.170	.01	.19
	04-03-95	--	370	8.0	<.01	.063	.060	.01	.16
	04-13-95	77	438	8.2	<.01	.040	.040	.02	.13
	04-19-95	--	438	8.1	<.01	.012	.060	.01	.08
	05-03-95	--	950	7.9	.02	.035	.080	<.01	.11
	05-10-95	--	417	8.3	.01	.063	.030	<.01	<.05
	05-17-95	89	449	8.2	.02	.043	.030	<.01	<.05
	05-24-95	--	--	--	.01	.050	.030	<.01	<.05
	05-31-95	--	481	8.6	.02	.050	.020	<.01	<.05
	06-07-95	39	524	8.3	.03	.066	.110	.03	.18
	06-14-95	--	471	8.2	.03	.062	.070	.02	.16
	06-20-95	--	465	8.3	.05	.071	.060	.02	.21
	06-28-95	--	631	8.3	.03	.075	.040	.02	.16
	07-05-95	60	380	7.9	.03	.088	.060	<.01	.06
	07-06-95	--	413	8.3	.04	.092	.030	.01	.20
	07-12-95	59	503	8.1	.04	.093	.040	.01	<.05
	07-19-95	--	422	8.1	.04	.083	.100	.02	.13
	07-26-95	--	438	8.5	.04	.073	<.015	.01	.11
	08-02-95	--	428	8.5	.04	.065	.030	.01	.19
	08-07-95	11	--	--	--	--	--	--	--
	08-09-95	--	374	8.2	.05	.076	.060	.03	.30
	08-16-95	--	353	7.9	.05	.079	.070	.02	.33
	08-23-95	--	428	8.1	.05	.081	.030	<.01	.26
	08-25-95	31	--	--	--	--	--	--	--
	08-29-95	--	396	7.5	.04	.140	.040	<.01	.05

Table 6.--Selected properties, phosphorus and nitrogen nutrients, and stream discharge at streamflow gaging stations on the Otter Tail and Toad Rivers near two inlets and one outlet for Big Pine Lake, eastern Otter Tail County, 1994–95—Continued

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

Site identifier for stream-flow gaging stations (fig. 1)	Date	Discharge, instantaneous (cubic feet per second)	Specific conductance, field (µS/cm at 25°C)	pH, field (standard units)	Phosphorus, ortho, dissolved (mg/L)	Phosphorus, total (mg/L)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)
	09-07-95	--	428	7.7	0.07	0.150	0.220	<0.01	0.07
	09-12-95	--	385	7.7	.05	.095	.150	.01	.15
	09-20-95	--	444	7.9	.04	.063	.140	.04	.48
	09-26-95	--	438	6.9	.02	.039	.050	.02	.38
	10-04-95	63	564	8.0	.03	.060	.030	<.01	.08
	10-18-95	89	439	7.9	.01	.041	<.015	<.01	.05
	11-01-95	76	433	7.6	<.01	.017	<.015	<.01	<.05
	11-21-95	46	483	7.6	<.01	.018	.020	<.01	.13
	01-11-96	24	532	7.6	.01	.039	.190	.01	.34
	02-06-96	20	546	8.2	.02	.046	.160	<.01	.41
	03-12-96	25	532	7.0	.02	.039	.210	<.01	.51
3 (Otter Tail River outlet from Big Pine Lake)	03-16-95	--	396	8.0	<.01	.018	.140	<.01	.15
	03-28-95	--	347	8.1	.02	.031	.190	.02	.30
	04-13-95	--	358	8.3	<.01	.028	.030	.03	.11
	04-20-95	420	--	--	--	--	--	--	--
	05-10-95	--	331	8.6	<.01	.025	.030	<.01	.08
	05-24-95	--	417	--	<.01	.021	.030	<.01	<.05
	06-05-95	255	--	--	--	--	--	--	--
	06-07-95	--	396	8.3	<.01	.022	.030	<.01	<.05
	06-20-95	--	412	8.5	<.01	.012	.040	<.01	<.05
	06-28-95	--	417	8.2	<.01	.017	.040	.01	<.05
	07-11-95	181	--	--	--	--	---	--	--
	07-19-95	--	312	8.6	<.01	.020	.030	<.01	<.05
	08-02-95	--	317	8.7	<.01	.017	.020	<.01	.12
	08-16-95	--	291	8.4	<.01	.022	.060	<.01	<.05
	08-25-95	131	--	--	--	--	--	--	--

Table 6.--Selected properties, phosphorus and nitrogen nutrients, and stream discharge at streamflow gaging stations on the Otter Tail and Toad Rivers near two inlets and one outlet for Big Pine Lake, eastern Otter Tail County, 1994–95—Continued

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

Site identifier for stream-flow gaging stations (fig. 1)	Date	Discharge, instantaneous (cubic feet per second)	Specific conductance, field (µS/cm at 25°C)	pH, field (standard units)	Phosphorus, ortho, dissolved (mg/L)	Phosphorus, total (mg/L)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate, dissolved (mg/L as N)
	08-29-95	--	312	8.2	<0.01	0.005	0.040	<0.01	<0.05
	09-12-95	--	299	8.0	<.01	.020	<.015	<.01	<.05
	09-26-95	--	312	8.1	.02	.020	.020	<.01	<.05
	10-18-95	--	310	8.1	<.01	.027	.040	<.01	<.05
	11-01-95	--	315	8.2	<.01	.012	.030	<.01	<.05
	11-21-95	--	458	8.5	<.01	.006	.030	<.01	<.05
	01-10-96	--	368	8.0	<.01	.011	.070	<.01	.32
	02-07-96	--	371	8.5	.01	.016	.050	<.01	.13
	03-12-96	--	376	7.4	<.01	.015	.040	<.01	.28