WATER RESOURCES OF THE RED LAKE INDIAN RESERVATION, NORTHWESTERN MINNESOTA

By James F. Ruhl

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound unit	By	To obtain SI unit
foot (ft)	0.3048	meter
square foot per day (ft^2/d)	0.09290	square meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.4	millimeter
acre	0.4047	hectare
degree Fahrenheit (°F)	°C = 5/9 x (°F - 32)	degree Celsius

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

DEFINITION OF TERMS

(From Skougstad and others, p. 4, 1979)

Dissolved. Pertaining to the material in a representative water sample that passes through a 0.45-micrometer membrane filter. This is a convenient operational definition used by the Federal agencies that collect water data. Determinations of "dissolved" constituents are made on subsamples of the filtrate.

Total Recoverable. The amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment, and thus the determination represents something less than the "total" amount (that is, less than 95 percent) of the constituent present in the dissolved and suspended phases of the sample.

Total. The total amount of the given constituent in a representative water-suspended sediment sample, regardless of the constituent's physical or chemical form. This term is used only when the analytical procedure assures measurement of at least 95 percent of the constituent present in both the dissolved and suspended phases of the sample.

Suspended Total. The total amount of a given constituent in the part of a representative sediment sample that is retained on a 0.45-micrometer membrane filter. This term is used only when the analytical procedure assures measurement of at least 95 percent of the constituent determined.

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ABSTRACT

This report presents the results of a study by the U.S. Geological Survey, done in cooperation with the Red Lake Indian Reservation Tribal Council, to evaluate the water resources of the contiguous Red Lake Indian Reservation. Water resources of the contiguous Red Lake Indian Reservation meet the present (1989) needs for potable supply and other household uses. In addition, they provide ecological, recreational, and aesthetic benefits.

Mean annual precipitation in the study area is 22.7 inches. Approximately 90 percent of this precipitation returns to the atmosphere by evapotranspiration; the remainder becomes runoff. Some of the precipitation that contributes to evapotranspiration and runoff initially infiltrates the land surface and recharges the ground-water reservoir. The net recharge to ground water generally ranges from roughly 0.5 to 1.35 inches per year. Assuming negligible long-term changes in the amount of ground water in storage, the recharge to and discharge from the ground-water reservoir balance each other over time.

Glacial-drift aquifers are the source of ground water in the Red Lake Indian Reservation. The most significant sources of ground-water supply are confined glacial-drift aquifers, which are discontinuous lenses of sand and gravel 50 to 150 feet below land surface. Estimated yields of wells completed in these aquifers range from approximately 20 to 240 gallons per minute.

Lower and Upper Red Lakes, which extend over one fourth of the study area, are the largest surface-water bodies. The study area also includes streams and many smaller lakes. Most of the streams drain into Lower and Upper Red Lakes, and the lakes discharge into the Red Lake River. Spring snowmelt generally causes peak flows in the streams. Low-flow conditions commonly occur during midsummer to early fall and winter.

The quality of ground water is suitable for drinking and other household uses, and the quality of the surface water generally meets U.S. Environmental Protection Agency criteria necessary for the maintenance of aquatic life. The major ions in both ground and surface water are calcium, magnesium, and bicarbonate. Lower and Upper Red Lakes are eutrophic to mesotrophic on the basis of their summer Secchi disk-transparency readings, which ranged from 2.6 to 8.2 feet. The concentration of total organic carbon in samples from Lower and Upper Red Lakes and four streams were below or, in the case of one stream, about equal to 30 milligrams per liter, which is indicative of water little affected by human activities. The sample with the highest organic carbon content was collected from a stream that drained peatlands, which were probably sources of organic matter in the runoff. The concentration of nitrite plus nitrate in samples collected from Lower and Upper Red Lakes in late summer was below 0.01 milligrams per liter, which is characteristic of water uncontaminated by animal wastes. Total phosphorus in these samples ranged from 0.01 to 0.02 milligrams per liter. Most of this phosphorus was in the particulate organic fraction because of the abundance of phytoplankton.

INTRODUCTION

In 1978, Congress directed the Bureau of Indian Affairs to review Indian water-rights issues in Reservations throughout the United States. Information about the water resources of the Red Lake Indian Reservation in northwestern Minnesota was insufficient to conduct this review as required by the Federal mandate. Consequently, the Minnesota District of the U.S. Geological Survey, in cooperation with the Red Lake Indian Reservation Tribal Council, conducted a study of the Reservation's water resources.

Purpose and Scope

This report describes the water resources of the contiguous area of the Red Lake Indian Reservation. This report contains (1) an evaluation of the availability of ground water in terms of hydraulic properties of the aquifers, (2) directions of ground-water flow, (3) estimates of the streamflow characteristics, and (4) a characterization of the quality of the ground and surface water. A brief description of the hydrogeology of sand and gravel aquifers in the study area also is included.

A literature survey summarized available information about the natural resources in the study area. Published materials, including many of those cited in the section describing previous investigations, provided information about the climate, soils, geology, hydrogeology, surface water, and water quality. Data collected in the field during the course of the study supplied additional information.

Evaluation of data from 10 test holes drilled for this project and from approximately 100 commercial drillers' logs furnished hydrogeologic information about the sand and gravel aquifers. Stage-discharge data collected at gages on four streams were used to estimate flow characteristics during the 1986 water year. Analysis of samples collected from four streams, five wells, and Lower and Upper Red Lakes provided data about the quality of water.

Physical Setting

The Red Lake Indian Reservation, located in northwestern Minnesota (fig. 1), comprises about 794,000 acres. Approximately 637,000 acres form a contiguous area in Beltrami and Clearwater Counties; this was the area of study for this project. The remainder of the Reservation outside the contiguous area is in scattered tracts of trust land located in Lake of the Woods and Roseau Counties, and in the northern part of Beltrami County (fig. 1).

Approximately 4,500 people live in the contiguous area of the Reservation (Bud Anderson, Red Lake Indian Reservation, personal commun., 1989). Most inhabitants in the study area live in and around the communities of Red Lake and Redby, which are located on the south side of Lower Red Lake, and the community of Ponemah, which is located on the peninsula that separates Lower and Upper Red Lakes.

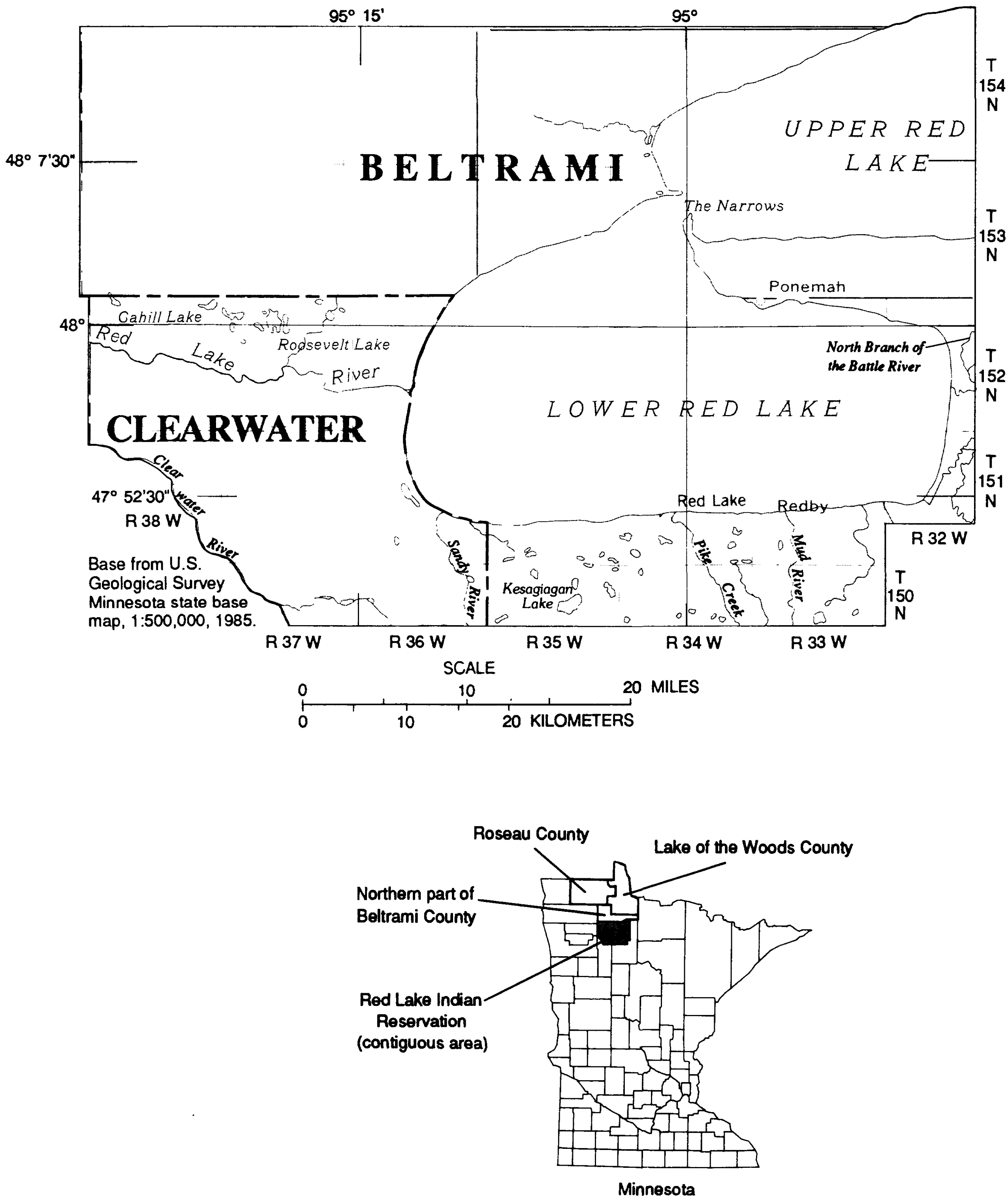


Figure 1.--Location of contiguous Red Lake Indian Reservation and counties containing scattered tracts of trust lands.

The study area lies within the watershed of the Red River of the North, which flows into Hudson Bay. Streams in the eastern half of the study area discharge into Lower and Upper Red Lakes, which discharge into the Red Lake River from the western side of Lower Red Lake (fig. 2). The Clearwater River, which is a tributary to the Red Lake River, flows along the southwestern boundary of the Reservation.

Land uses in the study area reflect the natural resources. Aspen and red pine grow on commercial forest land that covers slightly more than half of the study area. The remainder of the land in the study area is mainly wetlands, noncommercial forest land, and peat bogs. Wild rice is grown on about 15,000 acres in the western part of the study area; the rest of the study area is marginally suitable for agriculture. Lower and Upper Red Lakes, which extend over approximately one third of the study area, provide a commercial fishery of walleye pike.

Previous Investigations

Only reconnaissance-type investigations have been conducted in and around the Red Lake Indian Reservation study area. A hydrologic atlas summarizes the climate, hydrogeology, surface-water resources, and water quality of the Red Lake River drainage area, which includes the study area (Bidwell and others, 1970). Soil-survey atlases contain maps that show glacial geomorphic features and soil types (University of Minnesota Agricultural Experiment Station, 1980a, 1980b).

Many previous natural-resource investigations in the study area addressed peatland ecology. Heinselman (1963) described the development of the Red Lake peatlands and their present-day vegetation patterns. Proposals in the mid-1970's to harvest peat as an alternative energy source led to studies of peatlands. Brooks (1978) described the hydrologic characteristics of peatlands near the Red Lake Indian Reservation and evaluated the potential impacts of peat harvesting on their hydrology. The Minnesota Department of Natural Resources supported a multidisciplinary study of peat harvesting in the Red Lake Indian Reservation and the potential effects of peat harvesting on the Reservation's resources, including land, air, water, fish and wildlife, wild rice, and forests (Walter Butler Company, 1978).

Clausen and others (1981) summarized the results of field studies conducted on the hydrology of a peatland that is approximately 10 mi (miles) northeast of the study area. This report includes a water budget and provides surface-water quality data for the peatland. Siegel (1981) described the hydrogeologic setting of peatlands that include the northern part of the study area. His report assessed the relation of vegetation patterns to the quality and movement of the ground water. Verry (1975) and Clausen and Brooks (1983) conducted water-quality studies of surface runoff from peatlands.

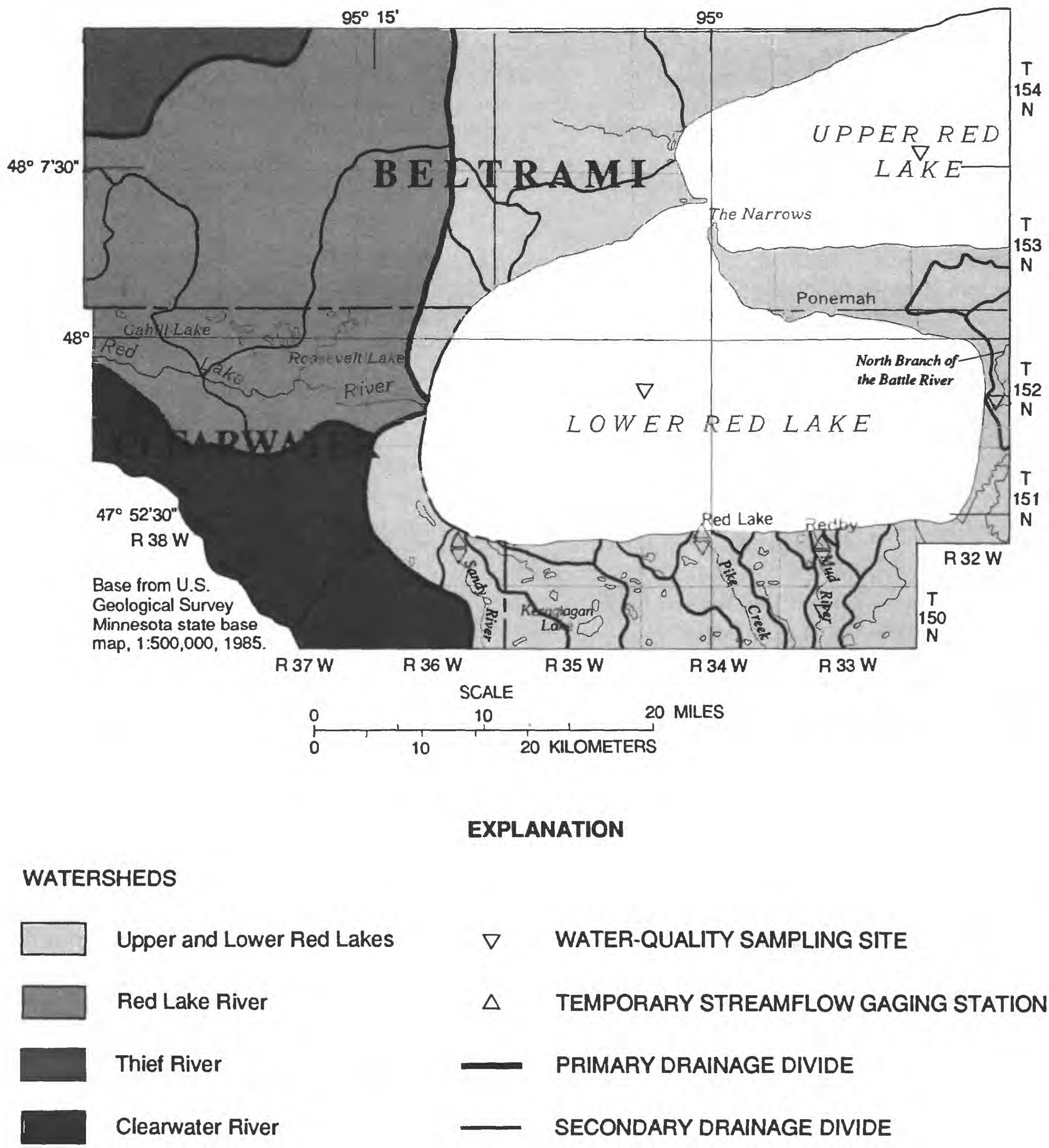


Figure 2.--Watersheds, temporary streamflow gaging stations, and water-quality sampling sites in the Red Lake Indian Reservation study area.

Studies of the flow characteristics of streams in the study area are unavailable, although Bidwell and others (1970) provided recurrence-interval flows and flow-duration curves for the Red Lake and Clearwater Rivers at sites downstream from the Reservation. Payne (1989) studied the impact of water withdrawals from the Clearwater River on streamflow. His report described the effect of withdrawals for wild rice irrigation on the streamflow of the Clearwater River along the southwestern part of the Reservation.

Methods of Investigation

A literature survey provided the basis for a preliminary evaluation of the study area. Data on the hydrogeology, streamflow characteristics, and water quality were collected in the field during the course of the study. Additional hydrogeologic data were compiled from well log records maintained by the Indian Public Health Service and the Minnesota Geological Survey.

Estimates of hydraulic properties of the aquifers were inferred from data obtained from drillers' logs. Most of the wells described in the logs have 6-in. (inch) diameters and are open to only part of the thickness of the aquifer. The drawdown data used to compute specific capacity were collected during the development of the wells. Typically the wells were pumped from 1 to 2 hours at rates that ranged from 8 to 25 gal/min (gallons per minute).

The estimates of aquifer transmissivity were calculated by a program developed for handheld programmable calculators (Czarnecki and Craig, 1985). The program utilizes well diameter and specific capacity data from well logs to solve a nonlinear equation for transmissivity derived by Theis and others (1963). This method required simplifying assumptions to be made about the aquifers and wells. A storage value of 2×10^{-4} was assumed because it is typical of confined aquifers. The wells were assumed to be 100 percent efficient and to be screened across the full thickness of the aquifers. The drawdowns used to calculate specific capacity were corrected to account for partial penetration by the method of Walton (1962).

The estimated well yields were calculated from adjusted values of the specific capacity multiplied times the lesser of two values of drawdown--an arbitrarily assumed drawdown of 30 ft, or the available drawdown, which was the difference between the static water level and the top of the aquifer. The basis for calculation of the adjusted specific capacity is the relation of transmissivity, storage, and specific capacity, derived by Meyer (1963, p. 338-340, fig. 100). The relation shows that the ratio of aquifer transmissivity to specific capacity of wells (expressed in units of gal/min/ft after 24 hours of pumping) completed in aquifers where storage is less than 0.005 (generally confined aquifers) is about 270:1, providing the transmissivity is in the range of 270 to 13,000 ft^2/d. This relation further assumes the wells are 100 percent efficient and the screened intervals of the wells extend across the full thickness of the aquifer.

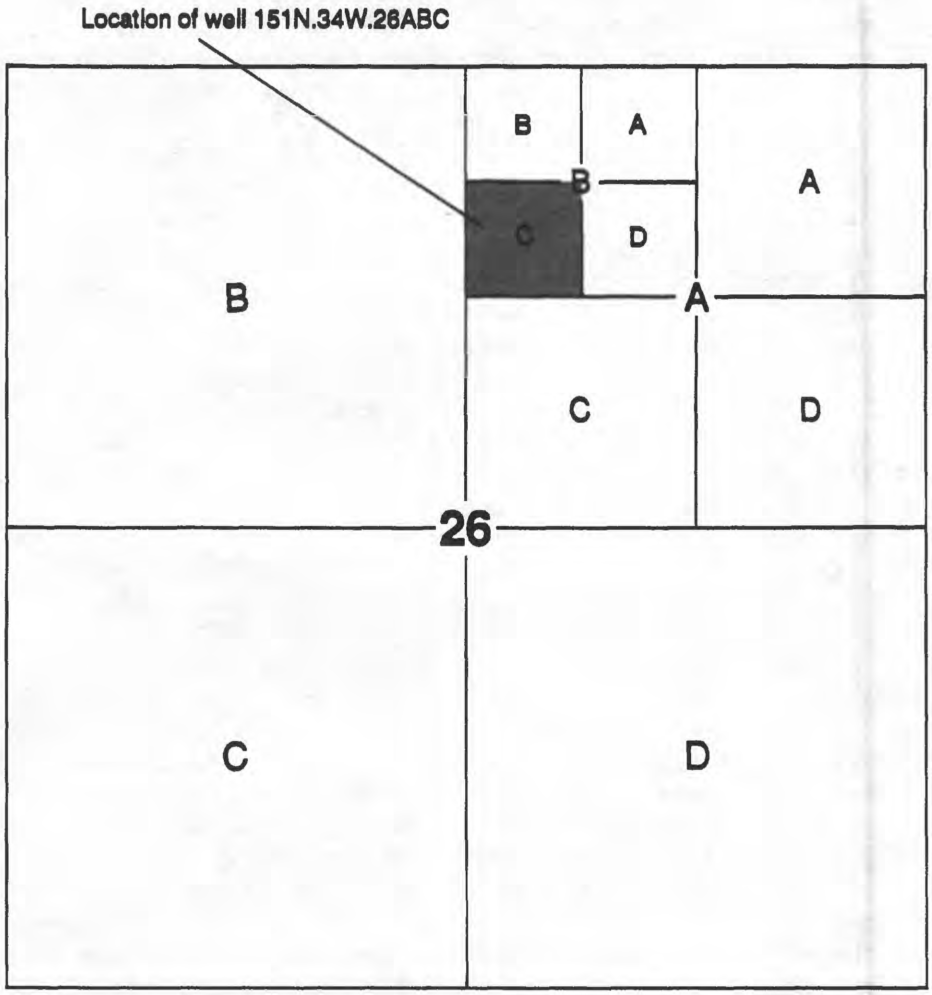
Streamflow data were collected at three temporary streamflow-gaging stations from October 1, 1985 through September 30, 1986 (the 1986 water year) at sites on Sandy River, Mud River, and Pike Creek near their mouths on Lower Red Lake (fig. 2). Discharge measurements were made at these stations approximately once a month; automatic stage recorders read the stage at 15-minute intervals during the open-water part of the year. The stage data were converted to daily mean discharge by interpretation of a curve that related the stage to discharge. Automatic readings of stage were temporarily discontinued during winter when the stream discharges were assumed to be at uniform, low-flow conditions. Multiple-linear-regression techniques were used to define relations between flood flows and basin characteristics (Jacques and Lorenz, 1988). Solutions of these equations provided estimates of flood flows for the three gaged streams for recurrence intervals of 2, 5, 10, 25, 50, and 100 years, and the values of the estimated flood flows were used to construct flood frequency graphs.

Water-quality samples were collected from five domestic-supply wells, four streams, and Lower and Upper Red Lakes. The procedures used to collect, treat, and store the samples are described by Fishman and others (1985) and Skougstad and others (1979). Prior to collection of the ground-water samples, water was pumped from the wells for approximately 15 minutes and frequent measurements were made of temperature, specific conductance, and pH. The water was assumed to be fresh from the aquifer when the values of these properties stabilized. Samples collected from Lower and Upper Red Lakes were collected from both the top and bottom layers of the lakes. Samples collected from the top layers were depth integrated from the upper 10 ft (feet). Samples collected from the bottom layers were collected with a 2-L (liter) Van Dorn water sampler within 3 ft of the bottom. Collection points for the lake samples were in the central part. Stream samples were collected near the mouths of the Pike Creek, the North Branch of the Battle River, the Sandy River, the Mud River, and at an upstream site on the Mud River (fig. 2).

The system of numbering wells used in this report is based on the U.S. Bureau of Land Management's system of land subdivision (township, range, and section). Figure 3 illustrates the numbering system. The first numeral of a well number indicates the township, the second the range, and the third the section where the point is located. Uppercase letters after the section numeral indicate the 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 letters A, B, C, and D are assigned in a counterclockwise direction, beginning in the northeast corner of each tract. The number of uppercase letters indicates the 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 well number 151N.34W.26ABC given in figure 3 defines the location of a well in the SW¼NW¼NE¼, sec.26, T.151 N., R.34 W.

Hydrogeologic Setting

The western third of the study area, the peninsula that separates Lower and Upper Red Lakes, and areas along the eastern and southern sides of Lower Red Lake, lie within the Agassiz lacustrine plain (fig. 4), which formed from sediments left behind by Lake Agassiz, a glacial lake that covered most of northern Minnesota approximately 10,000 year ago. The plain is almost flat except for shallow depressions. A sand cap covers most of the lake sediments along the southern and eastern sides of Lower Red Lake. Well- to poorly-drained soils are common on the sloping beach ridges left by Lake Agassiz. Peat, poorly drained organic material that generally is only a few feet thick, occupies depressional areas of the lacustrine plain to form the Lake Agassiz peatlands.



EXPLANATION

The well-numbering system indicates the location of wells within a rectangular subdivision of land defined by three numbers that indicate township, range, and section, respectively, and letters that designate successively smaller subdivisions of the section. Thus, the well designated above as 151N.34W.26ABC is located to the nearest 10 acres (shown by pattern) in township 151 north, range 34 west, section 26.

Figure 3.--Well numbering system.

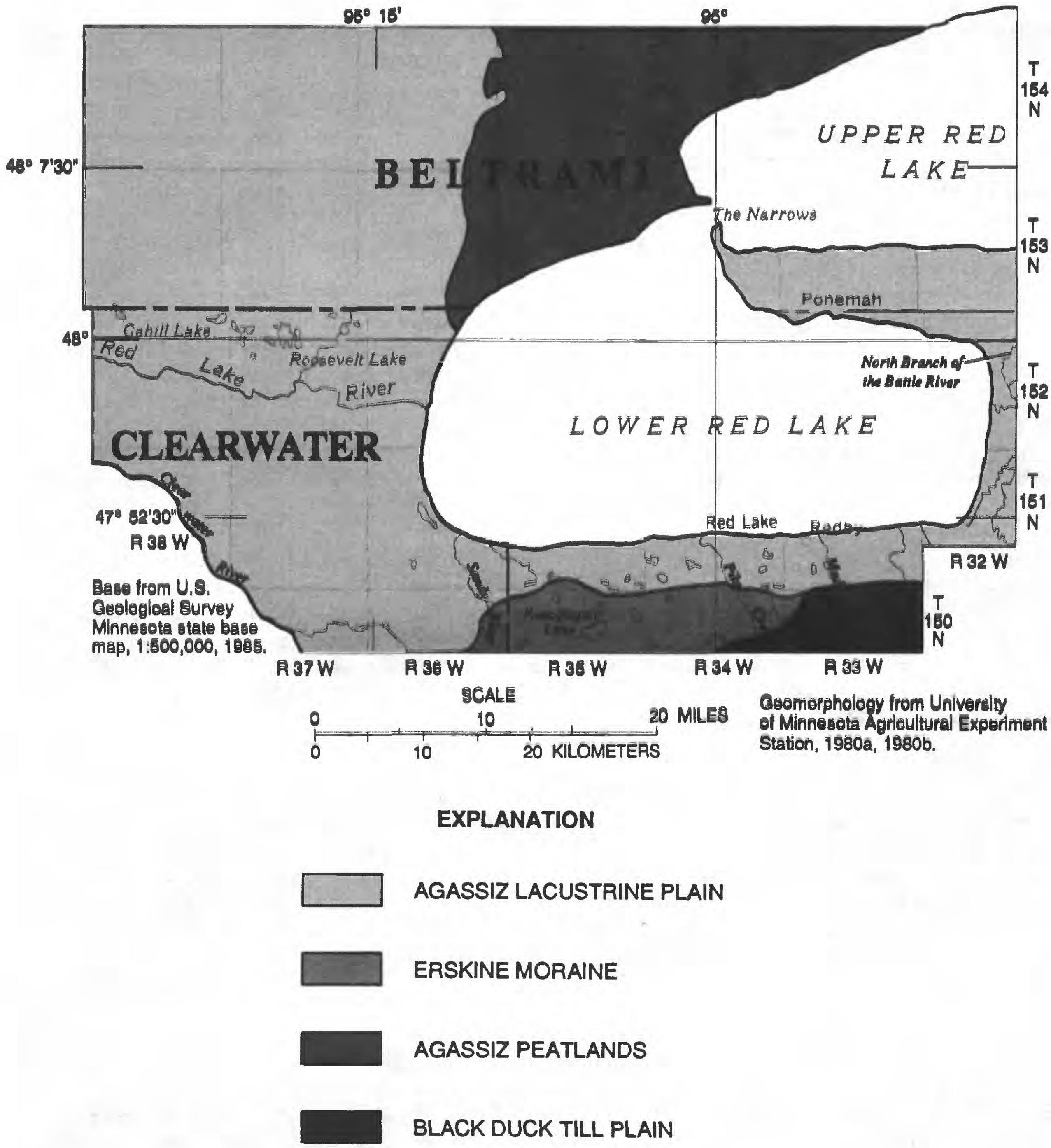


Figure 4.--Geomorphic features in the Red Lake Indian Reservation study area.

The Black Duck till plain and the rolling topography of the Erskine moraine covers the southeastern part of the study area. Soils in the till plain, which developed on calcareous glacial till, are well to moderately well drained; soils in the moraine are sandy to gravelly and well drained.

Glacial deposits that consist mostly of till, an unsorted mixture of clay- to boulder-sized particles, underlie the surficial deposits and overlie crystalline bedrock of Proterozoic age. The till ranges in thickness from approximately 300 ft (feet) in the southwestern part of the study area to 100 ft in the northeastern part (Bidwell and others, 1970). Stratified layers of silt, sand, and gravel, which range in thickness from a few inches to several feet, are locally intermixed with the till.

Glacial-drift aquifers are sand and gravel deposits that yield significant quantities of water to wells. Glacial-drift aquifers that underlie less permeable till are confined (artesian). Because the ground water is at greater-than-atmospheric pressure, water levels in wells completed in these aquifers rise above the upper surface of these aquifers. Ground water in unconfined (water table) glacial-drift aquifers is directly connected to the atmosphere. Water levels in water-table wells rise and fall with changes in elevation of the surrounding water table.

Confined glacial-drift aquifers are the principal source of ground water for households and municipalities in the study area. These aquifers consist of variably sized, discontinuous lenses of sand and gravel rather than a single,large, extensive deposit. These aquifers, which range in area from several square miles to tens of square miles, may be hydraulically connected but commonly are separated by till. Test drilling generally is necessary to locate these aquifers.

Data from well logs indicate that the confined glacial-drift aquifers generally are 50 to 150 ft below land surface. Locally, they can be up to 225 ft below land surface (fig. 5). The thickness of these aquifers generally ranges from 10 to 20 ft, as shown on figure 6, which schematically shows the presence of these aquifers along three lines of section. Surficial sand and gravel deposits that comprise unconfined glacial-drift aquifers range in thickness from 25 to 40 ft. These deposits are present mostly along the southern and eastern shores of Lower Red Lake.

WATER RESOURCES

Because of energy from gravity, wind, and the sun, water continuously moves between the land and the atmosphere. This continuous movement is the hydrologic cycle. Precipitation accumulates on or just below land surface and contributes to evapotranspiration and runoff, or infiltrates more deeply to the ground-water reservoir and becomes part of local and regional ground-water flow systems. The ground water in these flow systems eventually discharges to streams, lakes, and springs and becomes surface water that returns to the atmosphere by evaporation.

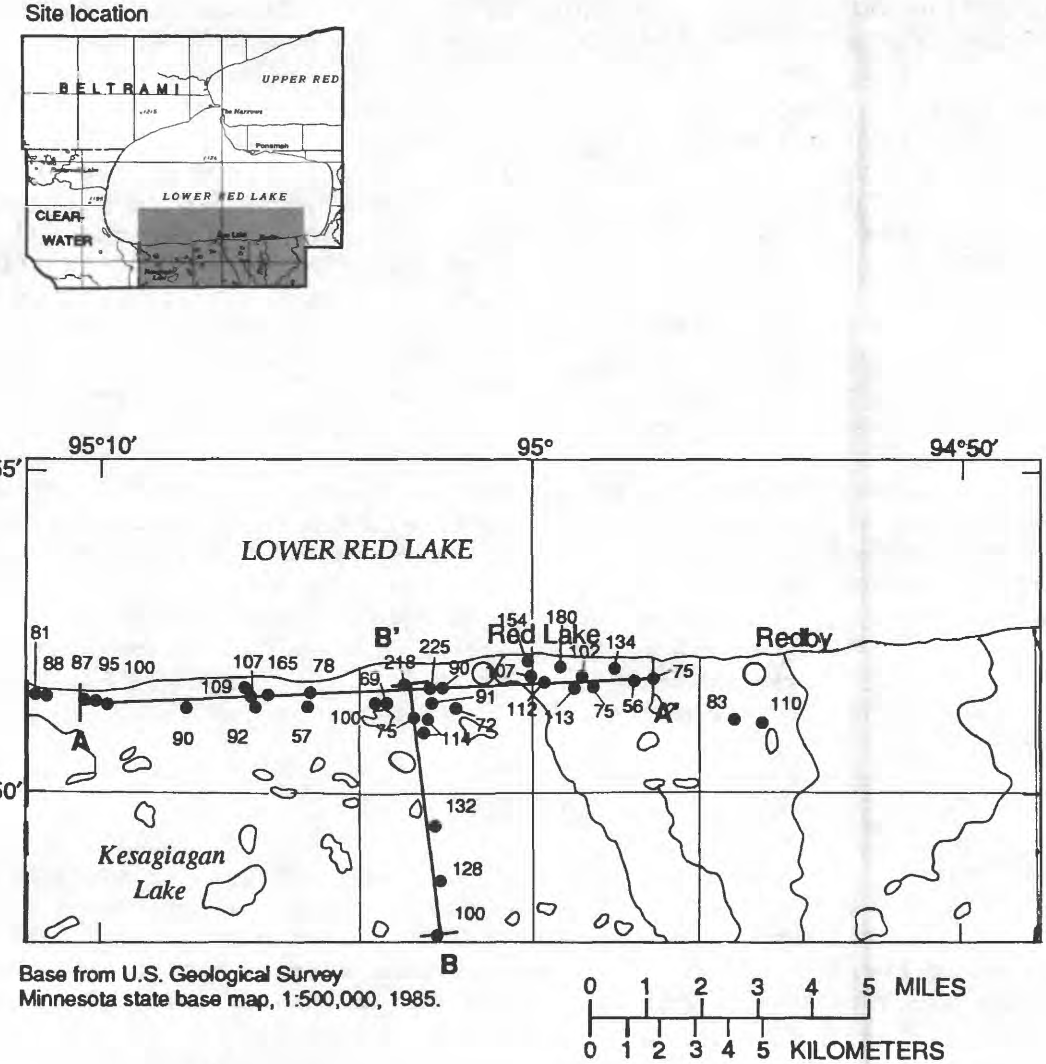
The study area is within a continental climatic zone where temperature and precipitation vary widely. Commonly, winters are cold and summers are warm. The thirty-year (1951-80) average temperatures measured at the weather station in the village of Red Lake ranged from 70 °F (degrees Fahrenheit) in the warmest month of the year (July) to 13 °F in the coldest month of the year (January). Precipitation in the study area ranged from approximately 22 in. in the western part to 23 in. in the eastern part based on the period of record 1890-1966 (Bidwell and others, 1970). The mean annual precipitation measured at Red Lake for the period 1952-87 was 22.7 in.; the maximum and minimum amounts of annual precipitation during that time were 30.35 in. (1957) and 14.35 in. (1976). Most of the precipitation occurs during the months of June, July, and August; the driest months generally occur from November through March. Average annual snowfall (1890-1966) in the study area varied from 45 to 50 in., which is approximately 20 percent of the total precipitation. Most of the measurable snowfall occurs between October and April.

Most of the precipitation returns to the atmosphere by evapotranspiration. A small proportion of the precipitation recharges the ground water or runs off to streams as overland flow. Kanivetsky (1979) estimated net recharge in the Red Lake River drainage area to be in the range of 0.54 to 1.35 in., and Bidwell and others (1970) estimated the annual runoff from the Red Lake drainage basin to be between two to three inches. Assuming the long-term change in the amount of ground-water in storage is negligible on a basin-wide basis, the basin-wide net recharge to the ground-water system is eventually lost as base flow in the runoff.

Ground Water

Ground water is the principal source of domestic supply for inhabitants of the Red Lake Indian Reservation. The amount of useable ground water depends on several factors, such as availability, directions of flow, and quality. Aquifers are the source of useable ground water. Two properties of aquifers that are used to evaluate their value as sources of water supply are storage coefficient and transmissivity.

Although estimated values of hydraulic properties of aquifers such as storage coefficient and transmissivity are useful for broad-scale appraisals of potential aquifer productivity, by themselves these estimated values provide insufficient information to accurately predict the long-term capability of aquifers to yield water to wells. Long-term productivity depends on many factors, such as climatic conditions (for example, droughts and flooding), stresses on the ground-water resources (such as large-scale ground-water withdrawals due to irrigation), and hydrogeologic boundaries (for example, low permeability bedrock that borders the aquifer).

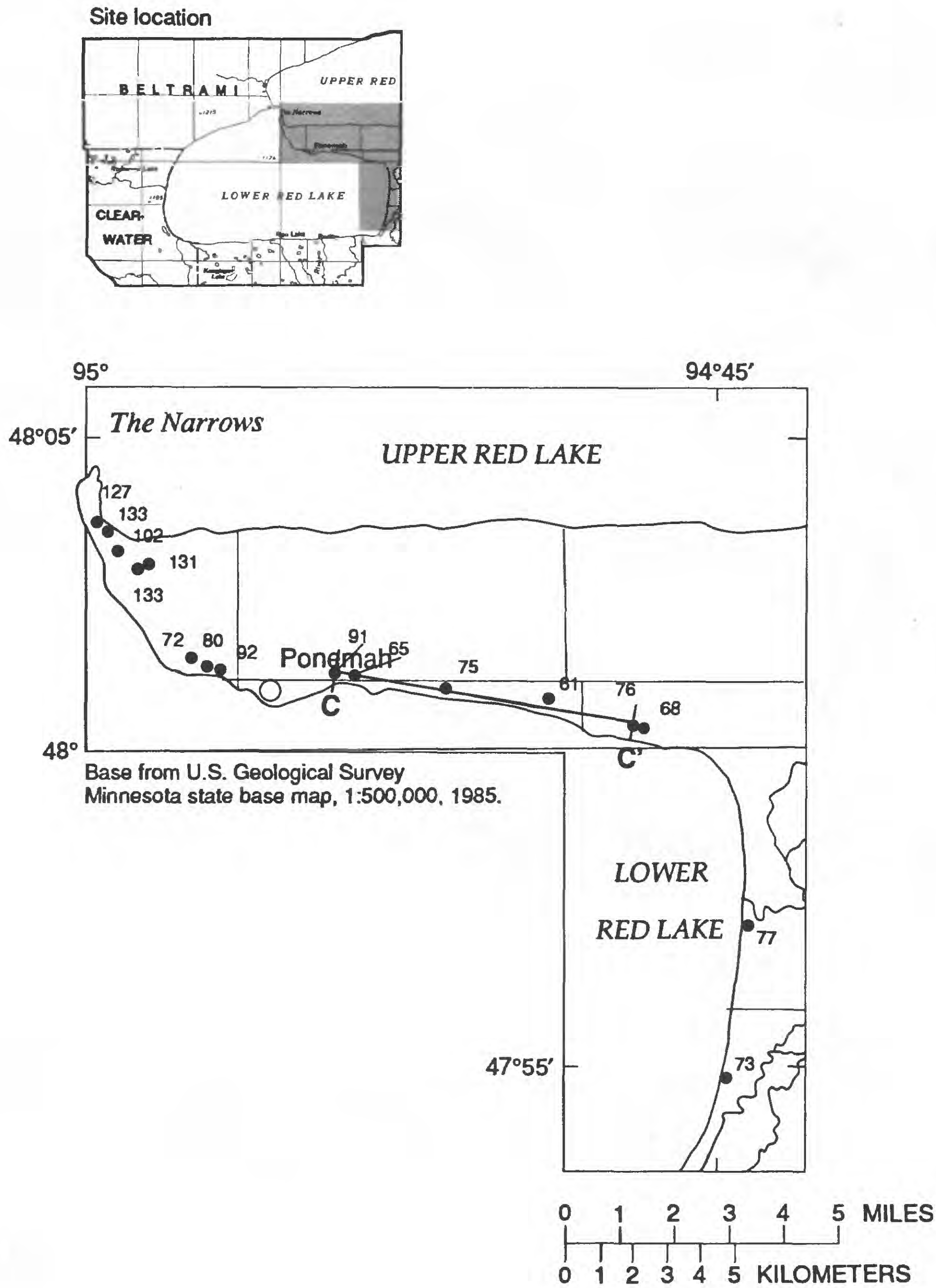


EXPLANATION

A —— A′ LINE OF SECTION (section shown in figure 6)

• 109 WELL LOCATION--Number indicates depth of well, in feet

Figure 5.--Depths of wells completed in confined glacial-drift



aquifers in the Red Lake Indian Reservation study area.

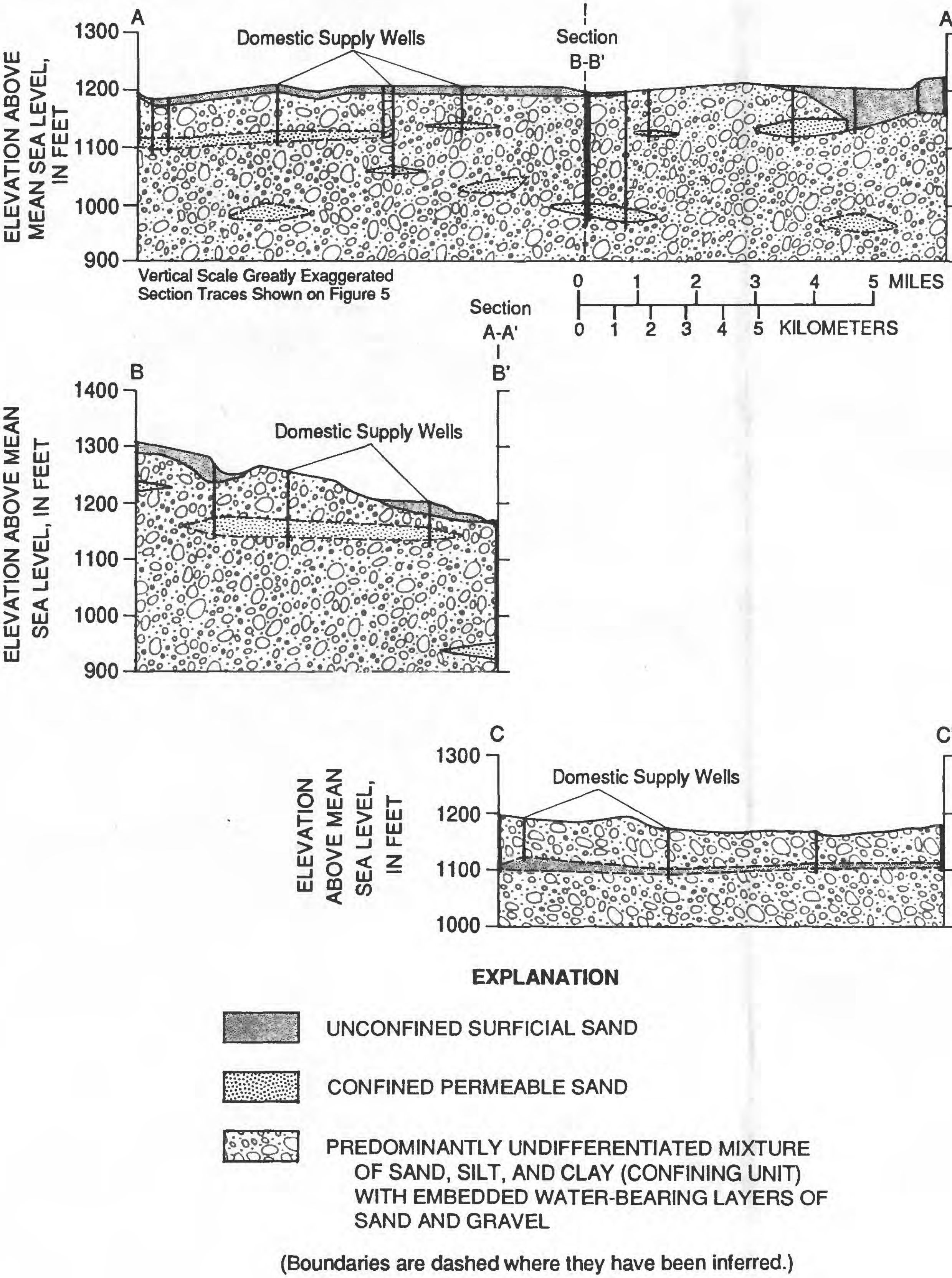


Figure 6.--Hydrogeologic sections in the Red Lake Indian Reservation study area.

Availability

The storage coefficient is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Storage coefficient is very low in confined aquifers. The release of water from these aquifers is due to expansion of the water and compression of the aquifer materials. The amount of water released by these aquifers in response to a given drop in total head (height of the water level above a defined datum that would be observed in a tightly cased well completed in the aquifers) is very small in comparison to unconfined aquifers, which release water by gravity drainage from the pores. Therefore, the storage coefficient of unconfined aquifers is 100 to 10,000 times the storage coefficient of confined aquifers. Values of the storage coefficient for confined aquifers range from 10^{-5} to 10^{-3} (0.00001 to 0.001), and values for unconfined aquifers range from about 0.1 to 0.3. This difference in storage coefficient results in significantly greater drawdown in confined aquifers than in unconfined aquifers for a given rate of withdrawal.

Transmissivity is a property of aquifers that indicates their ability to transmit water. It is the amount of water that will flow through a unit-width strip that extends the full thickness of an aquifer under a unit hydraulic gradient. This property is equal to the horizontal hydraulic conductivity of the aquifer (which is a measure of the permeability of aquifer materials to the flow of water) multiplied by the saturated thickness of the aquifer. Thus, the transmissivity of an aquifer that has a large saturated thickness and low horizontal hydraulic conductivity can be equal to the transmissivity of an aquifer that has a small saturated thickness and high horizontal hydraulic conductivity. Because of its dependence on both saturated thickness and hydraulic conductivity, transmissivity can differ significantly from place to place in the same aquifer. Transmissivity commonly is lower in confined than in unconfined glacial-drift aquifers because the saturated thickness generally is small in confined aquifers. Transmissivities of glacial-drift aquifers in Minnesota range from 5,000 to 20,000 ft^2/d (feet squared per day) (Helgesen, 1977; Lindholm, 1980; Miller, 1982; Myette, 1984; Wolf, 1976, 1981; and Delin, 1986).

Well yield is the volume of water discharged from the well head per unit of time. Wells completed in unconfined aquifers require pumps to discharge water because the water levels in these wells are below land surface. Wells completed in confined aquifers also require pumps unless the water levels in these wells rise above land surface to make the wells naturally flowing. Some wells along the southeastern side of Lower Red Lake are reported to be flowing (Siegel, 1981). The estimated yields given in table 1 are pumping rates for wells completed in confined glacial-drift aquifers that assume the following conditions: (1) the wells are 100 percent efficient, (2) the wells are screened across the full thickness of the aquifer, and (3) the wells are pumped for a 24-hour period to produce the drawdown represented by (s).

The estimated transmissivity of the confined glacial-drift aquifers within the study area ranged from 19 to 2,575 ft^2/d (table 1). The median of the estimated transmissivity values was 210 ft^2/d; approximately 75 percent of the estimated values were less than 500 ft^2/d. Some of the highest estimates were for the area immediately surrounding Ponemah (fig. 7), elsewhere, the estimates were variable. The estimated transmissivities showed little correlation with the thickness of the aquifers, which ranged from 4 to 66 ft. Of the 13 wells listed in table 1 associated with transmissivity estimates that exceeded 500 ft^2/d, the aquifer thicknesses ranged from 9 to 66 ft; the aquifer thicknesses associated with the four wells where the transmissivities were estimated to be greater than 1,000 ft^2/d ranged from 10 to 15 ft. Clearly the hydraulic conductivity of the aquifer materials has a greater effect on transmissivity than does the thickness of the aquifers. The hydraulic conductivity of the sand and gravel deposits mainly depends on the amount of fine-grained materials, such as clay and silt sized particles, that are present. These particles occupy the pore spaces in the sand and gravel and obstruct the flow of water.

The estimated yields of the confined glacial-drift aquifers within the study area roughly correlated with the estimated transmissivities; values ranged from 22 to 238 gal/min. Except for three estimates that exceeded 200 gal/min, all of the other estimates were less than 127 gal/min. The three highest estimates were based on data from the same wells near Ponemah that resulted in the large estimated transmissivities (fig. 7). Although the estimated yields primarily depended on the estimated transmissivities of the aquifers, the estimated yield for well index number 23 was limited by the available drawdown, which was only 7 ft.

Flow

Recharge to the ground-water system (1) escapes to the atmosphere through evapotranspiration; (2) enters into near-surface, local-flow systems and discharges into nearby streams, lakes, and wetlands; and (or) (3) percolates below the local-flow systems into regional flow-systems. The residence time of ground water in local-flow systems could be weeks to years--a relatively short period in terms of ground-water movement. Numerous local-flow systems occur in the peatlands of the study area (Siegel, 1981). Local precipitation causes ground-water mounds to develop in raised bogs, and the mounds become a source of ground-water discharge to surrounding fens.

Regional recharge to the ground-water reservoir of the study area originates in morainal uplands south of the study area (Bidwell and others, 1970). The estimated water-table surface indicates that ground-water discharges to Lower Red Lake from these upland areas (fig. 8). Flowing wells on the southern and southeastern sides of Lower Red Lake are likely to be discharge areas of these regional-flow systems.

Quality

Evaluation of the quality of ground water focused on suitability of the water for drinking. Concentrations of water-quality constituents and measurements of water-quality properties were compared to primary and secondary drinking-water regulations established by the U.S. Environmental Protection Agency (USEPA) (1986). Water-quality properties and constituents, applicable drinking-water regulations, and brief descriptions of their significance are in table 2.

The physical and chemical characteristics of water collected from five wells completed in the confined glacial-drift aquifers are given in table 3. None of the trace-element concentrations exceeded the USEPA maximum contaminant levels (U.S. Environmental Protection Agency, 1986). The concentrations of the trace elements varied only slightly except that for zinc--from 1 to almost 400 μg/L (micrograms per liter).

Water in the confined glacial-drift aquifers is a calcium magnesium bicarbonate type (fig. 9). Carbonate minerals in the glacial drift are sources of calcium and magnesium. Atmospheric carbon dioxide dissolves in the ground water to form carbonic acid, which reacts with the carbonate minerals to form calcium and magnesium cations and bicarbonate anions.

Surface Water

Liquid water on the land surface that exceeds the capacity of the soil for infiltration runs off the land due to gravity as streamflow or accumulates in enclosed depressions to form variably sized lakes and ponds. Lower and Upper Red Lakes are the principal lakes in the study area. Sandy River, Mud River, and Pike Creek are streams in the study area that drain major watersheds along the south side of Lower Red Lake. Their streamflows vary both daily and seasonally in response to changes in temperature and precipitation.

Streamflow Characteristics

The sources of water that become streamflow are drainage from surface water bodies, overland flow (the water that flows over the land surface to a stream channel), and ground-water discharge. Overland flow typically reaches a stream channel soon after a rainstorm or snowmelt when the soil is at or near saturation. Ground-water discharge (commonly called base flow) is the component of streamflow that comes directly from subsurface water. Streamflow data displayed as hydrographs provide a means to determine the components of the runoff and to understand the relation of precipitation and snowmelt to streamflow.

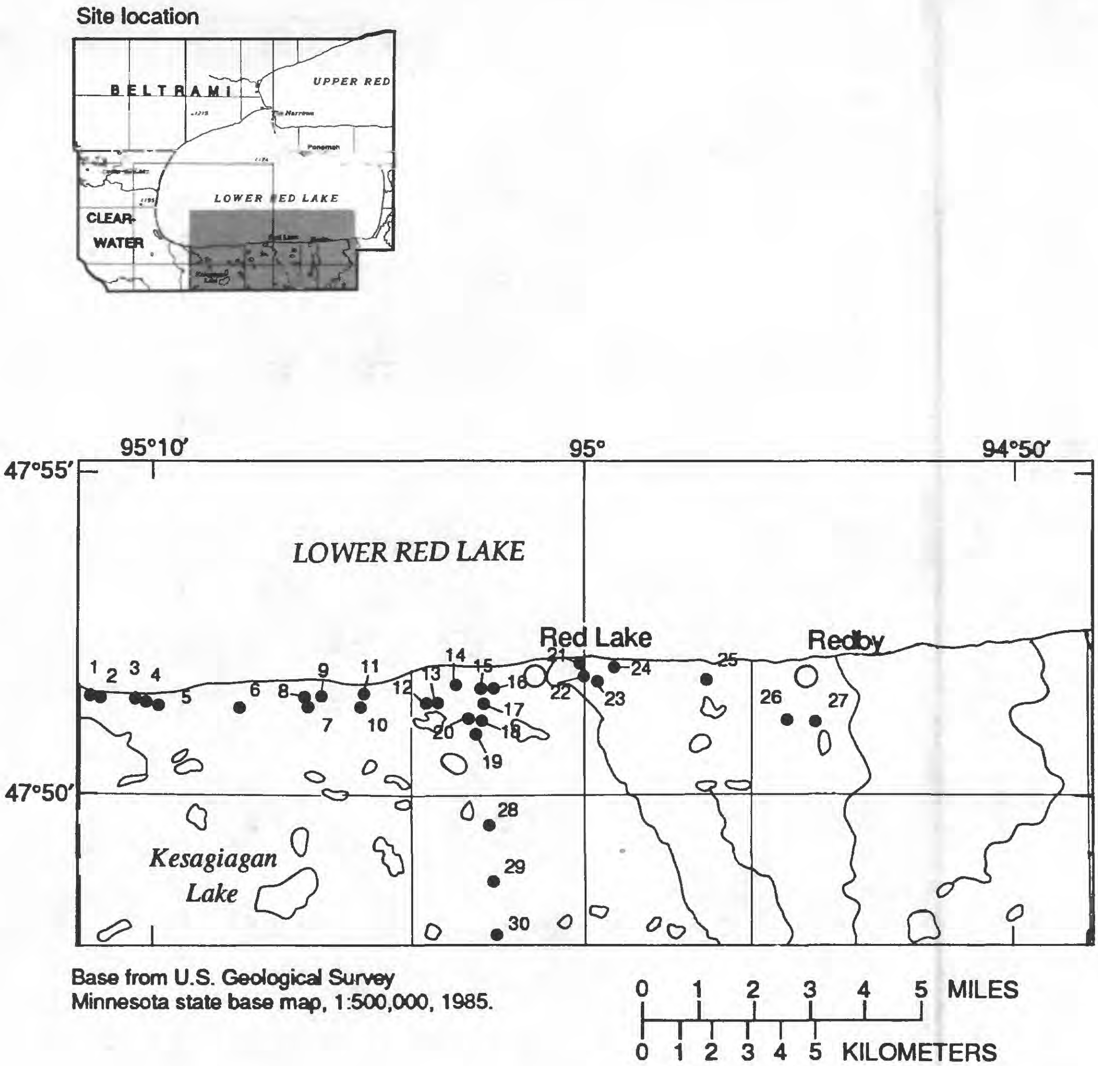
Table 1.--*Selected data from commercial drillers' logs of wells completed in confined glacial-drift aquifers in the Red Lake Indian Reservation study area*

Locations of wells shown by well index number on figure 7. Specific capacity is pumping rate divided by drawdown. Adjusted specific capacity is transmissivity divided by the conversion factor 270 (ft^2/d)/(gal/min/ft). Estimated yield is adjusted specific capacity multiplied by (s). The variable (s) is an assumed drawdown of 30 feet or the available drawdown from the static water level to the top of the aquifer if the drawdown is less than 30 feet.

Well index no.	Location	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)	Pumping time (min)	Aquifer thickness (ft)	Transmissivity (ft^2/d)	Adjusted specific capacity (gal/min/ft)	(s)	Estimated yield (gal/min)
1	151N.35W.30BCD	8	68	0.12	60	8	23	--		--
2	151N.35W.30CBA	8	61	0.13	60	4	26	--		--
3	151N.35W.29BCD	10	42	0.24	60	5	52	--		--
4	151N.35W.29BDD	20	14	1.43	120	7	479	1.7	30	53
5	151N.35W.29CAA	10	20	0.50	60	22	206	--		--
6	151N.35W.28DAB	7	30	0.23	120	16	57	--		--
7	151N.35W.26CBB	10	55	0.18	60	50	166	--		--
8	151N.35W.26CBB	6	34	0.18	120	12	46	--		--
9	151N.35W.26BDC	6	67	0.09	120	10	19	--		--
10	151N.35W.25BAD	9	5	1.80	120	12	561	2.1	23	48
11	151N.35W.25BCA	20	7	2.86	20	9	664	2.5	30	73
12	151N.34W.30BCD	10	58	0.17	60	58	252	--		--
13	151N.34W.30BDD	8	4	2.00	120	14	512	1.9	30	57
14	151N.34W.30AAC	10	19	0.52	120	22	151	--		--
15	151N.34W.29BBB	11	18	0.61	120	19	146	--		--
16	151N.34W.29BAC	6	45	0.13	120	8	28	--		--
17	151N.34W.29CBB	8	11	0.73	60	16	187	--		--
18	151N.34W.30DDA	11	14	0.79	120	16	214	--		--
19	151N.34W.29CCC	6	25	0.24	120	24	68	--		--
20	151N.34W.30DAD	10	20	0.50	60	37	415	1.5	16	24
21	151N.34W.21DAC	8	102	0.08	60	16	40	--		--
22	151N.34W.21DDD	15	8.5	1.76	120	8	448	1.7	30	50
23	151N.34W.22CCD	10	6	1.67	120	66	845	3.1	7	22
24	151N.34W.22CA	10	18	0.55	60	15	185	--		--
25	151N.34W.24CCC	10	7.2	1.39	60	11	422	1.6	30	47

Table 1.--*Selected data from commercial drillers' logs of wells completed in confined glacial-drift aquifers in the Red Lake Indian Reservation study area*--Continued

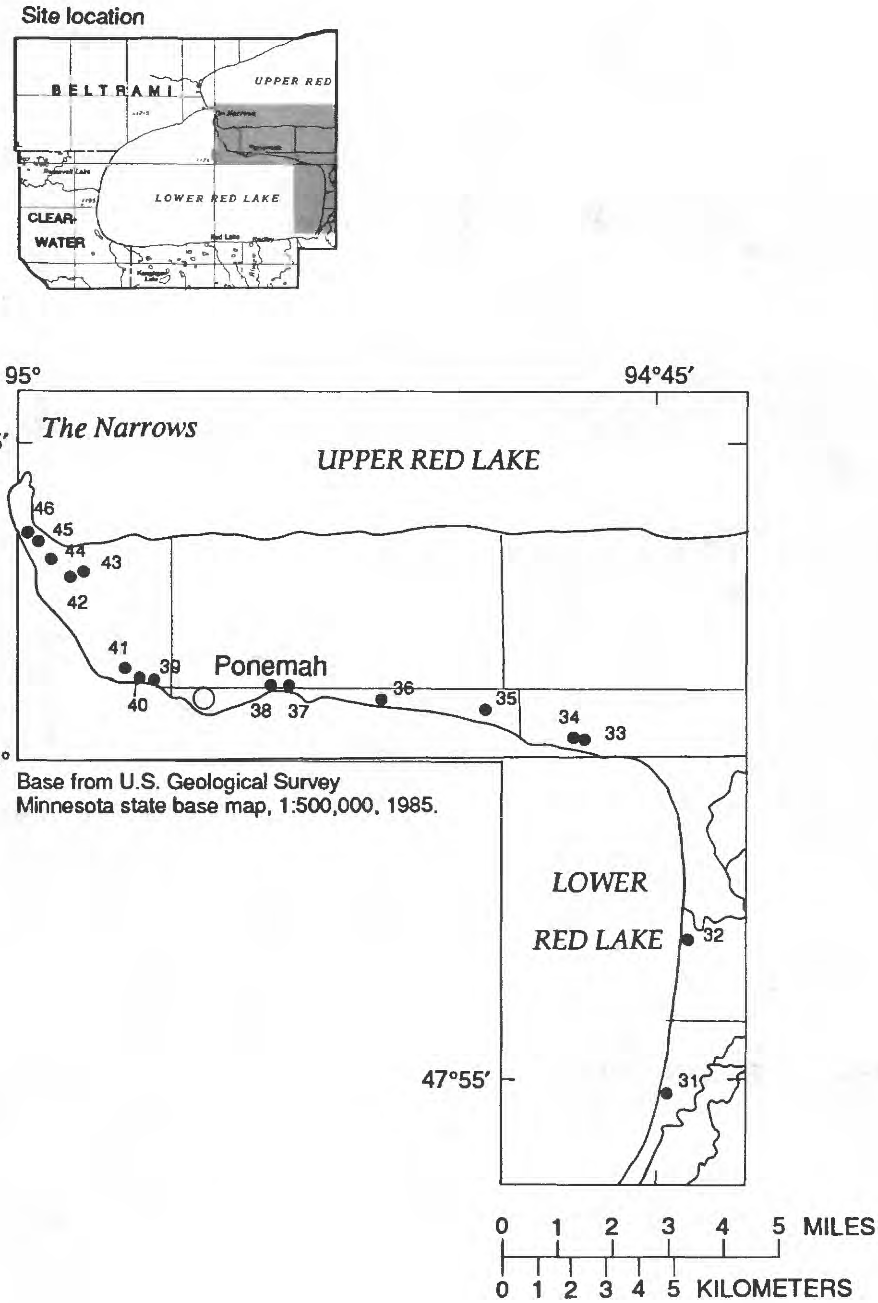
Well index no.	Location	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)	Pumping time (min)	Aquifer thickness (ft)	Transmissivity (ft^2/d)	Adjusted specific capacity (gal/min/ft)	(s)	Estimated yield (gal/min)
26	151N.33W.30CAA	10	12	0.83	60	10	202	--		--
27	151N.33W.29CBC	10.7	4	2.68	60	35	793	2.9	20.5	59
28	150N.34W.05CB	15	18	0.83	60	12	206	--		--
29	150N.34W.08CAB	10	40	0.25	60	34	127	--		--
30	150N.34W.17CA	25	7	3.57	60	23	907	3.4	30	100
31	151N.32W.09ABC	10	11	0.91	60	10	225	--		--
32	152N.32W.28DAD	8	4	2.00	120	8	512	1.9	30	56
33	152N.32W.05CCC	5	24	0.21	120	12	45	--		--
34	152N.32W.05CCD	5	15	0.33	120	13	100	--		--
35	152N.33W.01CAA	10	12	0.83	60	12	411	1.5	30	46
36	152N.33W.03ABD	8	4	2.00	60	30	522	1.9	14	27
37	153N.33W.33CCC	29	6	4.83	30	10	1,834	6.8	30	204
38	153N.33W.32DDC	20	3	6.67	15	15	2,014	7.5	30	224
39	153N.34W.36DCB	15	4.4	3.41	120	11	976	3.6	30	108
40	153N.34W.36DCB	8	7	1.14	60	10	490	1.8	30	54
41	153N.34W.36CB	13	1.4	9.29	120	10	2,575	9.5	25	238
42	153N.34W.23CCD	40	50	0.80	60	15	270	1.0	30	30
43	153N.34W.23CDC	8	45.5	0.18	120	44	138	--		--
44	153N.34W.22DCA	10	22	0.45	60	14	112	--		--
45	153N.34W.22BDD	8	1.7	4.71	120	13	1,145	4.2	30	127
46	153N.34W.22BAC	8	39.5	0.20	120	10	46	--		--



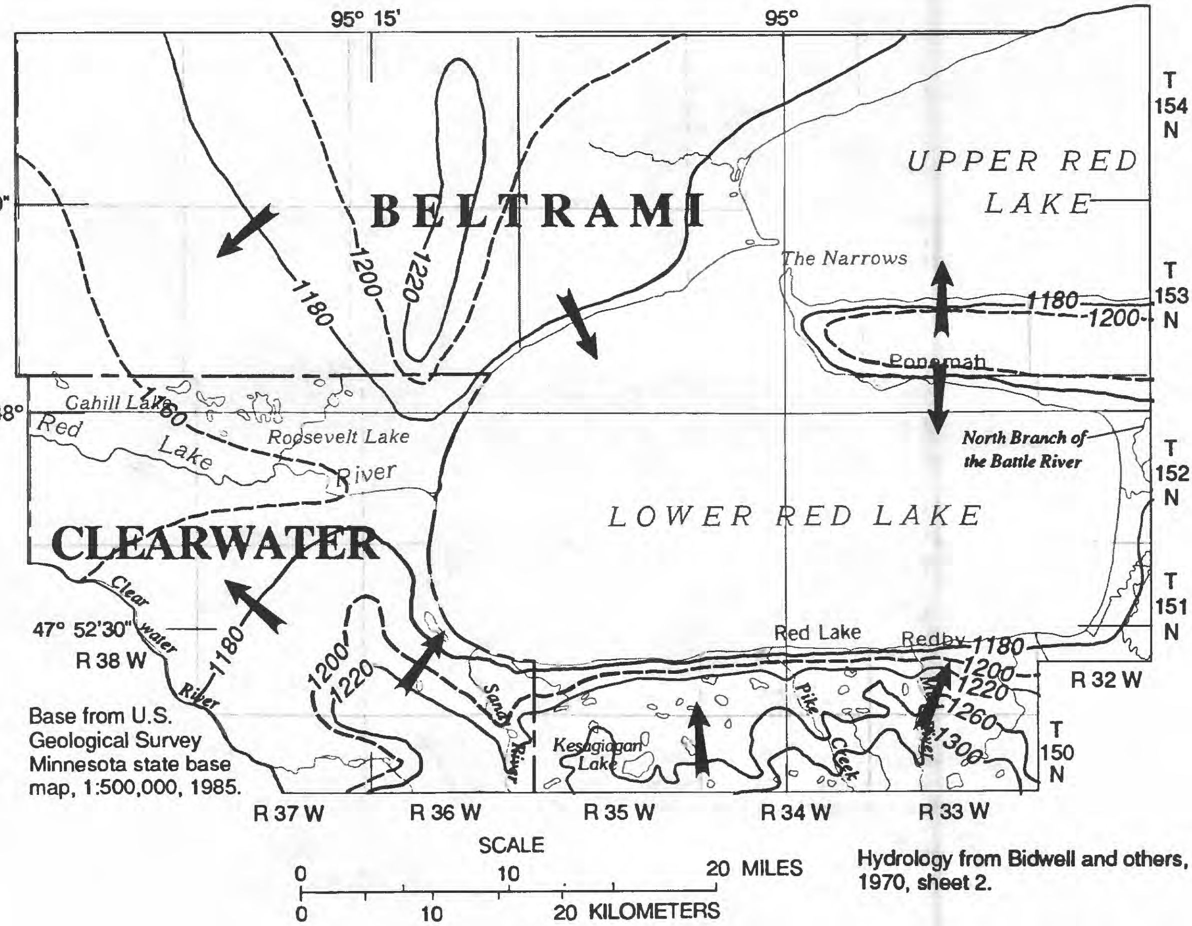
EXPLANATION

•[10] WELL LOCATION--Denotes location of well identified by index numbers used in table 1.

Figure 7.--Locations of wells with logs that are sources of data used to estimate hydraulic



properties of confined glacial-drift aquifers in the Red Lake Indian Reservation study area.



EXPLANATION

➡ DIRECTION OF REGIONAL GROUND-WATER FLOW IN SURFICIAL AND NEAR-SURFICIAL AQUIFERS

—*1220*— WATER-TABLE CONTOUR--Shows altitude of water table. Contour intervals 20 and 40 feet. Dashed where approximate. Based on data from wells less than 50 feet deep. Datum is sea level.

Figure 8.--Water-table surface and flow directions in the uppermost aquifers in the Red Lake Indian Reservation study area, 1970.

Table 2.--*U.S. Environmental Protection Agency water-quality criteria and significance of common water-quality properties and constituents (from USEPA 1986)*

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Property or constituent	Criterion and established or recommended limits	Source (see footnote)	Significance
Specific conductance		a	An indirect measure of total concentration of ions in the water.
Alkalinity	No less than 20 mg/L $CaCO_3$	e	Capacity for neutralizing acid. Attributed mostly to bicarbonate ion.
Calcium (Ca)		a	Principal cation in most of Minnesota's ground water. Major cause of hardness.
Magnesium (Mg)		a	Second-most abundant cation in Minnesota's ground water. A cause of hardness.
Sodium (Na)	270 mg/L	b	Principal cation in ground water from parts of western Minnesota. Sodium-type water is undesirable for irrigation.
Sulfate (SO_4)	250 mg/L	c	Principal anion in ground water from Cretaceous deposits, particularly those in the southwestern part of the State. Can have a laxative effect on people.
Chloride (Cl)	250 mg/L	b	Principal anion in ground water from parts of western Minnesota. Contributes to salinity and causes a salty taste.

Table 2.--*U.S. Environmental Protection Agency water-quality criteria and significance of common water-quality properties and constituents (from USEPA 1986)* --Continued

Property or constituent	Criterion and established or recommended limits	Source (see footnote)	Significance
Silica (SiO_2)	50 mg/L	b	Essential plant nutrient.
Dissolved solids	500 mg/L	c	Total concentration of dissolved substances. Freshwater generally contains less than 1,000 mg/L. Normally, the lower the dissolved-solids concentration, the better the quality of the water for all uses.
Nitrate (NO_3 as N)	10 mg/L	d	Can cause methemoglobinemia in infants. Indicates pollution from animal wastes or fertilizer.
Phosphorus (P)		a	Essential plant and animal nutrient. Can stimulate growth of algae in surface water.
Arsenic (As)	50 μg/L 190 μg/L	d e	Toxic to animals, including humans.
Barium (Ba)	1 mg/L	d	Toxic to plants and animals.
Boron (B)	750 μg/L	b	Essential plant micronutrient.
Cadmium (Cd)	10 μg/L 2 μg/L	d e	Toxic to animals, including humans.
Chromium (Cr)	50 μg/L 11 μg/L	d e	Toxic to humans.
Copper (Cu)	1 mg/L 34 μg/L	d	Essential nutrient for plants and animals. Imparts metallic taste to water.

Table 2.--*U.S. Environmental Protection Agency water-quality criteria and significance of common water-quality properties and constituents (from USEPA 1986)*--Continued

Property or constituent	Criterion and established or recommended limit	Source (see footnote)	Significance
Iron (Fe)	300 µg/L 1 mg/L	c e	Can cause stains on laundry and fixtures and unpleasant tastes in beverages. Widely distributed.
Lead (Pb)	50 µg/L 7.7 µg/L	d e	Toxic to plants and animals.
Manganese (Mn)	50 µg/L	c	Causes stains and affects taste.
Mercury (Hg)	2 µg/L 0.012 µg/L	d e	Toxic to plants and animals.
Zinc (Zn)	5 mg/L 190 µg/L	c e	Essential plant and animal nutrient. May impart metallic taste.

a--No recommended limits established.
b--Arbitrary limit suggested for public, livestock, and irrigation uses by the National Academy of Sciences and National Academy of Engineering (1974).
c--Secondary maximum contaminant level established by the U.S. Environmental Protection Agency (1986).
d--Maximum contaminant level established by the U.S. Environmental Protection Agency (1986).
e--Recommended limit established by the U.S. Environmental Protection Agency (1986) to protect against chronic effects on freshwater life. (Values represent a 4-day average that is not to be exceeded more than once every 3 years.)

Table 3.--*Chemical and physical characteristics of water from confined glacial-drift wells in the Red Lake Indian Reservation study area, 1987*

[See Definition of Terms, p 9; lab, analysis or measurement made in a laboratory; field, analysis or measurement made at collection site; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, not analyzed; <, less than; °C, degrees Celsius]

Local well number	USGS identification number	Local number
1	474852095021501	150N34W17BAD
2	475200095030001	151N34W30DBB
3	475220094575201	151N34W26ABC
4	480057094493901	153N33W02ADD
5	480107094551701	152N33W05BBB

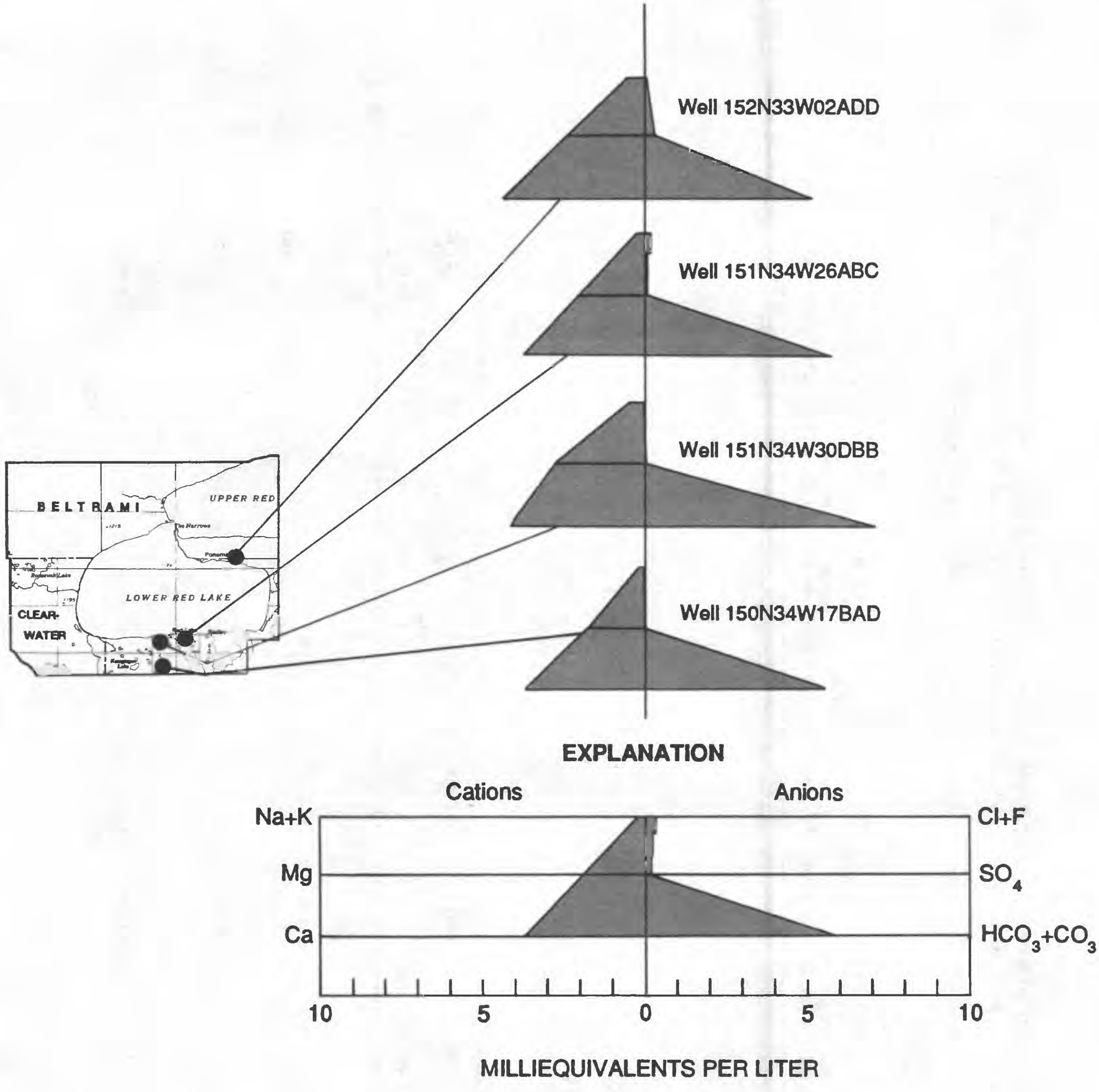
Local well number	Date	Depth of well, total (feet)	Specific conductance, (µS/cm)		pH (standard units)		Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
			field	lab	field	lab				
1	8/17/87	80	--	516	--	7.6	--	74	21	2.0
2	8/18/87	90	--	--	--	--	--	--	--	--
	8/11/87	90	558	625	7.6	7.4	--	81	33	6.6
3	8/18/87	85	--	536	--	7.4	--	75	22	2.6
4	8/11/87	111	400	478	--	8.1	11.0	31	16	48
	8/18/87	111	--	--	--	--	--	--	--	--
5	8/18/87	61	--	651	--	7.5	--	85	28	6.4

Local well number	Date	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)		Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
			field	lab				
1	8/17/87	1.0	--	279	8.9	0.5	0.1	23
2	8/18/87	--	--	--	--	--	--	--
	8/11/87	3.1	361	334	.9	.8	.2	29
3	8/18/87	1.6	--	292	2.8	9.7	.1	25
4	8/11/87	3.7	258	256	1.9	5.2	.3	14
	8/18/87	--	--	--	--	--	--	--
5	8/18/87	3.4	--	267	24	4.7	0.2	23

Table 3.--*Chemical and physical characteristics of water from confined glacial-drift wells in the Red Lake Indian Reservation study area, 1987*--Continued

Local well number	Date	Nitrogen (mg/L as N) Nitrite, dissolved	Nitrogen (mg/L as N) Nitrate plus nitrite, dissolved	Antimony, total (µG/L as Sb)	Arsenic, total (µG/L as As)	Beryllium, total recoverable (µG/L as Be)	Cadmium, total recoverable (µG/L as Cd)	Chromium, (µG/L as Cr) dissolved	Chromium, (µG/L as Cr) total recoverable
1	8/17/87	<0.01	<0.1	<1	<1	<10	<1	--	6
2	8/18/87	<.01	<.1	--	--	--	--	--	--
	8/11/87	--	--	<1	<1	<10	<1	1	<1
3	8/18/87	<.01	<.1	<1	<1	<10	<1	--	<1
4	8/11/87	--	--	<1	7	<10	<1	--	<1
	8/18/87	<.01	<.1	--	--	--	--	--	--
5	8/18/87	<.01	<.1	<1	6	<10	<1	--	2

Local well number	Date	Copper, total recoverable (µG/L as Cu)	Lead, total recoverable (µG/L as Pb)	Mercury, total recoverable (µG/L as Hg)	Nickel, total recoverable (µG/L as Ni)	Selenium, total (µG/L as Se)	Silver, total recoverable (µG/L as Ag)	Zinc, total recoverable (µG/L as Zn)
1	8/17/87	<1	<5	0.2	16	<1	<1	360
2	8/18/87	--	--	--	--	--	--	--
	8/11/87	13	<5	.2	4	<1	<1	<10
3	8/18/87	1	<5	.1	6	<1	<1	80
4	8/11/87	<1	<5	.2	<1	<1	<1	30
	8/18/87	--	--	--	--	--	--	--
5	8/18/87	2	<1	<0.1	1	<1	<1	10



Water-quality diagram based on an analysis of a sample collected from the indicated well. The size of the diagram is directly proportional to the dissolved solids concentration.

Figure 9.--Water-quality diagrams for samples collected from confined glacial-drift aquifers in the Red Lake Indian Reservation study area, August 1987.

Streamflow characteristics of interest are annual volumes of flow, low-flow rates, and high-flow rates, or floods. Flood frequency curves indicate the probability that a given annual peak discharge will be exceeded (exceedance probability). The recurrence interval, which is the reciprocal of the exceedance probability, is the average number of years that will elapse before a given flood event will be exceeded. For instance, if the exceedance probability is 50 percent for an annual peak of 100 ft^3/s, the recurrence interval is 2 years. Predictions of the probabilities of given peak flows at specified locations generally require long records of streamflow data. However, long-term records commonly are unavailable at sites of interest, and as a consequence, other techniques, such as the formulation and solution of multiple-linear-regression equations that define relations between flood peaks and basin characteristics, are used to estimate the magnitude and frequency of streamflows.

Streamflow in the study area was probably near normal during the 1986 water year based on long-term precipitation and streamflow data collected in and near the study area. Precipitation measured at the U.S. National Weather Service Station in Red Lake during the 1986 water year was 21.89 in., which is slightly less than the 36-year (1952-87) average of 22.7 in. Analysis of a 17-year streamflow record (1961-77) from a gaging station on Ruffy Brook, within 4 miles of the study area, indicate flow was in the normal range from March through October 1986 (Payne, 1989).

Streamflow in the study area depends on the amount and rapidity of snowmelt, the intensity and duration of rainstorms, and the antecedent soil-moisture conditions. During October, daily rainfalls of 0.3 to 1 in. caused observable increases in streamflow in Sandy River and Mud River (fig. 10). By early November, streamflow in Sandy River, in Mud River, and in Pike Creek (fig. 10) had receded to base-flow conditions that continued through the winter. Snowmelt caused the spring high-flow period for the three streams in late March and early April. Streamflow quickly receded after these peak flows of early spring, but rose sharply again following rainstorms in early May. Streamflows gradually receded during the last 4 months of the water year and increased only slightly in response to rainstorms.

The streamflow hydrographs show that the effects of rainstorms on streamflow were nonuniform during the year. Soil-moisture conditions were very likely at field capacity immediately following snowmelt in the spring, and the storms in early May produced large amounts of runoff. Soil-moisture conditions were less than field capacity by mid-summer because of evapotranspiration. The storms during this period produced small amounts of runoff because the rate of evapotranspiration was very high and most or all of the precipitation was retained in the soil. Low-flow conditions commonly occur during mid to late summer when rates of evapotranspiration are high and the amount of precipitation is often small.

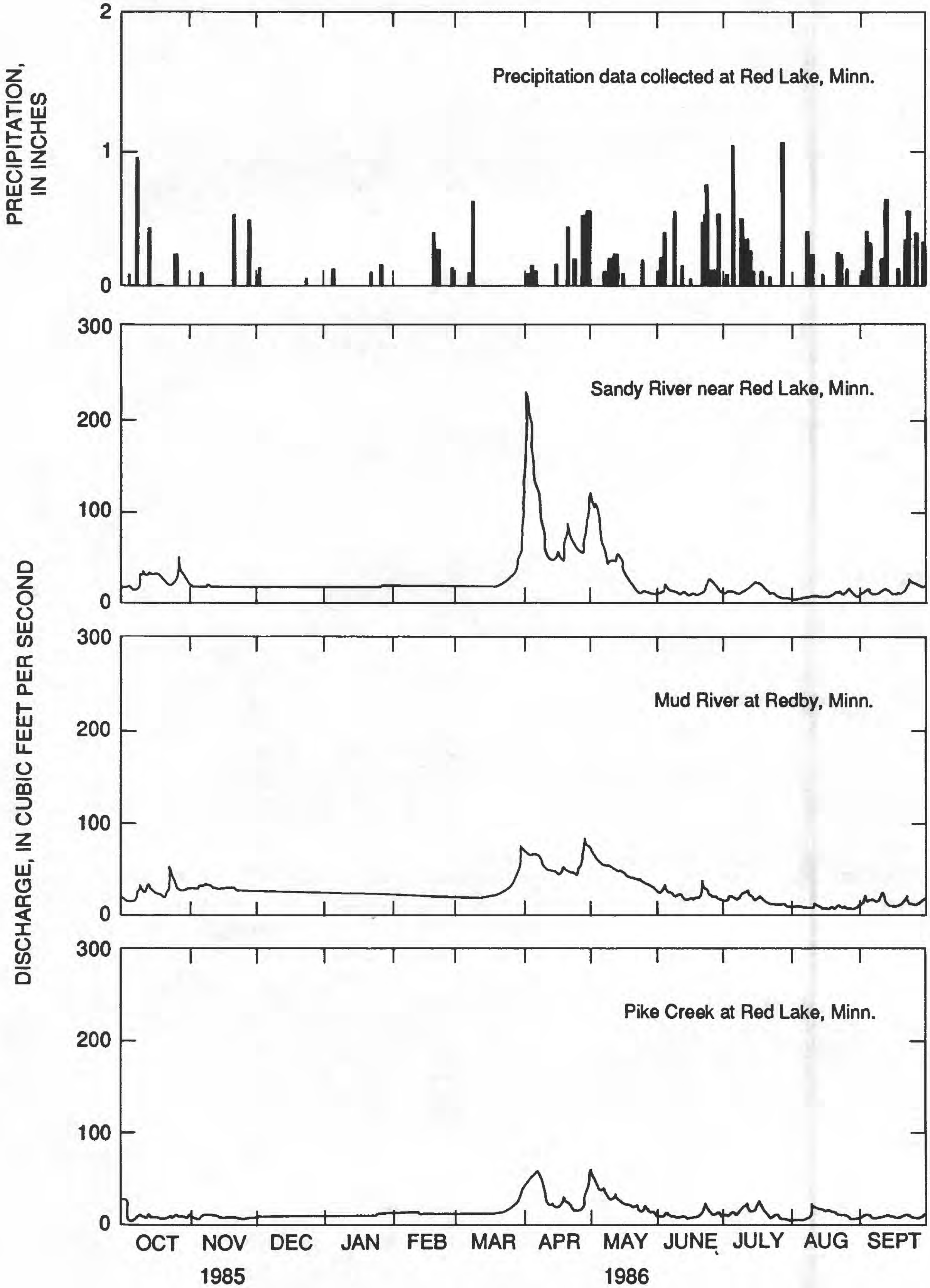


Figure 10.--Discharge of three streams and precipitation in the Red Lake Indian Reservation study area for the 1986 water year.

Peak flows at the gaging stations on Sandy River, Mud River, and Pike Creek were estimated with the following multiple regression equations that relate area and storage of the basins to the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence-interval flood discharges (Jacques and Lorenz, 1988):

$$Q_2 = 28.2\ A^{0.616}\ (St + 1)^{-0.108}$$
$$Q_5 = 62.3\ A^{0.617}\ (St + 1)^{-0.186}$$
$$Q_{10} = 92.5\ A^{0.615}\ (St + 1)^{-0.227}$$
$$Q_{25} = 139.\ A^{0.613}\ (St + 1)^{-0.270}$$
$$Q_{50} = 179.\ A^{0.610}\ (St + 1)^{-0.298}$$
$$Q_{100} = 224.\ A^{0.608}\ (St + 1)^{-0.323}$$

where Q_T is the T-year flood-magnitude estimate for the ungaged site in ft^3/s,
A is the area of the drainage basin above the ungaged site in mi^2, and
St is the storage area in the drainage basin above the ungaged site expressed as a percentage of the basin area. The storage area includes all lakes, ponds, and wetlands in the basin.

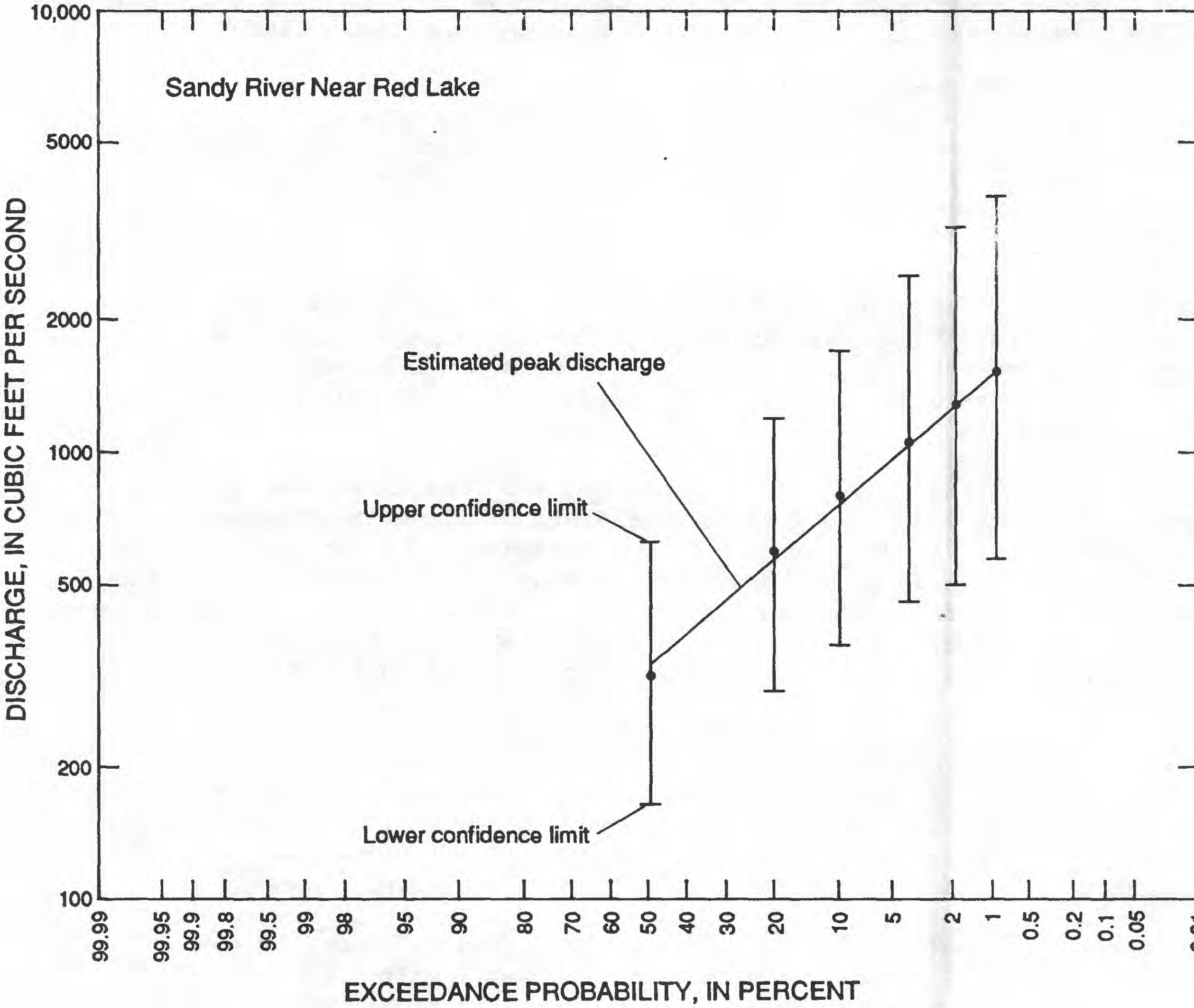
The drainage areas of Sandy River, Mud River, and Pike Creek basins were estimated from the 1:500,000 scale map of State of Minnesota Watershed Boundaries (1979) to be 76, 44, and 31 mi^2, respectively. The estimated storage, which is the percentage of the basin occupied by lakes, ponds, and wetlands, is estimated to be 8.0, 24.9, and 10.1 percent, respectively, for each of these three basins. Figures 11, 12, and 13 show the estimated flood peaks of the three streams are directly proportional to the area of their drainage basins.

Quality

Evaluation of the quality of surface water addressed the ability of Lower and Upper Red Lakes and the sampled streams to support fish and other kinds of wildlife. The results of analyses of samples collected from Lower and Upper Red Lakes and four streams in the study area are in tables 4 and 5.

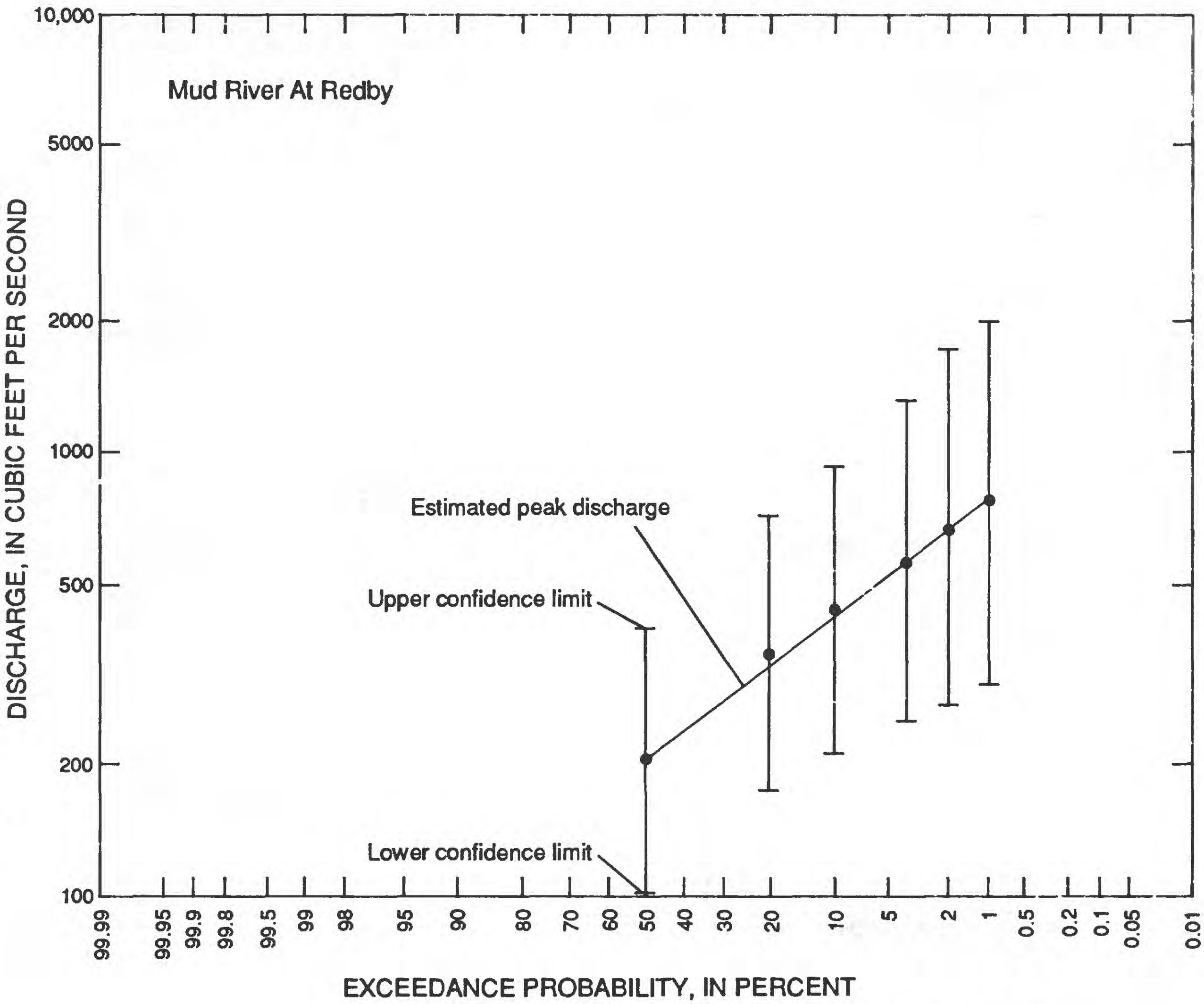
The prevalent water in Lower and Upper Red Lakes and the four sampled streams was calcium-magnesium-bicarbonate type water (fig. 14). The major ions in the surface water reflect the quality of the ground water that discharges into the lakes and streams. The concentrations of trace elements in samples collected from Lower and Upper Red Lakes and the four streams met criteria proposed by USEPA to protect against chronic effects on freshwater biota.

The concentration of dissolved mercury in the sample from Lower Red Lake was 0.1 μg/L. The USEPA recommended unit of 0.012 μg/L for mercury given in table 2 was established for the dissolved organic form of mercury, which is methyl mercury. The mercury concentration reported in this study includes the dissolved inorganic form of mercury, and a comparison of this concentration to the recommended limit, therefore, is inappropriate. The concentration of total dissolved mercury reported for Lower Red Lake appears to be very similar to the concentrations reported by Jenkins (1981), who estimated the background concentration of dissolved mercury in freshwater to be 0.08 μg/L. The median concentration of dissolved mercury in the major rivers of the United States was 0.2 μg/L during 1974-81 (Smith and others, 1987). Much of the observed mercury in surface water is likely to be from deposition of mercury that is released into the atmosphere from smelting and the combustion of fossil fuels (Hem, 1985).



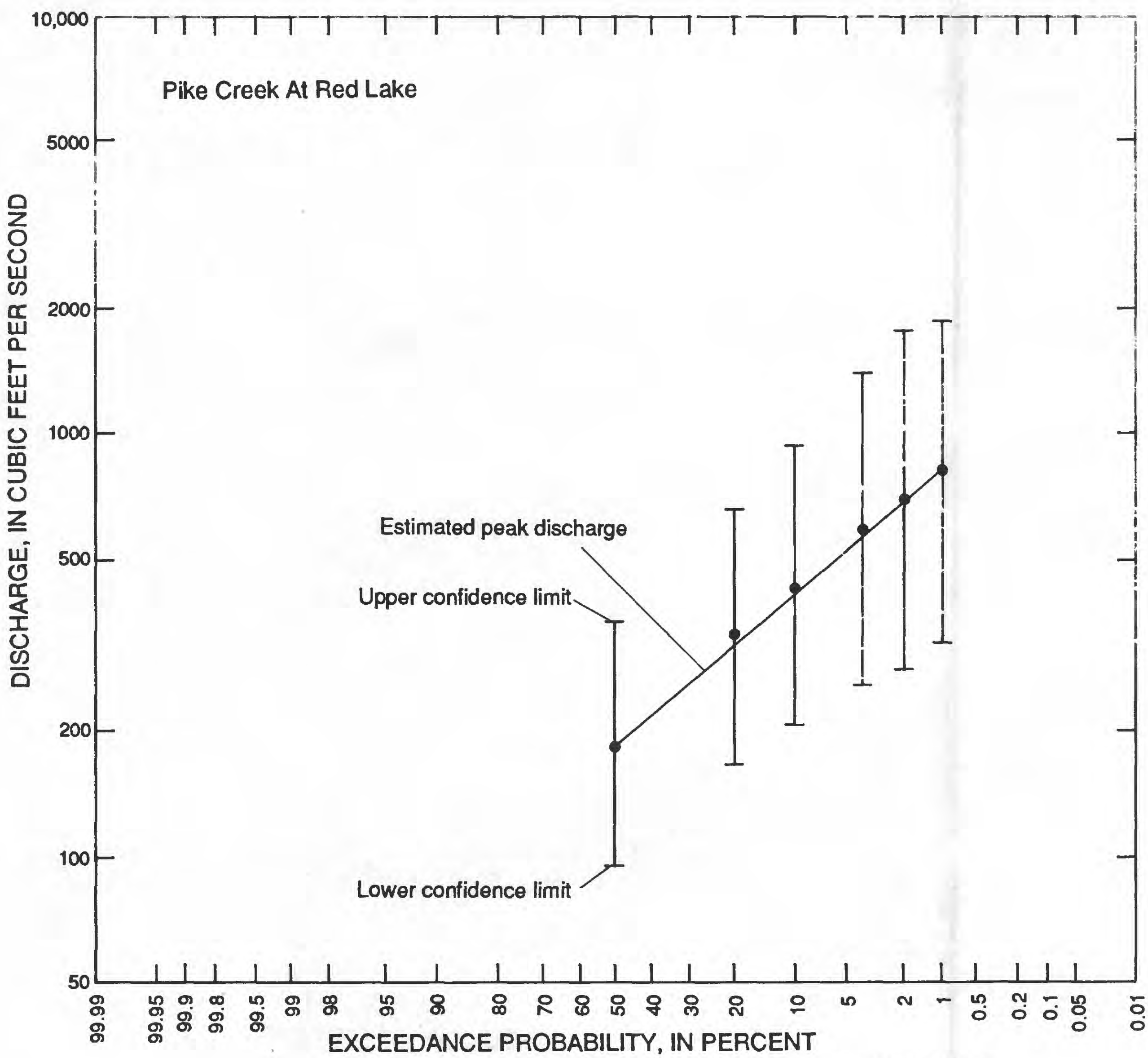
RECURRENCE INTERVAL, IN YEARS	ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND	95 PERCENT CONFIDENCE INTERVAL FOR THE ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND
100	1540	596 - 3982
50	1311	510 - 3367
25	1097	467 - 2574
10	809	377 - 1735
5	602	296 - 1223
2	322	161 - 642

Figure 11.--Flood frequency plots of the Sandy River in the Red Lake Indian Reservation study area.



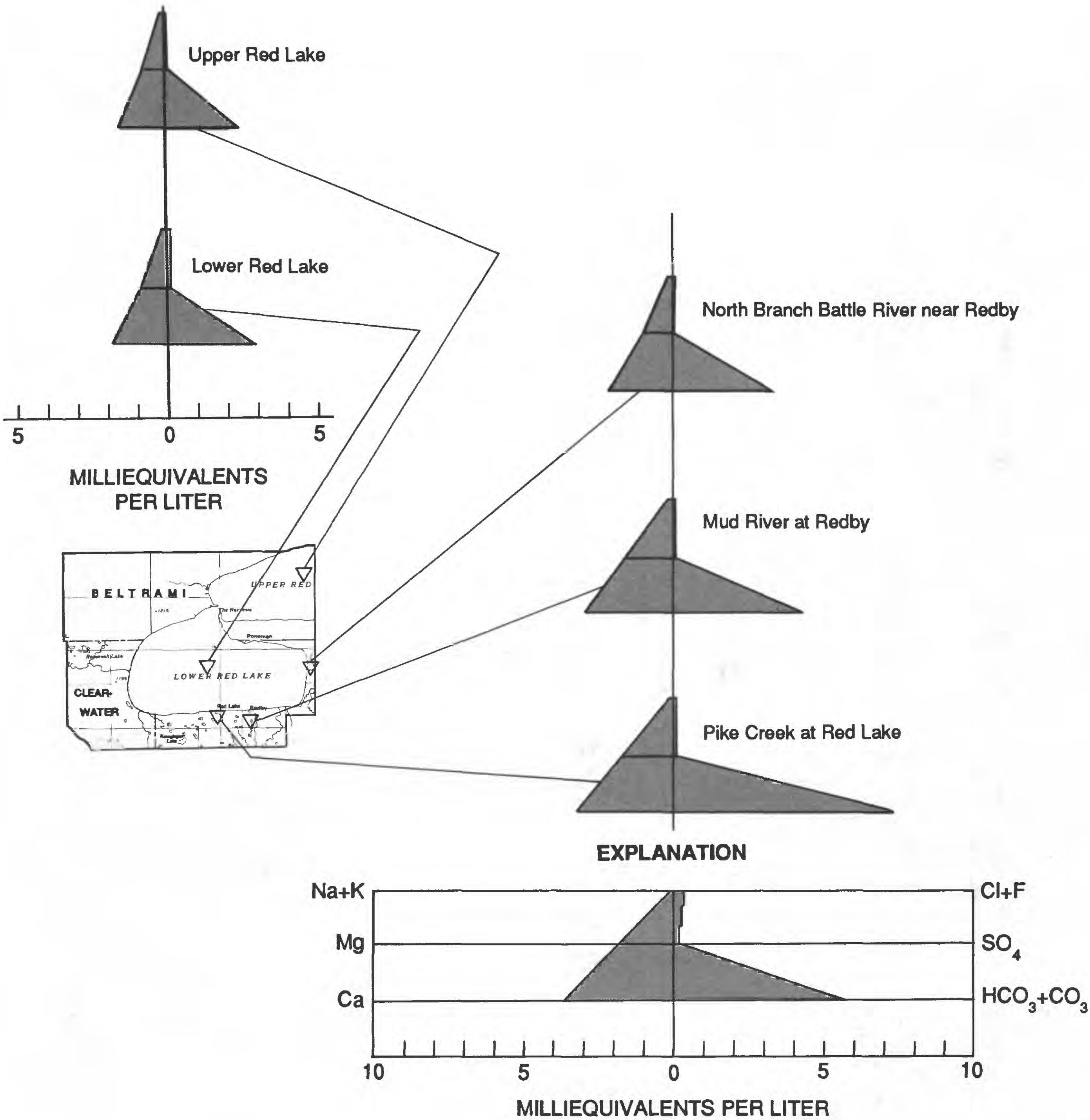
RECURRENCE INTERVAL, IN YEARS	ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND	95 PERCENT CONFIDENCE INTERVAL FOR THE ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND
100	781	302 - 2022
50	682	270 - 1720
25	587	250 - 1377
10	453	211 - 971
5	351	173 - 713
2	204	102 - 407

Figure 12.--Flood frequency plots of the Mud River in the Red Lake Indian Reservation study area.



RECURRENCE INTERVAL, IN YEARS	ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND	95 PERCENT CONFIDENCE INTERVAL FOR THE ESTIMATED PEAK DISCHARGE, IN CUBIC FEET PER SECOND
100	837	323 - 1934
50	715	283 - 1803
25	600	256 - 1408
10	446	208 - 956
5	334	164 - 678
2	182	91 - 363

Figure 13.--Flood frequency plots of Pike Creek in the Red Lake Indian Reservation study area.



Water-quality diagram based on an analysis of a sample collected from the indicated well. The size of the diagram is directly proportional to the dissolved solids concentration.

Figure 14.--Water-quality diagrams for samples collected from lakes and streams in the Red Lake Indian Reservation study area, August 1987.

Table 4.--*Chemical and physical characteristics of water from Lower and Upper Red Lakes in the Red Lake Indian Reservation study area, 1985-87*

[See Definition of Terms, p 9; lab, analysis or measurement made in a laboratory; field, analysis or measurement made at collection site; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; *E means estimated value; --, not analyzed; <, less than; °C, degrees Celsius; NTU, nephelometric turbidity units]

Station	USGS identification number	Location
1	480000095000001	Lower Red Lake, near center
2	480730094523001	Upper Red Lake, near center

Station	Date	Reservoir depth (feet)	Depth to top of sample interval (feet)	Depth to bottom of sample interval (feet)	Reservoir elevation in feet above sea level	Specific conductance, (µS/cm)		pH (standard units)		Temperature (°C)	
						field	lab	field	lab	air	water
1	8/7/85	31	--	--	1175	256	276	7.5	7.9	--	22.0
	8/11/87	--	0.0	1.5	1175	246	--	8.3	--	27.4	23.0
2	8/7/85	17	--	--	1175	212	--	8.0	--	--	22.0
	8/12/87	--	.0	1.5	1175	247	--	8.2	--	--	22.2
	8/7/85	--	--	--	1175	--	233	--	8.0	--	--

Table 4.--*Chemical and physical characteristics of water from Lower and Upper Red Lakes in the Red Lake Indian Reservation study area, 1985-87*--Continued

Station	Date	Barometric pressure (millimeters of mercury)	Turbidity (NTU)	Transparency, secchi disk (feet)	Oxygen, dissolved (mg/L)	Hardness, (mg/L as $CaCO_3$) total	Hardness, (mg/L as $CaCO_3$) noncarbonate lab	Calcium, dissolved (mg/L as Ca)
1	8/7/85	-	2.5	3.6	8.3	--	--	38
	8/11/87	729	--	8.2	7.9	--	--	--
						--	--	--
2	8/7/85	-	--	2.6	8.7	--	--	--
	8/12/87	-	--	5.6	7.8	120	2	32
	8/7/85	-	6.5	--	--			

Station	Date	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, total (mg/L)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, residue at 180 °C dissolved (mg/L)	Residue, total at 105 °C, suspended (mg/L)
1	8/7/85	12	*E4.6	2.0	142	6.2	1.9	176	5
	8/11/87	--	--	--	--	--	--	--	--
2	8/7/85	--	--	--	--	--	--	--	--
	8/12/87	--	--	--	--	--	--	--	--
	8/7/85	10	*E4.6	1.8	119	5.1	1.6	159	26

Table 4.--*Chemical and physical ch aracteristics of water from Lower and Upper Red Lakes in the Red Lake In dian Reservation study area, 1985-87*--Continued

		Nitrogen (mg/l as N)									
		Nitrite		Nitrite plus nitrate		Ammonia		Ammonia plus organic			
Station	Date	total	dissolved	total	dissolved	total	dissolved	total	suspended, total	dissolved	dissolved
1	8/7/85	--	0.11	--	--	0.03	--	0.6	0.0	0.6	0.71
	8/11/87	<0.01	<.10	<0.01	<0.1	.02	<0.01	1.7	--	1.2	--
2	8/7/85	--	<.01	--	<.1	.02	--	--	1.1	.6	--
	8/12/87	<.01	<.10	<.01	<.1	<.01	.01	2.0	--	1.4	--
	8/7/85	--	--	--	--	--	--	--	--	--	--

		Phosphorous (mg/L as P)								
Station	Date	total	dissolved	ortho, total	ortho, dissolved	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)
1	8/7/85	<0.01	<0.01	--	--	10	52	30	<1	<10
	8/11/87	.07	.02	<0.01	<0.01	--	--	--	--	--
2	8/7/85	<.01	--	--	--	--	--	--	--	--
	8/12/87	.12	.01	<.01	--	--	--	--	--	--
	8/7/85	--	--	--	.01	1	40	30	<1	10

Table 4.--*Chemical and physical characteristics of water from Lower and Upper Red Lakes in the Red Lake Indian Reservation study area, 1985-87*--Continued

Station	Date	Copper, dissolved (μg/L as Cu)	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Mercury, dissolved (μg/L as Hg)	Selenium, dissolved (μg/L as Se)
1	8/7/85	7	19	2	8	0.1	<1
	8/11/87	--	--	--	--	--	--
2	8/7/85	--	--	--	--	--	--
	8/12/87	--	--	--	--	--	--
	8/7/85	10	35	<1	9	--	<1

Station	Date	Silver, dissolved (μg/L as Ag)	Zinc, dissolved (μg/L as Zn)	Carbon (mg/L as C) organic suspended, total	Carbon (mg/L as C) organic dissolved	Carbon (mg/L as C) inorganic, dissolved	Cyanide total (mg/L as CN)
1	8/7/85	<1	9	--	--	--	<0.01
	8/11/87	--	--	4.3	15	22	--
2	8/7/85	--	--	--	--	--	--
	8/12/87	--	--	4.5	16	21	--
	8/7/85	<1	8	--	--	--	<.01

Table 5.--*Chemical and physical characteristics of water from four streams in the Red Lake Indian Reservation study area, 1985-87*

[See Definition of Terms, p 9; lab, analysis or measurement made in a laboratory; field, analysis or measurement made at collection site; mL, milliliter; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; *E means estimated value; --, not analyzed; <, less than; °C, degrees Celsius; NTU, nephelometric turbidity units]

Station	USGS identification number	Location
1	480013094403501	North Branch Battle River near Redby
2	475043095133101	Sandy River near Red Lake
3	475236095010301	Pike Creek at Red Lake
4	475254094541601	Mud River at mouth at Redby
5	474626094541001	Mud River above Redby

Station	Date	Elevation of land surface datum (feet above NGVD)	Discharge, instantaneous cubic feet per second	Specific conductance, (µS/cm)		pH (standard units)		Temperature (°C)		Turbidity (NTU)
				field	lab	field	lab	air	water	
1	8/15/85	1180	12	295	283	8.0	7.7	21	13.0	0.4
2	8/15/85	--	--	--	--	--	--	--	--	--
	8/8/85	--	--	440	421	8.1	7.9	26	17.5	1.5
3	8/15/85	--	--	480	459	8.0	7.8	--	14.5	.7
4	8/15/85	1175	--	410	408	8.0	7.8	--	14.5	15
5	8/20/85	1175	--	340	332	7.9	7.6	22	13.0	1.0

Station	Date	Coliform, fecal, (colonies per 100 mL)	Streptococci, fecal, (colonies per 100 mL)	Oxygen, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)			Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Ca)
					total	noncarbonate, field	noncarbonate, lab		
1	8/15/85	--	--	9.7	--	--	--	43	13
2	8/15/85	--	--	--	--	--	--	--	--
	8/8/85	--	--	8.7	--	--	--	59	22
3	8/15/85	110	90	9.1	260	0.0	3	66	22
4	8/15/85	--	--	9.4	230	--	1	59	19
5	8/20/85	--	--	8.8	--	--	--	45	17

Table 5.--*Chemical and physical characteristics of water from four streams in the Red Lake Indian Reservation study area, 1985-87*--Continued

Station	Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$) field	Alkalinity (mg/L as $CaCO_3$) lab	Sulfide, total (mg/L as S)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
1	8/15/85	*E4.6	0.4	162	151	<0.5	6.3	1.3
2	8/15/85	--	--	--	--	<.5	--	--
	8/8/85	*E4.6	2.0	227	233	--	3.8	1.6
3	8/15/85	*E4.6	1.5	360	253	<.5	1.5	5.1
4	8/15/85	*E4.6	2.3	214	225	<.5	<1.2	2.4
5	8/20/85	*E4.6	1.6	187	175	<.5	.2	1.8

				Nitrogen (mg/L as N)						Phosphorous (mg/L as P)		
					Ammonia	Ammonia plus organic						
Station	Date	Solids, residue at 180 °C dissolved (mg/L)	Residue, total at 105 °C, suspended (mg/L)	Nitrite plus nitrate dissolved	total	total	dissolved	suspended total	dissolved	total	total	dissolved
1	8/15/85	214	2	<0.1	0.08	1.1	0.8	0.3	--	0.18	0.06	0.05
2	8/15/85	--	--	--	--	--	--	--	--	--	--	--
	8/8/85	273	5	<.1	.03	.7	.6	.1	--	.06	.02	<.01
3	8/15/85	294	4	<.1	.01	.6	.5	.1	--	--	<.01	<.01
4	8/15/85	283	4	.11	.04	.9	.8	.1	0.91	.09	.03	<.01
5	8/20/85	221	2	<.1	.07	.9	.8	.1	--	.15	.05	.04

Table 5.--*Chemical and physical characteristics of water from four streams in the Red Lake Indian Reservation study area, 1985-87*--Continued

Station	Date	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Fe)	Iron, dissolved (µg/L as Pb)
1	8/15/85	1	36	<20	1	<10	<1	100
2	8/15/85	--	--	--	--	--	--	--
	8/8/85	4	110	40	1	<10	2	160
3	8/15/85	1	110	20	<1	<10	8	46
4	8/15/85	4	110	30	1	<10	5	240
5	8/20/85	3	67	<20	<1	<10	<1	290

Station	Date	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Carbon, organic dissolved	Carbon, organic suspended total	Cyanide total (mg/L CN)
1	8/15/85	3	32	0.3	<1	<1	12	30	0.2	<0.01
2	8/15/85	--	--	--	--	--	--	--	--	--
	8/8/85	<1	52	<.1	<1	<1	9	10	.4	<.01
3	8/15/85	1	33	<.1	<1	<1	6	15	.3	<.01
4	8/15/85	3	69	<.1	<1	<1	19	15	.3	<.01
5	8/20/85	2	51	.3	<1	<1	16	19	.2	<.01

The trophic state of lakes is a measure of their productivity. Eutrophic lakes support abundant plant and animal life; mesotrophic lakes support moderate levels of biological activity. The amount of nutrients in the biologically-active upper stratum of water in a lake affects the trophic state. Nutrient input to a lake depends on soil fertility, biological activity, and land-use practices in the drainage basin of the lake. Ground-water and streams that flow into a lake can potentially transport nutrients to the open water. These nutrients are used by phytoplankton or deposited onto the bottom sediments.

Lower and Upper Red Lakes appear to be eutrophic to slightly mesotrophic. The summer Secchi disk transparency, which is an indirect measure of the biomass in the upper layer of a lake, ranged from 2.6 to 8.2 ft in these lakes during midsummer of 1985 and 1987 (table 4). Eutrophic lakes in Minnesota tend to have Secchi disk transparencies that range from 1.5 to 6.5 ft (Heiskary and Helwig, 1985).

The total (dissolved plus suspended) organic-carbon concentrations in water collected from Lower and Upper Red Lakes during the summer of 1987 were 20 and 19 mg/L, respectively (table 4). Total organic-carbon concentrations in water from the four sampled streams ranged from 10 to 30 mg/L (table 5). Concentrations higher than 30 mg/L generally are above background levels and are indicative of polluted conditions (Wetzel, 1975, p. 542). The sample collected from the North Branch of the Battle River had a high total-organic-carbon concentration of 30 mg/L probably because peatlands, which supply organic compounds to runoff, comprise most of the drainage area for this stream.

Most organic carbon in the streams and lakes is in the dissolved form that plants and animals can rapidly metabolize. The ratio of dissolved organic carbon to suspended organic carbon commonly ranges from 6:1 to 10:1 in lakes and streams (Wetzel, 1975, p. 540). In samples from Lower and Upper Red Lakes, these ratios were approximately 3.5:1 because of the elevated levels of suspended organic carbon. Phytoplankton and littoral flora of the lakes were likely sources of the suspended organic carbon. The samples were collected in late summer when phytoplankton populations may have been near a late-season peak.

Most nitrogen compounds in samples collected from Lower and Upper Red Lakes during the summers of 1985 and 1987 were organic (table 4). The amount of dissolved organic nitrogen in the samples collected during the summer of 1987 was two to three times greater than the amount of particulate organic nitrogen. The dissolved fraction of organic nitrogen commonly exceeds the particulate fraction in freshwater, mesotrophic lakes.

The maximum concentrations of ammonia and nitrite plus nitrate, which are inorganic forms of nitrogen, were 0.02 and less than 0.01 mg/L, respectively, in samples collected in 1987. The low concentration of nitrite plus nitrate, which was probably due to the assimilation of these compounds by phytoplankton, was within the range of 0 to 10 mg/L that is commonly observed in unpolluted fresh water (Wetzel, 1975, p. 195-6). The ammonia concentration in the samples from Lower and Upper Red Lakes also were within the normal range (0 to 5 mg/L) for unpolluted surface water (Wetzel, 1975, p. 197). The ammonia in surface water generally forms as the end product of the decomposition of nitrogenous-organic compounds.

Phosphorus, which is a less abundant nutrient than carbon and nitrogen, commonly is the nutrient that limits growth of many kinds of algae. Total phosphorus concentration is the most meaningful indicator of potential algal productivity because of the rapid recycling and utilization of orthophosphate by algae. Typically, soluble inorganic orthophosphate comprises less than 5 percent of the total phosphorus in temperate zone lakes (Wetzel, 1975, p. 219).

The total phosphorus concentrations in samples collected from Lower and Upper Red Lakes in 1987, which were 0.07 and 0.12 mg/L respectively, exceeded the dissolved orthophosphate concentrations, which were less than 0.01 mg/L (table 4). The total phosphorus concentrations were outside the range of 0.01 to 0.05 mg/L that is characteristic of unpolluted surface water (Wetzel, 1975, p. 217). Runoff from bogs and peatlands that are rich in organic compounds possibly contribute phosphorus to Lower and Upper Red Lakes. Table 5 shows that the concentration of total phosphorus in samples collected from four streams flowing into Lower Red Lake ranged from less than 0.01 to 0.06 mg/L. The sample from the North Branch of the Battle River had the highest total phosphorus concentration, probably because of the large area of peatlands in the streams drainage basin.

The concentrations of nutrients in samples from Lower and Upper Red Lakes and from four inflowing streams were very similar (fig. 15). Suspended organic-carbon concentration was considerably higher in the lake samples than in the stream samples, however, because of the seasonal increase of phytoplankton populations in the lakes at the time of sample collection. The particulate, organic-carbon concentration in the open water of lakes generally decreases during late fall and winter when phytoplankton grow more slowly and settle to the bottom.

Vertical profiles of temperature, specific conductance, pH, and dissolved-oxygen concentration show the variation with depth of these properties and constituents in Lower Red Lake during August of 1987 (fig. 16). These profiles indicate that wind action thoroughly mixed the water in Lower Red Lake because of its shallow depth. The mixing action of the wind continuously circulated dissolved oxygen throughout the lake and prevented the depletion of dissolved oxygen in the bottom of the lake where decomposition of organic matter causes the consumption of oxygen.

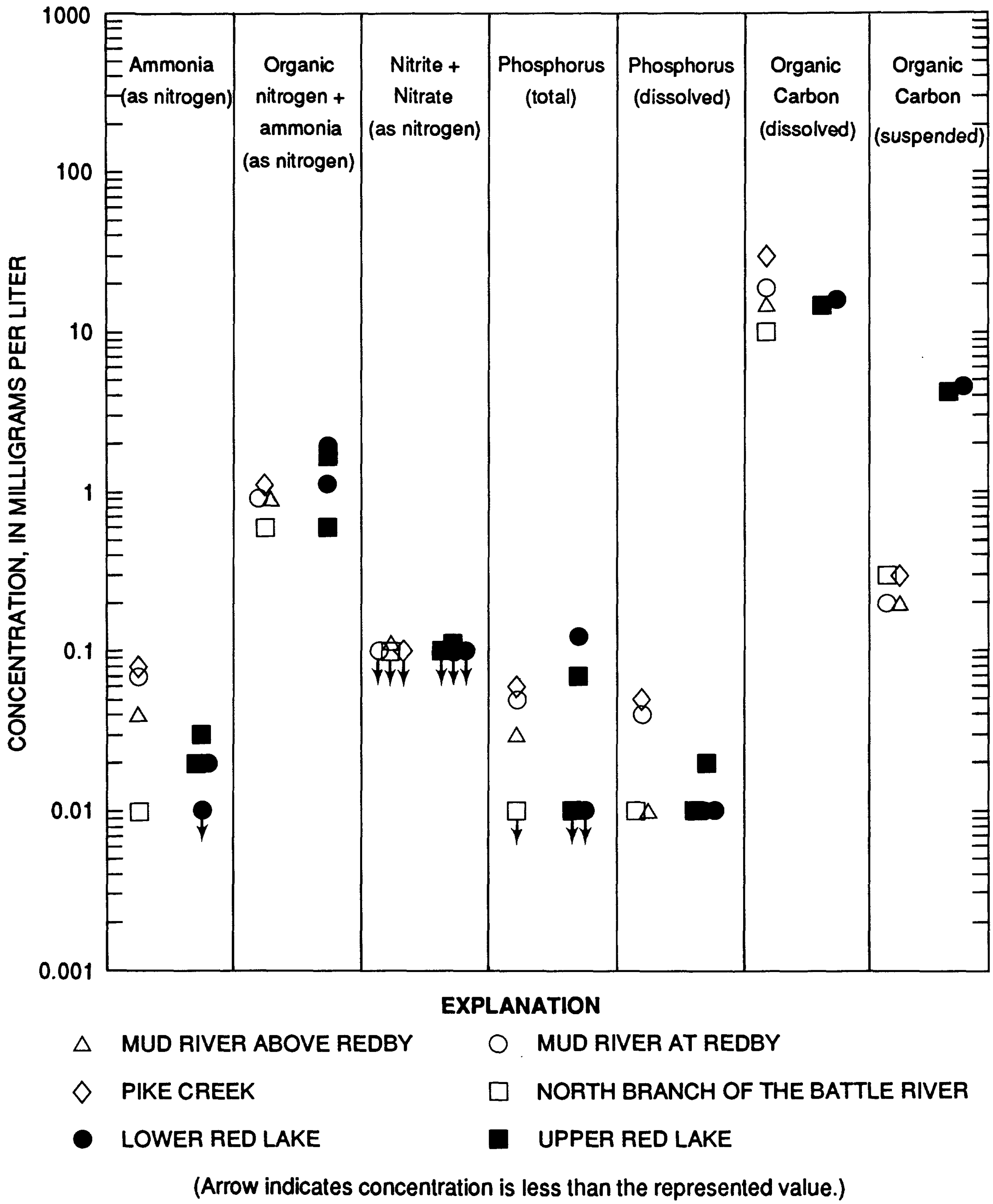


Figure 15.--Concentrations of selected nutrients in samples collected from Lower and Upper Red Lake, Mud River, North Branch of the Battle River, and Pike Creek, in the Red Lake Indian Reservation study area, August 1985 and August 1987.

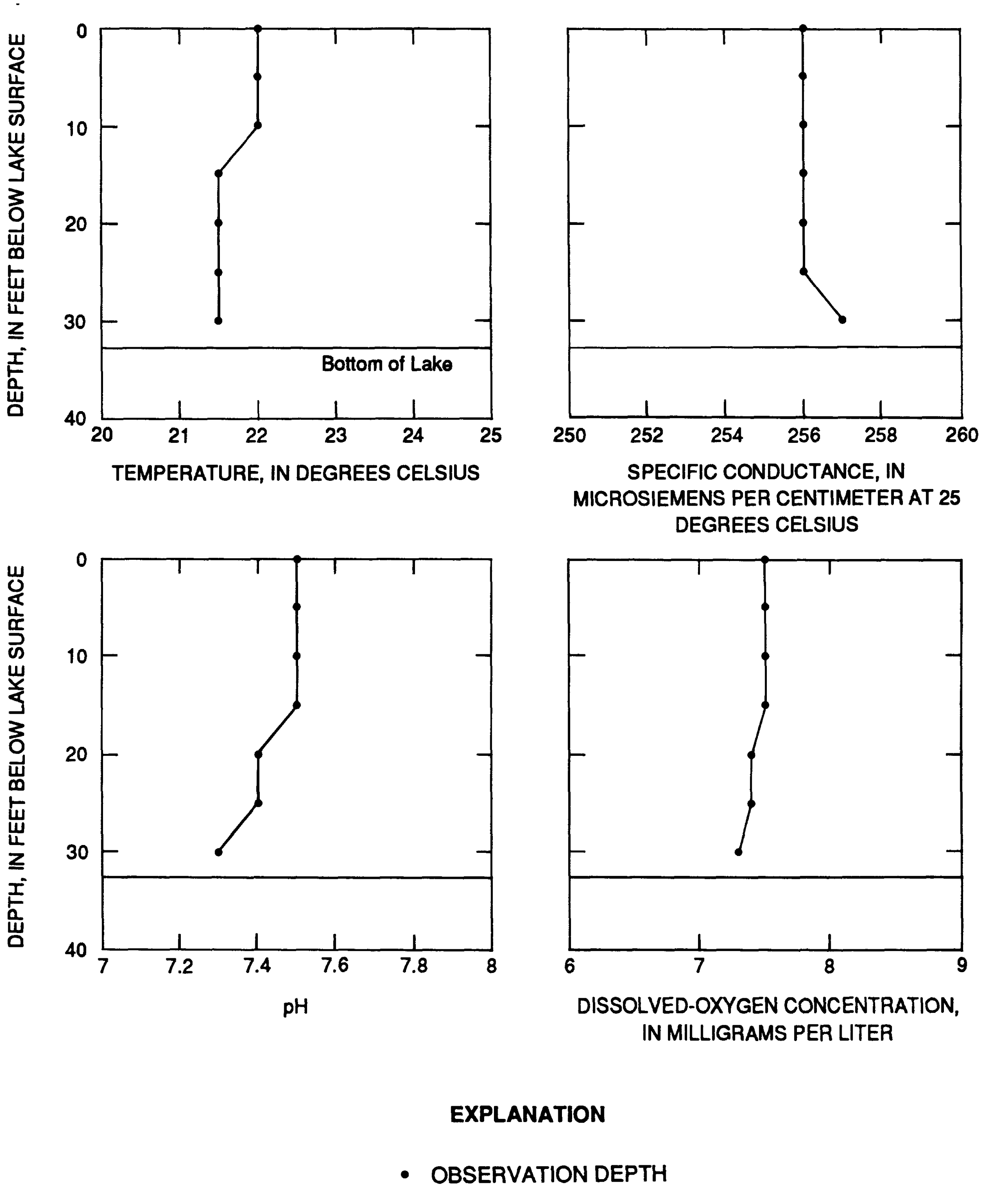


Figure 16.--Temperature, specific conductance, pH, and dissolved oxygen profiles at the approximate midpoint of Lower Red Lake in August 1987.

SUMMARY

This report presents an appraisal of the water resources of the Red Lake Indian Reservation in northwestern Minnesota. The study area is a contiguous block of land in Beltrami and Clearwater Counties that comprises approximately 80 percent of the 794,000-acre Reservation. Lower and Upper Red Lakes occupy 25 percent of the study area. Commercial forest land covers about one half of the study area, and noncommercial forest land, wetlands, and peat bogs cover most of the remainder.

Lake-plain deposits, till plains, and peatlands form the major landscape features. The peatlands were formed in lowland areas of lake-plain deposits. Glacial deposits (mostly till) underlie the surficial soils and the peat. Thin stratified layers of silt, sand, and gravel are interlayered with the till. Crystalline bedrock underlies the glacial deposits.

The study area is in a continental climatic zone of cold winters and warm summers. Mean annual precipitation is 22.7 in.; snowfall is approximately 20 percent of the total. Annual net recharge to the ground-water generally ranges from about 0.5 to 1.35 in., and annual runoff generally ranges from 2 to 3 in.

Most of the water pumped from wells in the study area comes from confined glacial-drift aquifers, which generally are 50 to 150 ft below land surface, but, locally, are as much as 225 ft below land surface. Estimates of the transmissivity of the confined glacial-drift aquifers range from 19 to 2,575 ft^2/d. Estimated yields from these aquifers range from 22 to 238 gal/min.

Quality of the ground water in the study area is suitable for drinking and other household uses. The concentrations of trace elements in samples collected from wells completed in the confined glacial-drift aquifers were below the maximum contaminant levels established by the U.S. Environmental Protection Agency for drinking water. Calcium, magnesium, and bicarbonate were the major inorganic ions in the ground water.

Surface water in the study area mainly consists of Lower and Upper Red Lakes, but also includes many smaller lakes and streams. Many of these streams flow into Lower Red Lake; Lower and Upper Red Lakes discharge into the Red Lake River. Discharge data collected during the 1986 water year from three streams flowing to Lower Red Lake show that the peak flows occurred in late March and early April in response to snowmelt.

The quality of the surface water generally met criteria established by the USEPA to protect against chronic effects on freshwater life. The major ions in the surface water are calcium, magnesium, and bicarbonate. The summer Secchi-disk transparencies were 2.6 and 8.2 ft in Lower and Upper Red Lakes, respectively. These measurements indicate productivity in these lakes was eutrophic to mesotrophic. The concentration of total organic carbon in samples collected from Lower and Upper Red Lakes and four streams were within limits that are characteristic of water little affected by human activity. The nitrogen compounds in samples collected from Lower and Upper Red Lakes were mostly organic. The concentrations of nitrite plus nitrate were less than 0.01 mg/L, which is indicative of unpolluted water. Most of the phosphorus in the samples, which ranged from 0.07 to 0.12 mg/L, was in the particulate organic fraction.

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