WATER RESOURCES OF THE WHITE EARTH INDIAN RESERVATION, NORTHWESTERN MINNESOTA

By J. F. Ruhl

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply Inch-Pound Unit	By	To Obtain Metric Unit
pounds per foot squared per year ($lbs/ft^2/yr$)	2.049×10^{-4}	grams per meter squared per year ($g/m^2/yr$)
foot (ft)	0.3048	meter (m)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
degree Fahrenheit (°F)	°C = 5/9 x (°F - 32)	degree Celsius (°C)

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

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ (°C) + 32$$

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

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.

Test-Hole and Well-Numbering System

The system of numbering wells and test holes is based on the U.S. Bureau of Land Management's system of land subdivision (township, range, and section). The first numeral of a test-hole or well number indicates the township, the second the range, and the third the section in which the point is located. Uppercase letters after the section number 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, and C 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; if a point can be located within a 10-acre tract, three uppercase letters are shown in the location number. For example, the number 143.39.19BCD indicates a test hole or well located in the SE¼SW¼NW¼, Sec. 19, T.143 N., R.39 W.

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ABSTRACT

Water resources in the White Earth Indian Reservation meet the present (1988) needs for potable supply and other household uses and provide valuable ecological, recreational, and aesthetic benefits. Total annual water use in the Reservation is about 460 million gallons per year. Domestic supply from privately owned wells and municipal systems accounts for roughly three-fourths of the water use, and irrigation of croplands and nurseries accounts for approximately one-fourth, depending on rainfall.

Glacial-drift aquifers are the source of ground water in the Reservation. Unconfined-drift aquifers consist of two surficial outwash deposits that extend over approximately one-fifth of the Reservation. One deposit trends along a north-south strip through the central part of the Reservation, and the other occupies the southeastern corner. Confined-drift aquifers are the most significant source of ground-water supply. These aquifers are discontinuous lenses of sand and gravel that hydraulically are poorly connected to each other. The aquifers are 50 to 300 feet below land surface and 5 to 25 feet thick. Yields from these aquifers typically range from 10 to 100 gallons per minute.

Surface water in the Reservation consist of numerous lakes, wetlands, prairie potholes, and streams. The larger, deeper lakes in the eastern and southern parts of the Reservation support walleye and northern pike and provide recreational opportunities for swimming and boating. The shallower lakes and prairie potholes are used to produce wild rice and also are managed to provide waterfowl habitat. Most of the streams in the Reservation drain the headwater areas of basins that are part of the Red River of the North watershed; however, several small streams in the southeastern part drain to the Crow Wing River, which is part of the Mississippi River drainage system. The Wild Rice River drains the largest basin in the Reservation.

Ground water is mostly a calcium magnesium bicarbonate type. Dissolved-solids concentration of the ground water generally is greater in the deeper confined-drift aquifers than in the shallower unconfined-drift aquifers. The concentrations of sodium and sulfate in water from the confined-drift aquifers are higher in the northwestern part of the Reservation than in the rest of the aquifer. Except for elevated concentrations of iron and manganese, the quality of the ground water meets the criteria established by the U.S. Environmental Protection Agency (USEPA) for drinking water.

Surface water also is a calcium magnesium bicarbonate type. Lake waters are hard and alkaline and are mesotrophic to eutrophic in productivity. Quality of the lake and stream water is suitable for native forms of freshwater biota, although the concentration of total recoverable mercury exceeds the 0.012 micrograms per liter maximum contaminant level; that level, established

by USEPA for the organic form of dissolved mercury, is intended to protect against chronic effects on freshwater life. Available information, however, indicates that the amount of mercury in edible tissue from fish in alkaline lakes of northwestern Minnesota is within safe limits. The concentrations of phosphorus and nitrate in the streams are below levels that indicate pollution problems.

INTRODUCTION

This report presents the findings of a water-resource study of the White Earth Indian Reservation. The impetus for this study was a 1978 federal mandate to the Bureau of Indian Affairs to review Indian water-rights claims in reservations throughout the United States. Information about the water resources of the 12 Indian Reservations in Minnesota presently is insufficient to review water rights claims as required by the Bureau of Indian Affairs. Consequently, the Minnesota District of the U.S. Geological Survey conducted this study in cooperation with the White Earth Indian Reservation to satisfy the need for information about the Reservation's water resources.

Purpose and Scope

This report describes the water resources of the White Earth Indian Reservation. The report (1) describes the areal extent and thickness of the unconfined-drift aquifers, (2) describes the hydraulic properties of the unconfined- and confined-drift aquifers, (3) describes the ground-water regional flow system, (4) estimates the streamflow characteristics for the 1985 water year, and (5) assesses the quality of the surface and ground water.

Available information about the natural resources in the Reservation was obtained from a literature survey. A wide range of published materials, including many of those cited in the following section, 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.

Population data and pumpage records from the Minnesota Department of Natural Resources and the Reservation were the basis for estimates of water use. Data on the hydrogeology and water levels of the unconfined-drift aquifers were obtained from 40 test wells and 10 observation wells installed for this project. Approximately 400 commercial drillers' logs provided hydrogeologic data about the confined-drift aquifers. Stage-discharge data collected during the 1985 water year from four streams were the basis for estimation of annual runoff from these drainage basins. Quality of water on the Reservation was assessed by evaluation of data collected from four gaged streams, nine lakes, and the unconfined-drift and confined-drift aquifers, and from historical data supplied by the White Earth Indian Reservation, Minnesota Chippewa Tribe, and Indian Public Health Service.

Previous Investigations

One of the earliest descriptions of the hydrogeology of the area was by Allison (1932), who studied the geology and water resources of northwestern Minnesota. More detailed information about the geology of northwestern Minnesota is given by Leverett (1932), Wright (1962), and Wright and Ruhe (1965). Hydrologic atlases by Maclay and others (1969), Winter and others (1969), and Winter and others (1970), summarize the climate, hydrogeology, surface-water resources, and water quality of the Buffalo, Otter Tail, and Wild Rice River watersheds, respectively. Helgesen (1977) evaluated the ground-water resources of the Pineland Sands area, which includes the southeastern part of the Reservation. Miller (1982) conducted a similar investigation of the Pelican River sand-plain aquifer, which borders the southern boundary of the Reservation. Ford and others (1979) and Tornes (1980) conducted water quality studies of the Wild Rice River.

Physical Setting

The White Earth Indian Reservation, located in northwestern Minnesota (fig. 1), covers about 1,300 square miles. Most of the western third of the Reservation is cultivated, and most of the eastern two-thirds is forested (fig. 2). Roughly one-fifth of the Reservation is pasture, open water, marshland, and residential development (written commun. from Minnesota Land Management Information Center). The landscape is gently to steeply rolling in the morainal areas and till plains, undulating and shallow depressional in the lacustrine plains, and nearly level in the outwash.

The Reservation contains many lakes and streams that provide recreational opportunities for fishing, waterfowl production, boating, and swimming. The major stream is the Wild Rice River, which drains approximately 60 percent of the Reservation. Drainage from the rest of the Reservation is in the Buffalo, Otter Tail, Crow Wing, and Red Lake River watersheds (fig. 3).

The surficial geological features in the Reservation are the result of multiple glaciations. Ice sheets that advanced across the north-central United States one or more times during the Pleistocene age left behind deposits of glacial drift as much as 300 feet thick. Glacial drift consists of unsorted clay, silt, sand, and boulders, known as till, and stratified deposits of sand and gravel. Most of the stratified glacial material is outwash deposited from glacial meltwater streams. Stratified glacial material also is present in ice-contact deposits, such as eskers and kames.

Till is the major component of glacial moraines, which extend over roughly three-fifths of the Reservation (fig. 4). Many of the outwash deposits in the Reservation are interbedded in the till. Two outwash deposits in the Reservation form surficial outwash plains on top of till. One of these outwash plains forms a narrow strip that trends along a north-south axis through the center of the Reservation, and the other occupies the southeastern part (fig. 4). Glacial lakes filled with silt and clay formed lacustrine plains that occupy the western side of the Reservation.

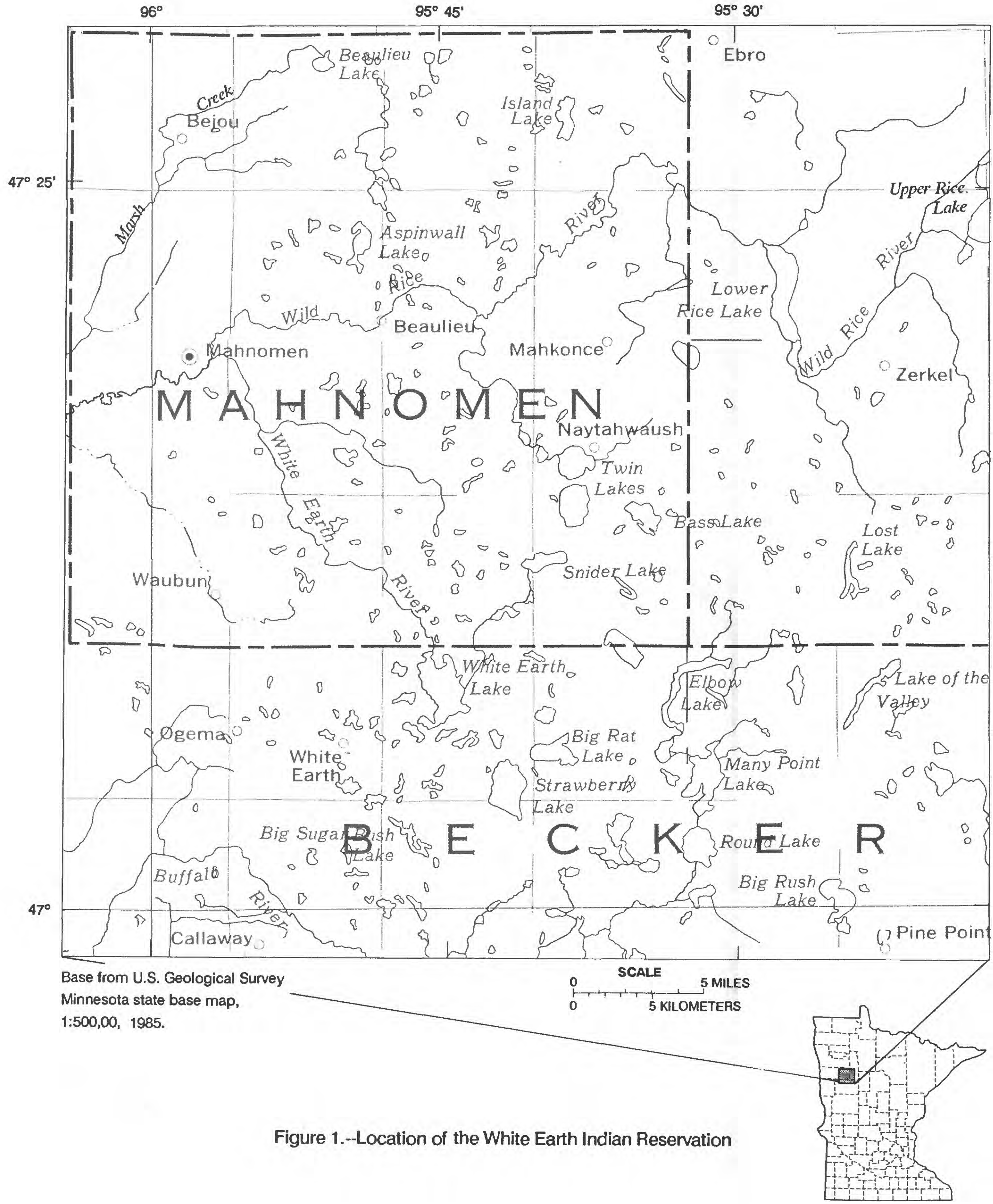


Figure 1.--Location of the White Earth Indian Reservation

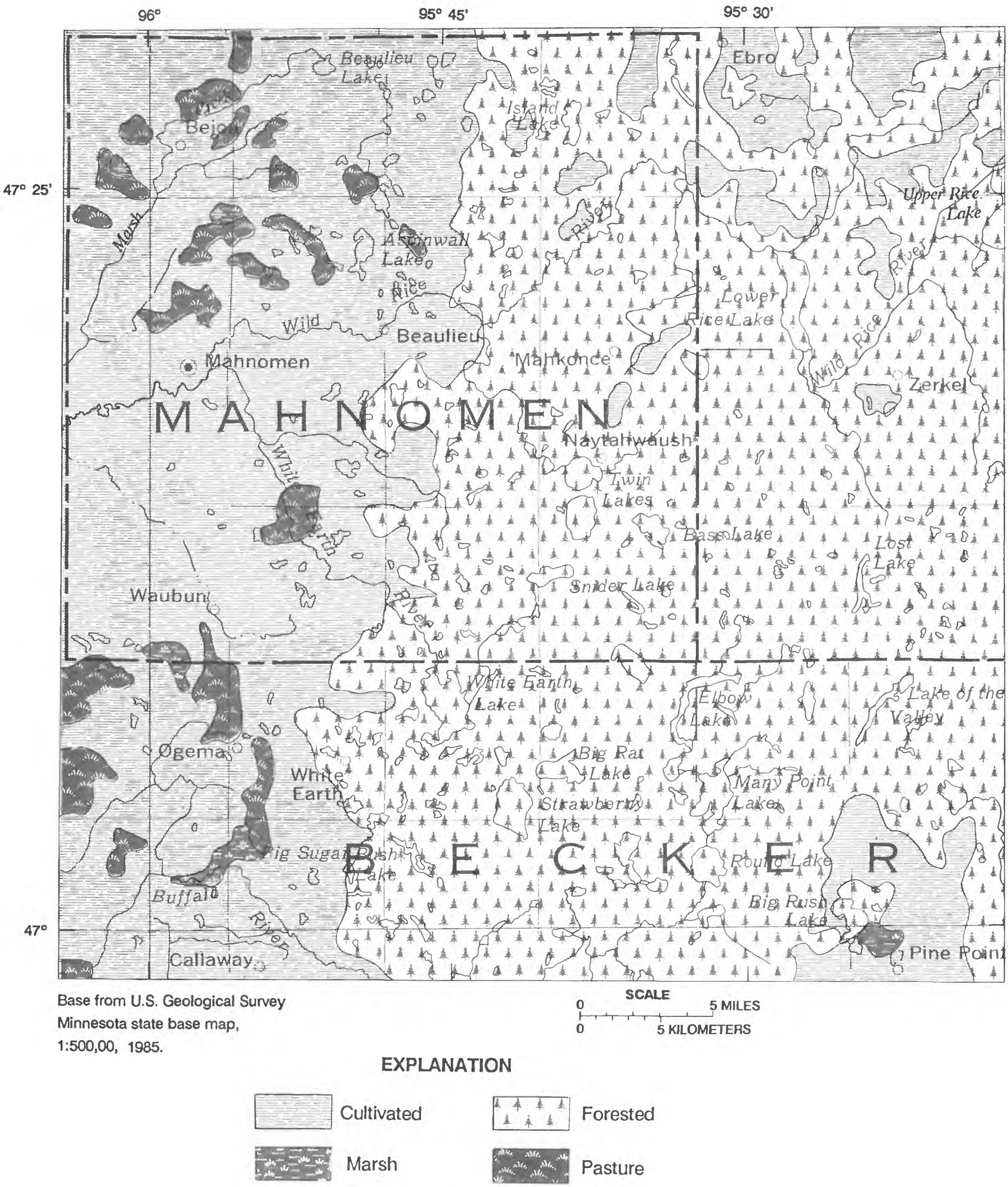


Figure 2.--Land use in the White Earth Indian Reservation (land-use data from the Land Management Information Center, Minnesota State Planing Agency, 1969 data base)

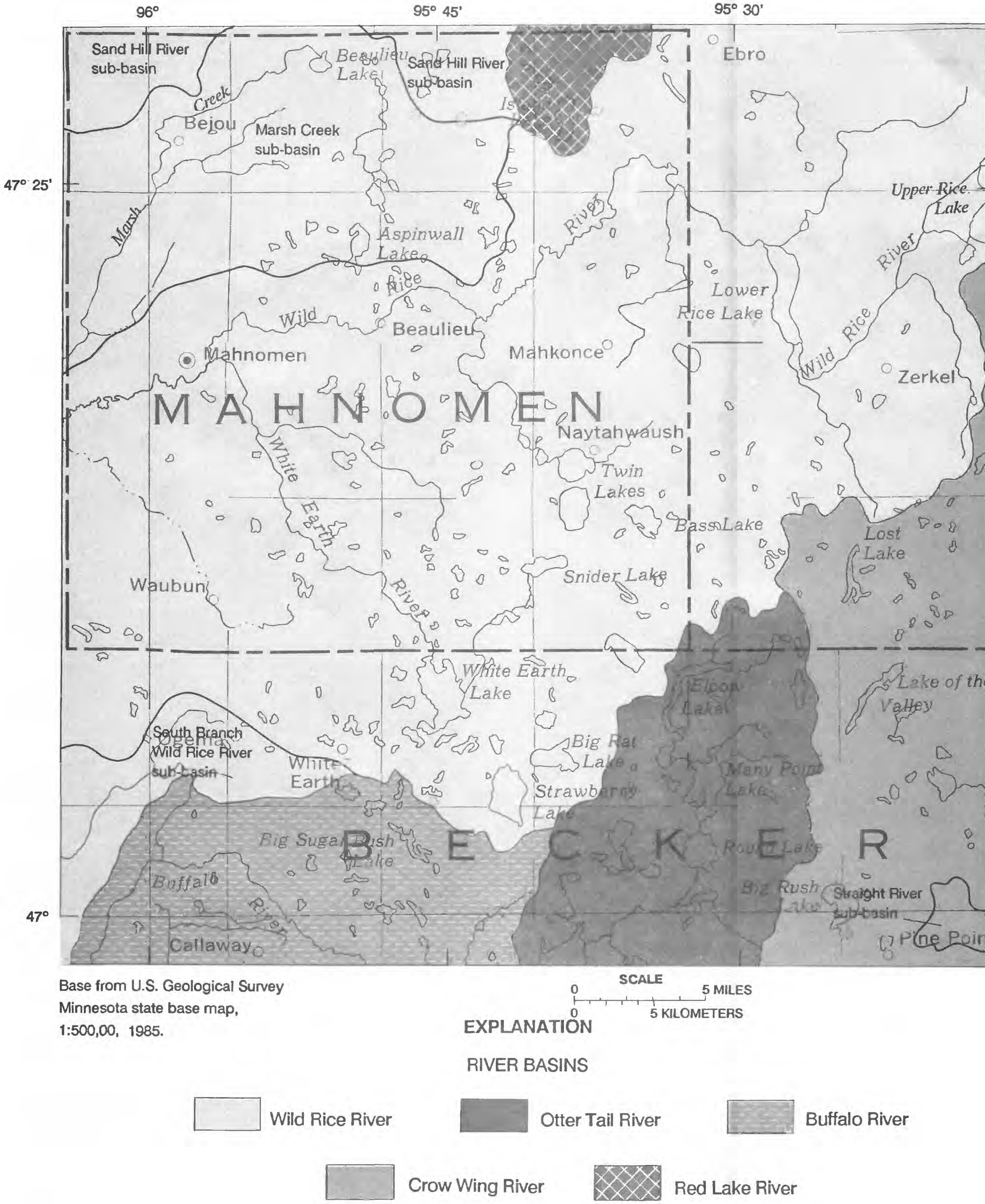
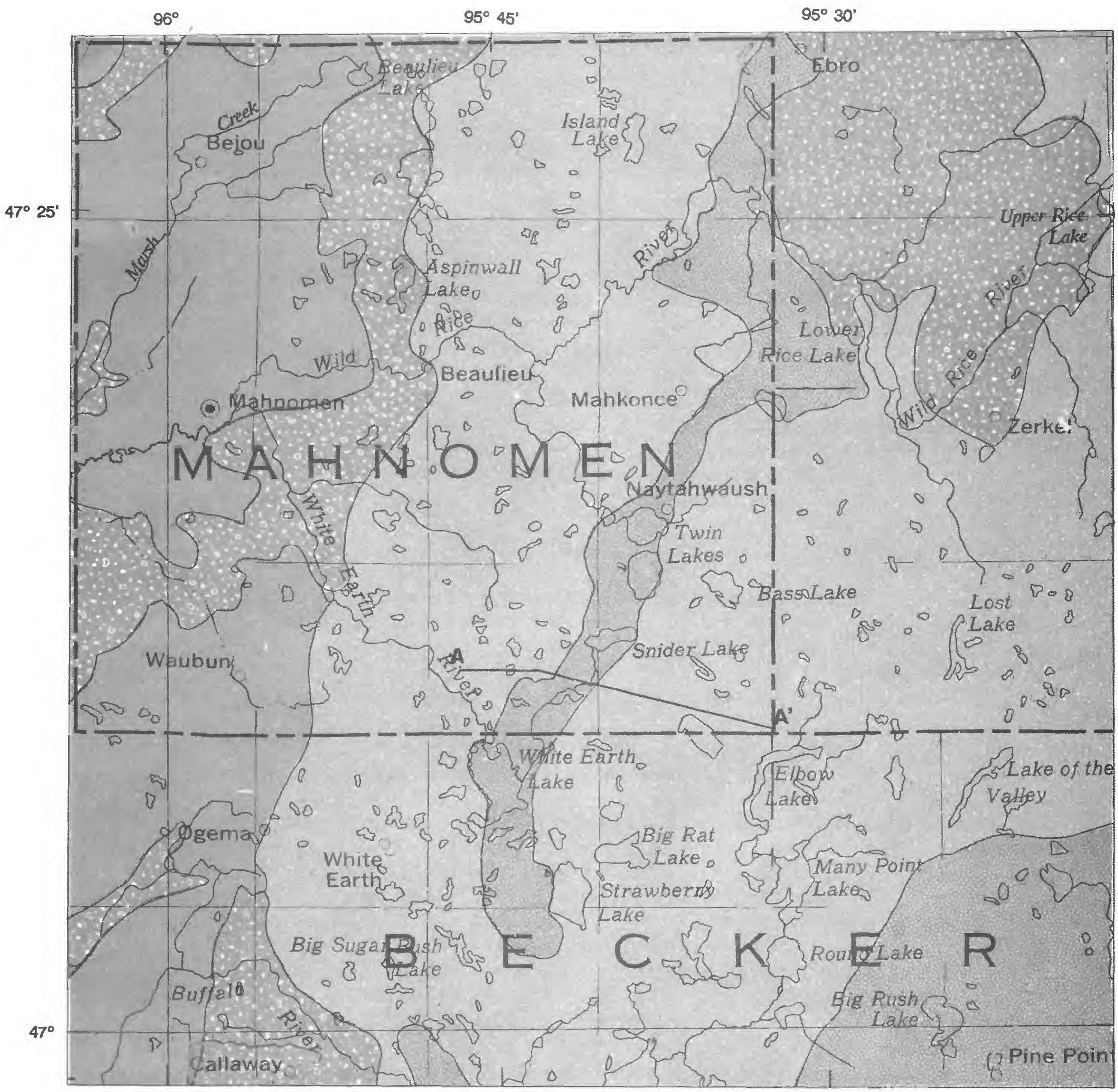


Figure 3.--Primary basins and sub-basins in the White Earth Indian Reservation



Base from U.S. Geological Survey Minnesota state base map, 1:500,00, 1985.

SCALE
0 — 5 MILES
0 — 5 KILOMETERS

Geology modified from Minnesota Soil Atlas, Bemidji Sheet, 1980.

EXPLANATION

- Glacial moraine
- Surficial outwash
- Till plain
- Lacustrine plain

Figure 4.--Surficial geology in the White Earth Indian Reservation

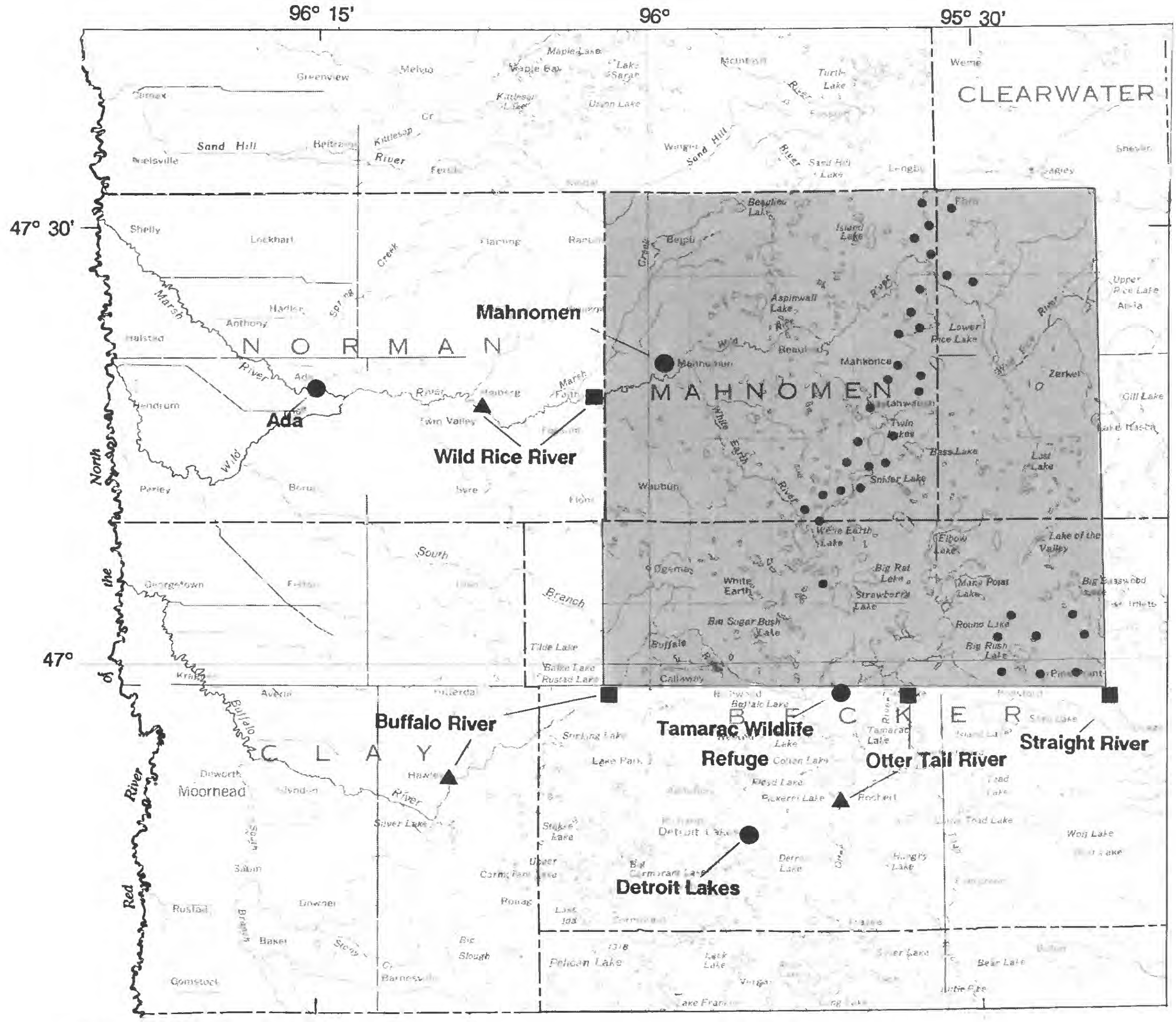
The stratified deposits of sand and gravel in the Reservation are aquifers. These deposits provide usable quantities of ground water to wells. The confined deposits of outwash embedded in the till are the primary aquifers, and the unconfined surficial-outwash deposits are secondary aquifers.

Soils in the Reservation are mainly deep, silty to loamy, and well drained (University of Minnesota Agricultural Experiment Station, 1980). These soils were formed from calcareous glacial till that is present in the morainal areas and till plains. Some soils, particularly those in the depressional areas of the lacustrine plains, are poorly drained. The parent materials of these soils were deposits that formed on glacial lake beds. These soils have more clay and, therefore, have a high water-holding capacity. The well-drained, sandy soils that developed in the outwash have a very low water-holding capacity.

The Reservation is within a continental climatic zone, where temperature and precipitation vary widely. Normal high temperatures during midsummer are 80 to 85 °F (degrees Fahrenheit), and normal lows during winter are about -10 °F. The average annual precipitation varies from 23 inches in the extreme southwestern corner of the Reservation to 26 inches along the eastern side. The annual snowfall is roughly 40 inches, which is about 15 percent of the total precipitation (Winter and others, 1970).

Long-term precipitation data collected at the Ada weather station (fig. 5) indicate that cycles of wet and dry periods lasting as long as 25 years may occur. The driest cycle of record was from approximately 1915 to 1940, which was followed by a 10-year period of above-normal precipitation, followed by another 5 years of below-normal precipitation. The cumulative departure from the average annual precipitation at the Mahnomen weather station (fig. 5) shows precipitation was above normal nearly every year from 1961 to 1975, and was below normal 5 out of the next 7 years until 1982 (fig. 6).

Most of the annual precipitation in the Reservation returns to the atmosphere by evapotranspiration. The potential evapotranspiration, on average, can be 3 to 6 inches greater per year than the precipitation. Approximately 10 to 20 percent of the precipitation becomes runoff. Annual runoff, which is the average depth of water over a drainage basin that is equivalent in volume to the annual streamflow from the drainage basin, generally ranges from 2 to 4 inches in the Reservation. Both overland flow, which is water that travels over the ground surface to a stream channel, and subsurface flow, which includes water that moves laterally through the upper soil layers into a stream channel immediately after storm events and groundwater that discharges into stream channels during dry weather, contribute to annual runoff. Estimates of the evapotranspiration and runoff in an annual water budget of the Wild Rice River basin are 20.1 and 2.46 inches, respectively (Winter and others, 1970). These components of the water budget vary in response to many factors, such as the precipitation, temperature, wind speed, and vegetative cover.



Base from U.S. Geological Survey Minnesota State base map, 1:500,000, 1985.

SCALE: 0–20 MILES; 0–20 KILOMETERS

EXPLANATION

- (shaded) White Earth Indian Reservation
- ● Weather service and observation wells
- • Test hole
- ▲ Long-term stream-flow gaging stations
- ■ Short-term stream-flow gaging station at Reservation boundry

Figure 5.--Hydrogeologic and climatologic data-collection sites used in the White Earth Indian Reservation

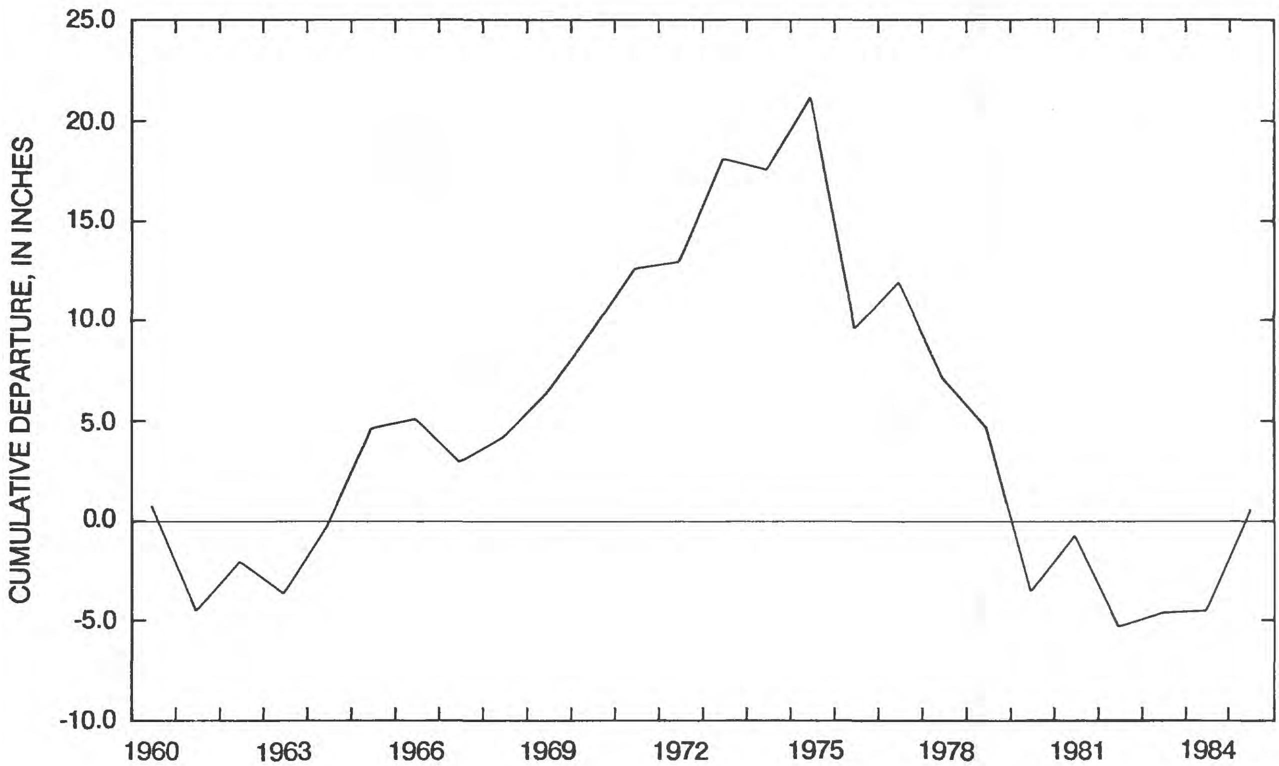


Figure 6.--Cumulative departure from average annual percipitation measured at the Mahnomen weather station, 1961-85

Total annual ground-water use in the Reservation estimated for 1985 is 458.7 million gallons (fig. 7). Rural domestic use accounted for slightly more than half, and municipal supply accounted for nearly one-fourth, of the estimated yearly total. Ground-water use for cropland irrigation varies in response to the amount of annual precipitation. The reported pumpage for cropland irrigation in 1982, when the annual rainfall in the Reservation was below normal (fig. 6), was 141.1 million gallons, which is nearly 1.5 times greater than the amount reported in 1985.

WATER RESOURCES

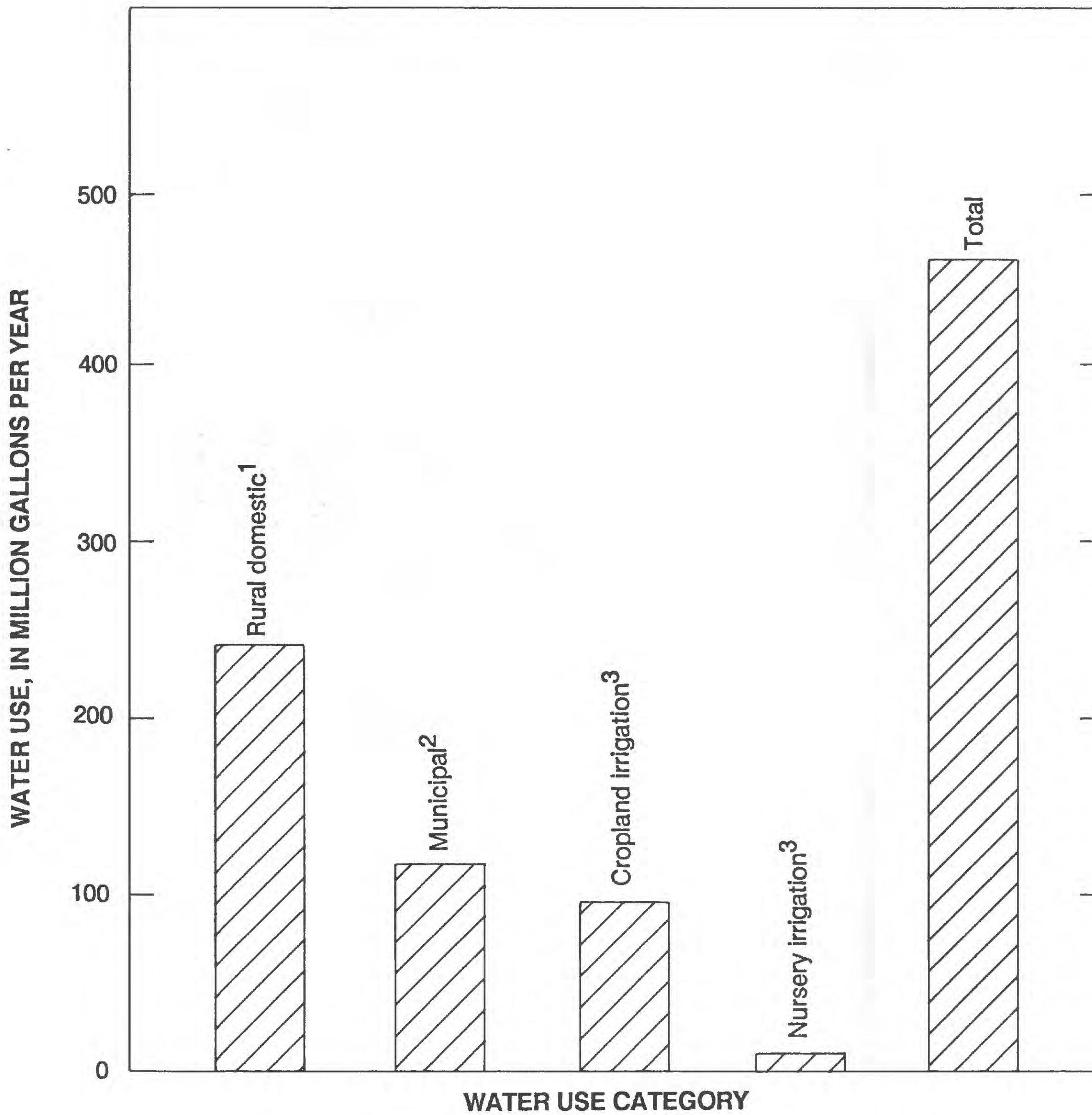
The White Earth Indian Reservation lies mainly in the Red River of the North drainage basin, which is the headwaters area of the greater Hudson Bay drainage system. The combined interactions of climate, geology, and vegetation in the Reservation have culminated in the formation of aquifers that are excellent sources of ground water and streams and lakes that are habitat for fish and wildlife. The Reservation is in a temperate, mildly humid region where much of the precipitation is available for evapotranspiration. The amount of runoff from the Reservation is equivalent to about 10 percent of the annual precipitation during a typical year. The source of most of the runoff is ground-water discharge. Precipitation and snowmelt within recharge areas of the Reservation replenish the ground-water reservoir. Although the total amount of ground water available in storage varies from year to year, the ground-water supplies in the Reservation aquifers are likely to be fairly constant over the long term barring any significant changes in the hydrologic system.

Ground Water

Glacial-drift aquifers are the source of water for households, municipalities, and irrigation in the Reservation. These aquifers consist of permeable deposits of sand and gravel that readily yield water to wells. These deposits are the surficial outwash shown in figure 4 and deep-drift outwash embedded in the till and lake-bed sediments. Most of the glacial drift in the Reservation is till. Till, which transmits very small quantities of water, is rarely used as an aquifer.

Hydrogeologic Framework

Glacial-drift aquifers are commonly classified as unconfined (water table) or confined (artesian). Ground water in unconfined-drift aquifers is open to the atmosphere, and the water level in these aquifers rises and falls with the surrounding water table in direct response to climatic conditions. The water level in wells completed in confined aquifers rises above the upper surface of these aquifers. Confined-drift aquifers underlie confining units, which consist of materials of low permeability, such as till. Figure 8 schematically shows the vertical sequence of aquifers and confining units in glacial drift along a representative line of section in the Reservation.



[1]Based on an assumed per-capita water use of 88 gallons per day for a rural population of 7,500 people.

[2]Based on pumpage data supplied by the White Earth Indian Reservation for the communities of Naytouwaush and White Earth and water utility officials for Waubun, Callaway and Mahnomen.

[3]Based on pumpage data supplied by the Division of Waters in the Minnesota Department of Natural Resources.

Figure 7.--Estimated ground-water withdrawals, by major use category in the White Earth Indian Reservation, for the 1985 water year

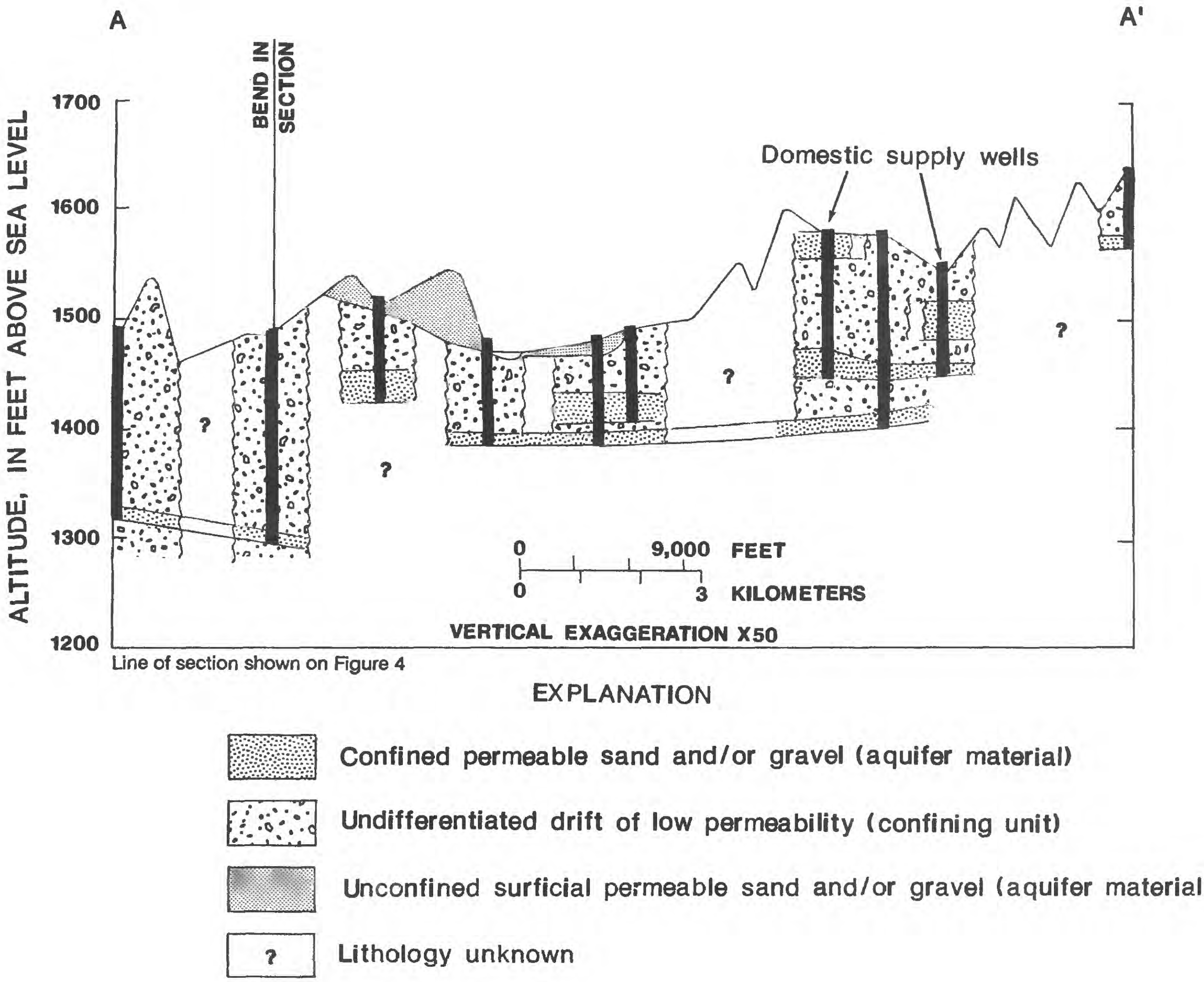


Figure 8.--Hydrogeologic section A - A' in the central part of the White Earth Indian Reservation

Water levels in wells completed in confined-drift aquifers drop more in response to pumping than in unconfined-drift aquifers because of lower storage capacity. Confined-drift aquifers yield water by expansion of the water and compression of the aquifer materials, and unconfined-drift aquifers yield water by gravity drainage from pore spaces. As a consequence, the withdrawal of equal volumes of water from wells completed in these two kinds of aquifers causes more drawdown in the confined-drift aquifer.

Saturated thickness, transmissivity, and potential yield are properties of aquifers that are indicative of their capability to store, transmit, and yield water. Illustrations in this report show the variation in these aquifer properties to identify regional trends and to allow broad-scale comparisons among different areas of the Reservation. This information is not intended to determine the best locations for wells on a site-specific basis, for knowledge of aquifer properties alone is insufficient to accurately predict the long-term capability of an aquifer to yield water to wells. Long-term productivity of an aquifer depends on many factors, such as climatic conditions, stresses on the ground-water resources (such as large-scale withdrawals or interception of recharge), and characteristics of hydrologic boundaries.

The saturated thickness, which, in unconfined-drift aquifers, indicates the amount of water potentially available to wells, is the vertical distance between the water table and the bottom of the aquifer. The saturated thickness of unconfined-drift aquifers in Minnesota ranges from 20 to 100 feet (Helgesen, 1977; Lindholm, 1980; Miller, 1982; and Myette, 1984). Recharge due to precipitation and discharge due to large-scale withdrawals directly affect the saturated thickness of unconfined-drift aquifers.

The water level measured in observation well T140NR41W26 completed in an unconfined-drift aquifer near the southern boundary of the Reservation fluctuated 4 feet during the period 1978-85 (fig. 9). These changes in water level are responses to the variation in precipitation. The drop in water level from 1979-82 represents a period of ground-water discharge. The period 1983-85, when the water level rose, was a period of ground-water recharge because of the elevated precipitation.

The saturated thickness of confined-drift aquifers is the vertical distance between the top and bottom of the water-bearing zone. A saturated thickness of only a few feet may be sufficient for development of household supplies in confined-drift aquifers if a small drawdown will produce the needed water. The available drawdown, or total available hydraulic head, is the vertical drop between the static water level and the bottom of the aquifer. The hydraulic head in confined-drift aquifers changes in response to long-term precipitation patterns.

The water level in well T144NR42W20, which taps a 130-foot-deep confined sand and gravel aquifer, rose nearly 4 feet during the period 1982-85 (fig. 10). This change was nearly the same as the increase during the same period in observation well T140NR41W26, which tapped an unconfined-drift aquifer near Detroit Lakes. Despite the nearly identical fluctuations in the water level of these two wells, the amount of ground-water recharge to the confined-drift aquifer was undoubtedly less than the amount of recharge to the unconfined-drift aquifer during this period. The storage capacity of unconfined-drift aquifers generally is 2 to 3 orders of magnitude greater than confined-drift

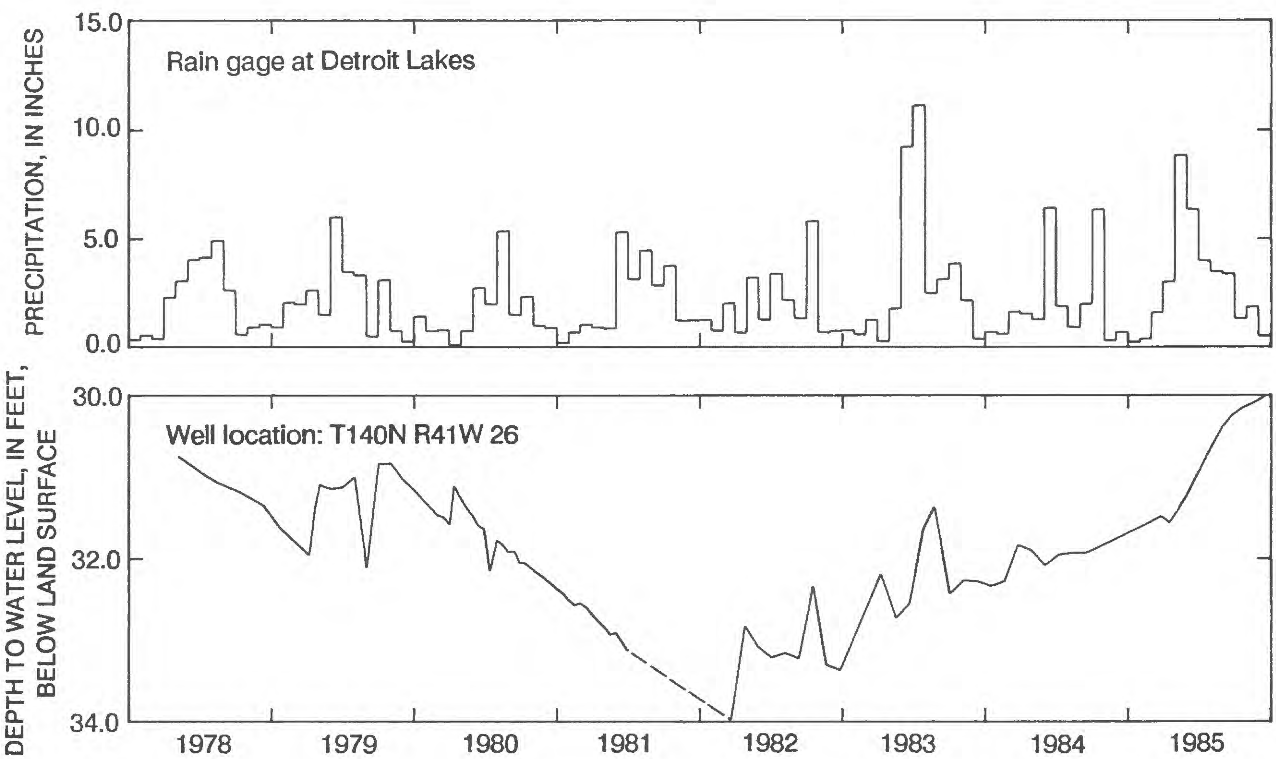


Figure 9.--Water levels in well and monthly precipitation near Detroit Lakes, 1978-85.

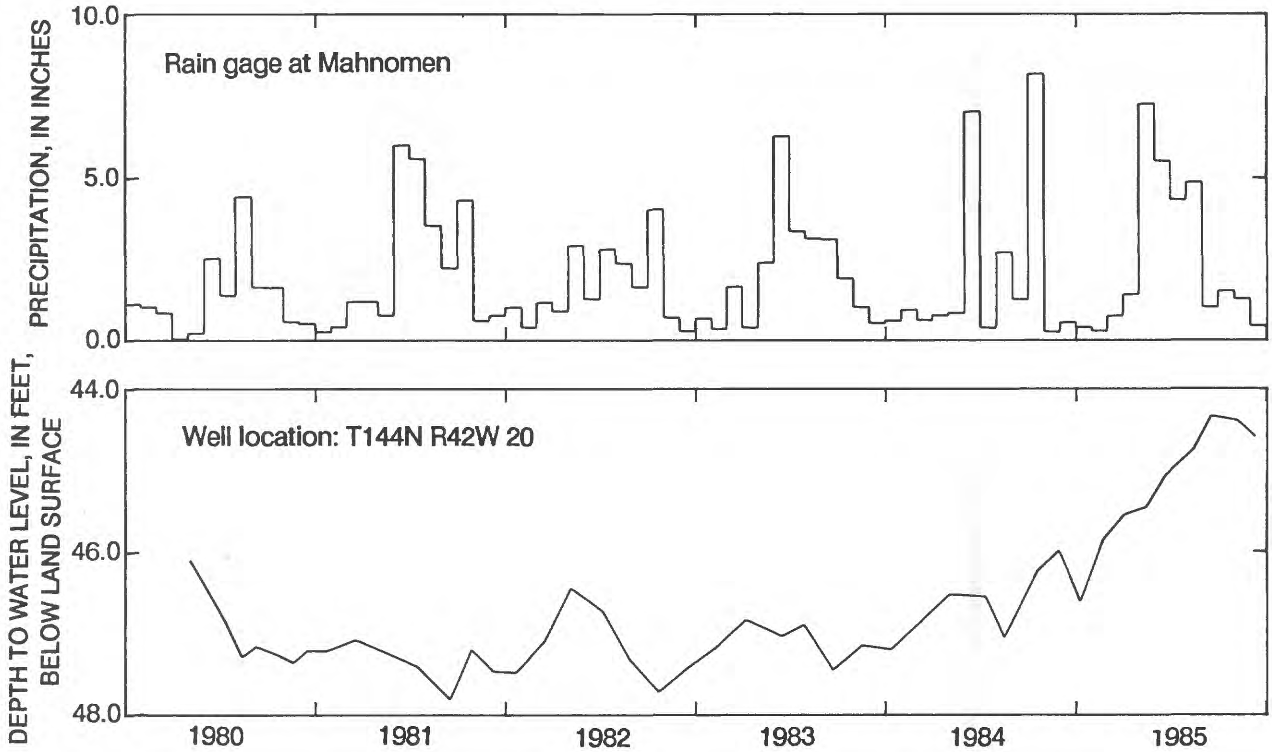


Figure 10.--Water levels in well and monthly precipitation near Mahnomen, 1980-85.

aquifers. Substantially more recharge, therefore, is necessary to raise the water level of an unconfined-drift aquifer well than the amount of recharge required to cause an identical rise in the water level of a confined-drift aquifer well.

Transmissivity is a measure of the capacity of an aquifer to transmit water. This property depends on saturated thickness and horizontal hydraulic conductivity, which is a measure of the permeability of the material. Transmissivity values 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). The transmissivity commonly is lower in confined-drift aquifers than in unconfined-drift aquifers because the saturated thickness generally is smaller.

Potential well yields given in this report are based on the following assumptions: (1) the diameter of the well is at least 12 inches; (2) the efficiency of the well is 100 percent; (3) interference from other pumped wells and the effects of hydrologic boundaries are negligible; and (4) the drawdown in the well due to pumping is two-thirds of the original saturated thickness or, in the case of confined-drift aquifers, two-thirds of the total available hydraulic head. These assumptions and the nonequilibrium equations of Theis (1935) and the correction for unconfined aquifers of Jacob (1944) were the basis for estimates of individual well yields. Potential well yields from glacial-drift aquifers in Minnesota range from several hundred to 5,000 gal/min (gallons per minute) (Helgesen, 1977; Lindholm, 1980; Miller, 1982; Myette, 1984; Wolf, 1976, 1981; and Delin, 1986).

Occurrence

Unconfined-drift aquifers

Geologic data from approximately 40 test holes (fig. 5) were the source of detailed information about the thickness, areal extent, saturated thickness, and hydraulic properties of the unconfined-drift aquifers. Examination of aquifer materials during drilling operations provided a basis for estimating hydraulic conductivity. Observation wells installed in 10 of the test holes were used to monitor water levels and to collect samples for water-quality analysis.

The outwash deposit that trends along a north-south strip through the central part of the Reservation is one of two unconfined-drift aquifers in the Reservation (fig. 4). This deposit is a pitted outwash plain formed in a glacial tunnel valley (University of Minnesota Agricultural Experiment Station, 1980). The outwash consists of medium-to-coarse sand and fine gravel. The water table generally is 5 to 15 feet below land surface, but locally it may be as much as 25 feet below land surface in areas that are topographically higher than adjacent discharge areas, such as lakes or marshes. Recharge to the aquifer is from precipitation and snowmelt that infiltrate directly into the aquifer and from ground water in the higher morainal areas to the east that enters into local ground-water-flow systems (Winter and others, 1970). The estimated annual recharge in the Wild Rice River basin, which includes this surficial aquifer, is estimated to be 2.03 inches during years of normal precipitation (Kanivetsky, 1979).

The saturated thickness ranges from 20 to 50 feet in the northern part and from 10 to 25 feet in the southern part. The permeability and saturated thickness of this aquifer indicates that wells could yield 500 to 1,000 gal/min (Winter and others, 1970). The most productive areas of the aquifer are likely to be in the northern part where the saturated thickness is greatest.

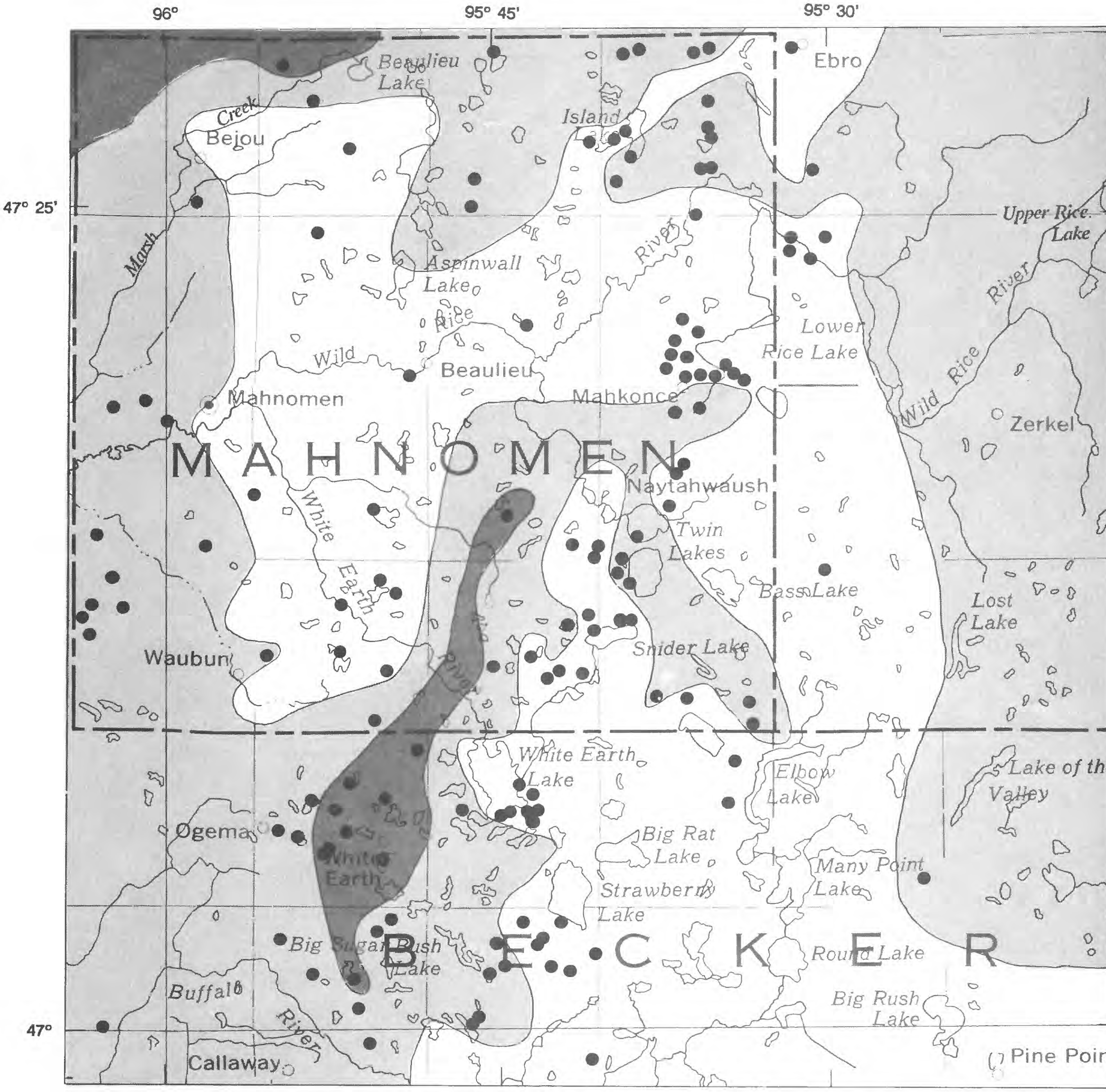
The outwash in the southeastern part of the Reservation is level except for a few peat bogs and depressions in the extreme southeastern corner. The grain size of the outwash ranges from fine sand to fine gravel, although cobbles and boulders also are present in some places. The thickness of the outwash ranges from 50 to 125 feet. The depth to the water table generally is 5 to 40 feet below land surface. Recharge to the aquifer is mainly from precipitation and snowmelt in spring, although some ground-water inflow enters the aquifer from the east. Recharge to this aquifer during a year of normal precipitation (1975) was estimated to be 4.3 inches (Helgesen, 1977). The saturated thickness of this aquifer ranges from 40 to 100 feet, and the potential yield to wells ranges from 500 to 2,000 gal/min (Helgesen, 1977).

Confined-drift aquifers

Interpretation of data from approximately 400 drillers' logs provided the basis for assessment of the hydrogeology and hydraulic properties of the confined-drift aquifers. Estimates of transmissivity and potential well yield were based on specific capacity data reported on drillers' logs. Most of the wells described by the logs are 6 inches in diameter and are open to only part of the full 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 2 to 6 hours at rates that ranged from 10 to 25 gal/min. Static-water-level measurements defined the regional potentiometric surface and flow directions.

The confined-drift aquifers consist of lenses of sand and gravel that underlie less permeable till or clay. These lenses are discontinuous rather than one large, extensive deposit. These aquifers range in size from several square miles to tens of square miles or more. The aquifers may be hydraulically connected, but commonly are separated by till. Well-log data indicate the aquifers are 50 to 300 feet below land surface. Well depths in much of the Reservation are less than 100 feet but are in the range of 200 to 300 feet in the southwestern and extreme northwestern parts (fig. 11). The aquifers generally are 5 to 25 feet thick, but locally are as much as 100 feet thick.

Transmissivity is less than 1,000 ft^2/d throughout much of the northwestern and southeastern parts of the Reservation, and from 1,000 to 5,000 ft^2/d in the northeastern part of the Reservation (fig. 12). The transmissivity is as high as 10,000 ft^2/d where the aquifer thickness exceeds 50 feet. Estimates of the potential yield from wells tapping confined-drift aquifers are as high as 100 gal/min in a large part of the Reservation and, locally, are greater than 1,000 gal/min (fig. 13). The potential yield is directly proportional to the transmissivity and the available drawdown, which is affected by the amount of recharge to the aquifers and stresses on the aquifers due to pumping or abnormally low recharge.



Base from U.S. Geological Survey
Minnesota state base map,
1:500,00, 1985.

SCALE
0 5 MILES
0 5 KILOMETERS

EXPLANATION

Depth of wells, in feet below land surface

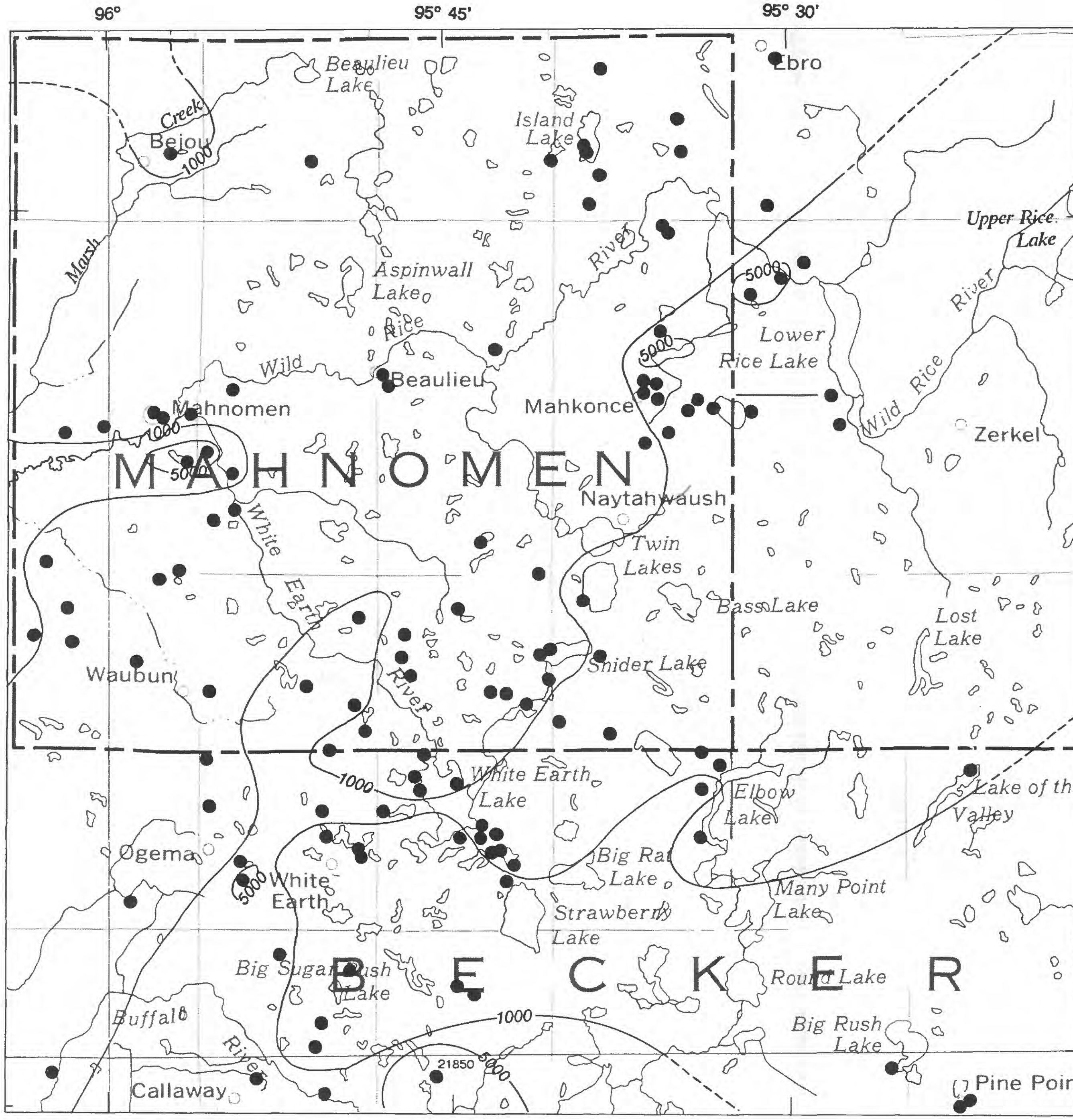
≥200 feet

≤100 feet

>100 feet and <200 feet

● Well Location

Figure 11.--Areal distribution depth of wells completed in confined-drift aquifers in the White Earth Indian Reservation



Base from U.S. Geological Survey Minnesota state base map, 1:500,00, 1985.

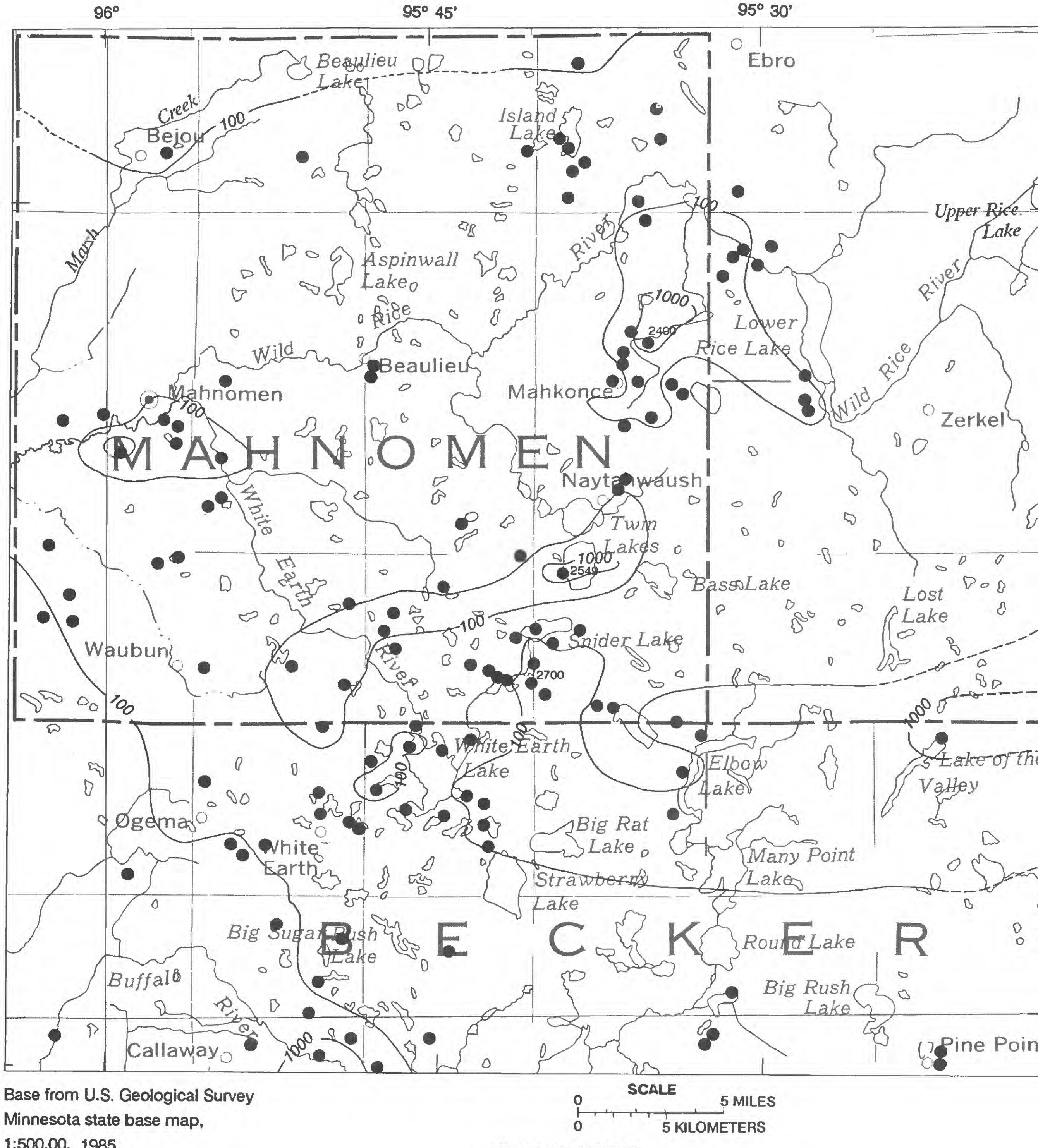
SCALE
0 5 MILES
0 5 KILOMETERS

EXPLANATION

——1000--- Line of equal transmissivity, in feet squared per day. Interval of 4,000 feet squared per day. Dashed where approximate.

● 21850 Well location--number is value of transmissivity where greater than that indicated by lines of equal transmissivity.

Figure 12.--Transmissivity of confined-drift aquifers in the White Earth Indian Reservation



Base from U.S. Geological Survey
Minnesota state base map,
1:500,00, 1985.

EXPLANATION

—1000--- Line of equal potential yield. Interval 900, in gallons per minute. Dashed where approximate.

●2549 Well location--number is value of yield where greater than that indicated by lines of equal potential yield.

Figure 13.--Potential yield of wells completed in confined-drift aquifers in the White Earth Indian Reservation

Ground-water Recharge, Discharge, and Directions of Flow

Recharge to the ground-water reservoir in the Reservation ranges from about 2 to 4 inches (Kanivetsky, 1979; and Helgesen, 1977). Most of the water that infiltrates the land surface as recharge subsequently discharges into stream channels, lakes, and marshes. This component of the ground water is part of near-surface, local flow systems. The residence time of water in these flow systems may be several weeks to several months, which is a relatively short period in terms of ground-water movement.

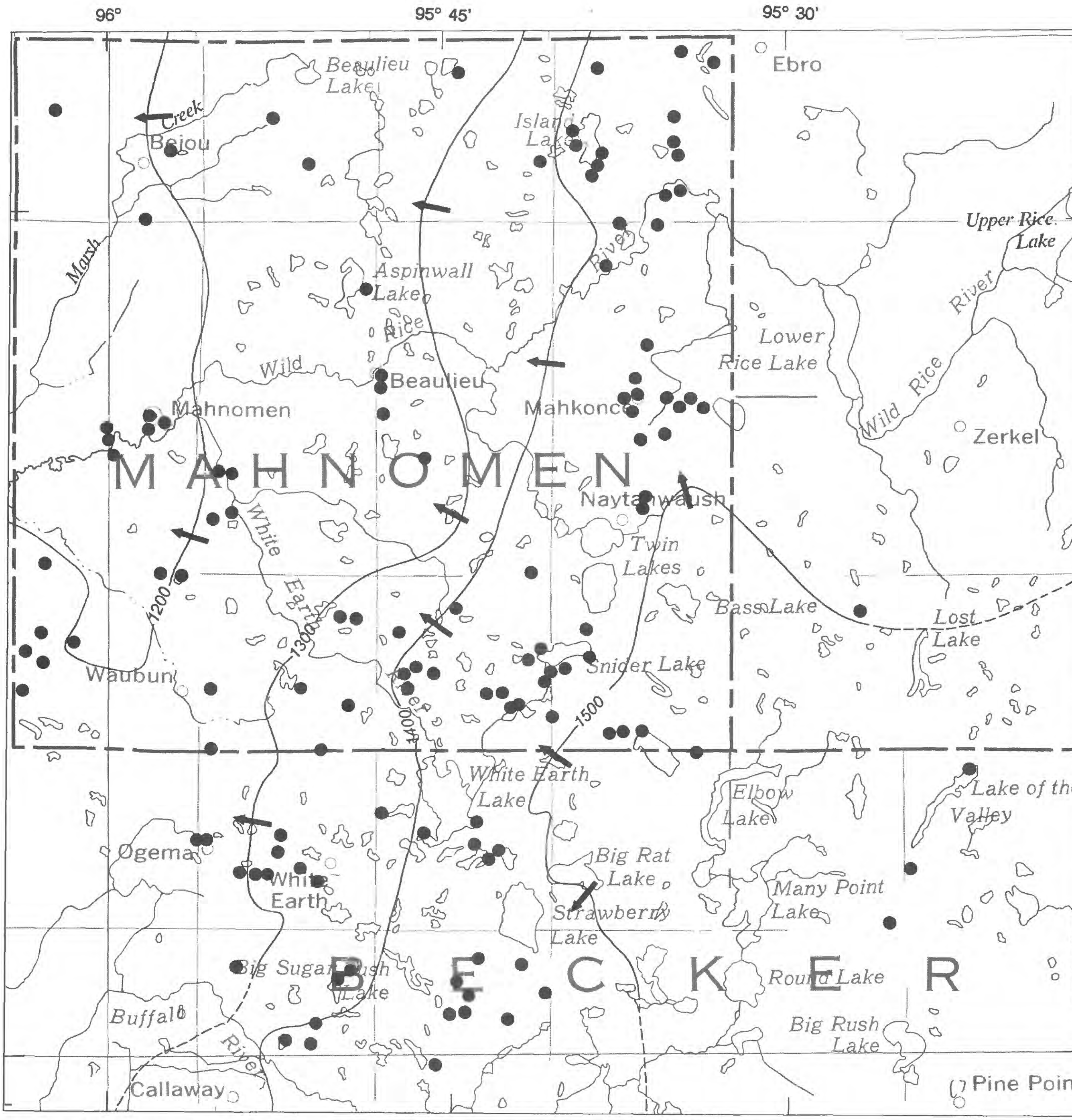
Some ground water is lost directly to the atmosphere during summer months through evapotranspiration. Climatic conditions that favor high rates of evapotranspiration are warm air temperature, low humidity, and high wind speeds. Under these conditions evapotranspiration readily occurs in vegetated areas where the water table is within 5 feet of land surface. The water table is nearest to land surface in discharge areas, which are generally wetlands, lakes, or stream channels in topographically low areas. The depth to the water table ranges from 20 to 40 feet in much of the Reservation.

Some of the recharge enters into deep zones of the ground-water reservoir and becomes part of regional flow systems, where the residence time may be a period of many months or years. The rolling uplands of the morainal areas in the eastern part of the Reservation are a regional recharge area, and the lake plain in the western part of the Reservation is a regional discharge area (Winter, 1970). The estimated potentiometric surface of the uppermost confined-drift aquifers of the Reservation indicates the general directions of regional flow are from southeast to northwest (fig. 14). These directions are variable, however, because of fluctuations in the hydraulic gradient due to seasonal changes in ground-water levels (fig. 9 and 10).

The surficial outwash surrounding the community of Naytahwaush may be a discharge area of a smaller local flow system. The presence of flowing wells completed in the deeper drift indicates that the ground water confined beneath till or clay layers is under sufficient hydraulic head to move upward and mix with shallow ground water or to discharge directly into surface water. The source of the elevated hydraulic head is most likely the recharge of water in the morainal uplands to the east.

Quality

Water-quality samples were collected from five observation wells installed in the unconfined-drift aquifers and eight domestic-supply wells completed in the confined-drift aquifers. Tables 1 and 2 show the results of individual analyses. Assessment of the quality of ground water focused on suitability for drinking. Concentrations of water-quality constituents and properties were compared to criteria established by the U.S. Environmental Protection Agency (USEPA) (table 3).



Base from U.S. Geological Survey
Minnesota state base map,
1:500,00, 1985.

EXPLANATION

——1400—— POTENTIOMETRIC CONTOUR--Altitude of water level in tightly cased wells. Intervals of 100 feet. Dashed where approximate. Datum is sea level.

Direction of ground-water flow

● Well location

Figure 14.--Potentiometric surface and regional flow directions of ground water in the uppermost confined-drift aquifers in the White Earth Indian Reservation, 1975-85

Table 1.--*Chemical analyses of samples from unconfined-drift aquifer wells in the White Earth Indian Reservation, 1984-85*

Well	USGS identification number	Local number	Well	USGS identification number	Local number
1	470749095311201	142N38W08ACB	4	470405095425808	142N40W35CB
2	470842095435801	143N40W34CDA	5	470627095425401	142N40W23BAB
3	472155095364501	145N39W16DAD	6	470203095252801	141N38W13AAA

[Samples collected in 1965 and 1966 were sampled in accordance with the methods in Rainwater and Thatcher (1960). µs/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; °C, degrees Celsius; --, not determined]

					Nitrogen (mg/l as N)					Phosphorus (mg/l as P)	
					Ammonia plus organic						
Well	Date	Specific conductance (µs/cm)	pH (standard units)	Alkalinity, total (mg/L as $CaCo_3$)	Ammonia, total	Dissolved	Suspended, total	Total	Nitrate plus nitrite	Total	Dissolved
1	09/08/65	598	7.9	200	--	--	--	--	13.00	--	--
2	09/05/84	455	7.2	--	0.01	0.40	--	0.40	1.80	0.03	0.03
3	09/09/66	565	8.1	320	--	--	--	--	--	--	--
4	09/05/85	--	--	--	.02	.20	.00	.20	.51	.19	.18
5	09/09/66	400	8.1	208	--	--	--	--	--	--	--
6	09/05/84	448	7.5	--	<.01	.20	--	.20	4.30	<.01	<.01

Well	Date	Cyanide, total (mg/L as CN)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
1	09/08/65	--	265	65.00	70	22	19	0.5	1.4	17.0	37
2	09/05/84	<0.01	--	--	85	21	--	--	1.2	1.5	3.5
3	09/09/66	--	317	0	88	24	2.6	.1	3.0	1.4	5.0
4	09/05/85	--	--	--	59	15	--	--	2.5	2.7	2.1
5	09/09/66	--	216	8	46	24	2.2	.1	2.4	1.0	12
6	09/05/84	<.01	--	--	69	23	--	--	1.9	1.7	8.7

Table 1.--*Chemical analyses of samples from unconfined-drift aquifer wells in the White Earth Indian Reservation, 1984-85*--Continued

Well	Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	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 Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)
1	09/08/65	0.1	21	--	--	50	--	--	--	--	--
2	09/05/84	--	--	2	93	<20	<1	10	2	9	4
3	09/09/66	.1	25	--	--	20	--	--	--	--	--
4	09/05/85	--	--	--	--	30	--	--	--	--	--
5	09/09/66	.1	20	--	--	20	--	--	--	--	--
6	09/05/84	--	--	1	42	<20	<1	10	3	6	2

Well	Date	Manganese, dissolved (µg/L as Mn)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Selenium, dissolved (µg/L as Se)	Solids, residue at 180° C, dissolved (mg/L)	Manganese (µg/L as Mn)	Iron (µg/L as Fe)	Mercury dissolved (µg/L as Hg)	Depth of well, total (feet)
1	09/08/65	--	--	--	--	383	0	40	--	14
2	09/05/84	120	<1	1400	<1	327	--	--	<.1	14
3	09/09/66	--	--	--	--	346	560	500	--	40
4	09/05/85	--	--	--	--	230	--	--	--	--
5	09/09/66	--	--	--	--	246	--	--	--	40
6	09/05/84	2	<1	34	<1	250	--	--	<.1	59

Table 2.--*Chemical analyses of samples from confined-drift aquifer wells in the White Earth Indian Reservation, 1965-84*

Well	USGS identification number	Local number	Well	USGS identification number	Local number	Well	USGS identification number	Local number
1	465359095494001	140N41W35BDD	6	470414095241401	142N37W31DDA	10	471055095512801	143NR41W22DCB
2	470042095510701	141N41W22DDA	7	470452095580301	142N42W26CDA	11	471115095403201	143N39W19BCD
3	470148095541801	141N41W08CDB	8	471030096034501	143N42W30BBB	12	472040095480001	145N40W15CDA
4	470200095441401	141N40W15BAB	9	471042095324501	143N40W23CDD	13	472220096004501	145N42W17DAD
5	470306096075101	141N43W04DDD						

[Samples collected in 1965 and 1966 were sampled in accordance with the methods in Rainwater and Thatcher (1960). µs/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; <, less than; --, not determined]

							Nitrogen (mg/l as N)			
								Ammonia plus organic		
Well	Date	Sampling depth (feet)	Temperature water (°C)	Specific conductance (µs/cm)	pH (standard units)	Alkalinity, total (mg/L as $CaCO_3$)	Ammonia, total	Dissolved	Total	Nitrate plus nitrite, dissolved
1	09/09/65	--	--	346	8.2	194	--	--	--	--
2	09/08/65	--	--	679	8.5	363	--	--	--	--
3	09/04/84	--	8.0	675	7.4	--	0.58	0.80	1.70	<0.10
4	09/08/65	--	--	298	8.4	151	--	--	--	--
5	09/07/66	--	--	712	8.1	327	--	--	--	--
6	08/31/76	65	9.0	515	7.6	249	--	--	.15	--
7	09/08/65	--	--	373	8.5	184	--	--	--	--
8	09/09/66	--	--	436	8.2	225	--	--	--	--
9	09/09/66	--	--	482	8.0	214	--	--	--	--
10	09/04/84	--	8.0	760	7.6	--	.60	.70	1.10	<.10
11	09/05/84	--	7.0	529	7.4	--	.60	.70	.70	<.10
12	09/08/66	--	--	531	8.2	262	--	--	--	--
13	08/04/66	--	--	912	8.2	244	--	--	--	--

Table 2.--*Chemical analyses of samples from confined-drift aquifer wells in the White Earth Indian Reservation, 1965-84*--Continued

Well	Date	Phosphorus (mg/l as P)		Cyanide, total (mg/L as CN)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
		Total	Dissolved						
1	09/09/65	--	--	--	184	0	36	23	5.3
2	09/08/65	--	--	--	370	7	83	40	11
3	09/04/84	0.01	<0.01	<0.01	--	--	80	30	--
4	09/08/65	--	--	--	155	4	20	26	1.9
5	09/07/66	--	--	--	314	0	74	31	42
6	08/31/76	.01	--	--	260	15	71	21	1.2
7	09/08/65	--	--	--	165	0	20	28	16
8	09/09/66	--	--	--	213	0	39	28	15
9	09/09/66	--	--	--	252	38	74	16	.8
10	09/04/84	.03	.03	<.01	--	--	77	33	--
11	09/05/84	.02	.02	<.01	--	--	79	28	--
12	09/08/66	--	--	--	213	0	35	30	37
13	08/04/66	--	--	--	314	70	86	24	90

Table 2.--*Chemical analyses of samples from confined-drift aquifer wells in the White Earth Indian Reservation, 1965-84*--Continued

Well	Date	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)
1	09/09/65	0.2	2.6	1.2	1.8	0.1	28	--	--
2	09/08/65	.2	3.9	1.3	29	.2	26	--	--
3	09/04/84	--	3.5	1.6	46	--	--	19	66
4	09/08/65	.1	2.7	2.2	11	.2	21	--	--
5	09/07/66	1.0	3.5	6.8	64	.2	23	--	--
6	08/31/76	0	1.9	0.8	6.5	.2	13	--	--
7	09/08/65	.5	3.8	1.5	17	.3	28	--	--
8	09/09/66	.4	3.7	2.2	16	.2	28	--	--
9	09/09/66	0	0.9	19	7.8	.3	22	--	--
10	09/04/84	--	3.8	2.6	44	--	--	19	86
11	09/05/84	--	2.4	1.6	2.3	--	--	5	230
12	09/08/66	1.1	3.1	12	9.2	.3	22	--	--
13	08/04/66	2.2	5.8	18	225	.4	27	--	--

Table 2.--*Chemical analyses of samples from confined-drift aquifer wells in the White Earth Indian Reservation, 1965-84*--Continued

Well	Date	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron (µg/L as Fe)		Lead, dissolved (µg/L as Fe)	Manganese (µg/L as Mn)	
						Total recoverable	Dissolved		Total recoverable	Dissolved
1	09/09/65	50	--	--	--	--	--	--	--	--
2	09/08/65	70	--	--	--	--	--	--	--	--
3	09/04/84	80	<1	<10	1	--	690	4	--	81
4	09/08/65	10	--	--	--	--	--	--	--	--
5	09/07/66	190	--	--	--	--	--	--	--	--
6	08/31/76	9	--	--	--	20	--	--	<10	--
7	09/08/65	90	--	--	--	--	--	--	--	--
8	09/09/66	90	--	--	--	--	--	--	--	--
9	09/09/66	20	--	--	--	--	--	--	--	--
10	09/04/84	120	<1	<10	<1	--	1700	5	--	180
11	09/05/84	30	<1	<10	<1	--	3900	3	--	84
12	09/08/66	160	--	--	--	--	--	--	--	--
13	08/04/66	320	--	--	--	--	--	--	--	--

Table 2.--*Chemical analyses of samples from confined-drift aquifer wells in the White Earth Indian Reservation, 1965-84*--Continued

Well	Date	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Selenium, dissolved (µg/L as Se)	Solids, residue at 180° C dissolved (mg/L)	Nitrogen, nitrate dissolved (mg/L as NO_3)	Iron (µg/L as Fe)	Mercury dissolved (µg/L as Hg)	Depth of well, total (feet)	Specific conductance, laboratory value (µs/cm)
1	09/09/65	--	--	--	213	0.10	880	--	103	--
2	09/08/65	--	--	--	414	.30	1300	--	150	--
3	09/04/84	<1	45	<1	368	--	--	0.2	127	675
4	09/08/65	--	--	--	172	0	40	--	100	--
5	09/07/66	--	--	--	430	2.4	770	--	187	--
6	08/31/76	--	--	--	252	--	--	--	--	--
7	09/08/65	--	--	--	221	1.4	980	--	80	--
8	09/09/66	--	--	--	271	1	1000	--	70	--
9	09/09/66	--	--	--	321	13	400	--	60	--
10	09/04/84	<1	10	<1	362	--	--	.1	161	700
11	09/05/84	<1	27	<1	365	--	--	<.1	--	585
12	09/08/66	--	--	--	310	2.6	2700	--	188	--
13	08/04/66	--	--	--	626	1.1	880	--	160	--

Table 3.--*Water quality criteria and significance of common water-quality properties and constituents*

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 drinking-water recommended limit established by the U.S. Environmental Protection Agency (1986).
d--Primary drinking-water regulation 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.)

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

Property or constituent	Recommended criterion		Significance
Specific conductance		a	An indirect measure of the total concentration of the ions in the water.
Alkalinity	No less than 20 mg/L $CaCO_3$	e	Capacity for neutralizing acid. Attributed mostly to bicarbonate ion.
Calcium		a	Principal cation in most of Minnesota's ground water. Major cause of hardness.
Magnesium		a	Second-most abundant cation in Minnesota's waters. A cause of hardness.
Sodium	270 mg/L	b	Principal cation in ground water from parts of western Minnesota. Sodium-type water undesirable for irrigation.
Sulfate	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.

Table 3.--***Water quality criteria and significance of common water-quality properties and constituents***--Continued

Property or constituent	Recommended criterion		Significance
Chloride	250 mg/L	b	Principal anion in some of the ground water in western Minnesota. Contributes to salinity and causes a salty taste.
Silica (SiO_2)	50 mg/L	b	Essential plant nutrient.
Dissolved solids	500 mg/L	c	Total concentration of dissolved substances. Fresh water generally contains less than 1,000 [redacted] mg/L. Normally, the lower the dissolved-solids concentration, the better the quality of the water for all uses.
Nitrate + nitrite as nitrogen	10 mg/L	d	May cause methemoglobinemia in infants. Indicates pollution from animal wastes or fertilizer.
Phosphorus		a	Essential plant and animal nutrient. Can stimulate growth of algae in surface water.
Arsenic	50 μg/L 190 μg/L	d; e	Toxic to animals, including humans.
Barium	1,000 μg/L	d	Toxic to plants and animals.
Boron	750 μg/L	c	Essential plant micronutrient.
Cadmium	10 μg/L 2 μg/L	d; e	Toxic to animals, including humans.
Chromium	50 μg/L 11 μg/L	d; e	Toxic to humans.
Copper	1,000 μg/L 34 μg/L	c; e	Essential nutrient for plants and animals. Imparts metallic taste to water.

Table 3.--*Water quality criteria and significance of common water-quality properties and constituents*--Continued

Property or constituent	Recommended criterion		Significance
Iron	300 µg/L 1,000 µg/L	c; e	Can cause stains on laundry and fixtures and unpleasant tastes in beverages. Widely distributed.
Lead	50 µg/L 7.7 µg/L	d; e	Toxic to plants and animals.
Manganese	50 µg/L	c	Causes stains and affects taste.
Mercury	2 µg/L 0.012 µg/L	d; e	Toxic to plants and animals.
Zinc	5,000 µg/L 190 µg/L	c; e	Essential plant and animal nutrient. May impart metallic taste.

The concentrations of constituents listed in tables 1 and 2, with the exception of iron, manganese, and dissolved solids, generally are below recommended limits for drinking water established by the USEPA. Iron and manganese affect the aesthetic quality of domestic water supplies. For instance, articles of clothing may become stained or discolored if laundered in water with high concentrations of manganese or iron. These constituents may also cause unpleasant tastes in beverages such as coffee or tea. Neither of these constituents is present at high enough concentrations to cause human health problems. The dissolved-solids content at high concentrations limits the suitability of water for all uses except possibly fire control. Water with dissolved solids above 1,000 mg/L generally is considered to be saline. Concern about excessive dissolved solids in ground water is unwarranted, however, because the dissolved-solids content was just marginally above the secondary recommended limit for drinking water in only one sample from a confined-drift aquifer well (table 2).

Figures 15 and 16 show the chemical composition of individual water samples collected from wells completed in unconfined- and confined-drift aquifer wells in the Reservation. Each point on the diagrams defines the proportion of major cations and anions in the sample as a percentage of the total milliequivalents of cations and anions. The percentage distribution of the ions determines the water type. Ground water in both unconfined- and confined-drift aquifers in the Reservation is a calcium magnesium bicarbonate type.

Although the water in the two aquifers is of the same general type, the diagrams indicate that some samples from the confined-drift aquifer contain higher proportions of sodium and sulfate than do samples from the unconfined-drift aquifers. Water that percolates deeper into the ground-water reservoir tends to change in chemical composition because of the increased contact time with aquifer materials and confining units.

Figure 17 schematically presents the ionic composition of individual samples from the unconfined- and confined-drift aquifers. These diagrams show the similarity and differences in water quality between the two aquifers. The total amount of cations represented on the left side of each diagram balances within 10 percent with the total amount of anions represented on the right side. Calcium, magnesium, and bicarbonate are the dominant ions in many of the samples, although the proportions of sodium and sulfate were significant in some of the samples from the confined-drift aquifers. The size of each diagram is directly proportional to the dissolved solids content of the sample. The dissolved-solids content of ground water tends to increase with depth below land surface because of increased time for dissolution of minerals from glacial-drift materials.

The concentration of nitrite plus nitrate in one of the samples from an unconfined-drift aquifer well is 13 mg/L as N (table 1). This concentration is unusually high and is potentially harmful to the health of infants. The concentration of chloride in two samples collected from confined-drift aquifer wells in the Reservation are 18 and 19 mg/L, which also are unusually high (table 2). The median concentration of chloride in samples collected from wells in confined-drift aquifers throughout Minnesota is 4.5 mg/L (Ruhl, 1987).

EXPLANATION

Diagram shows water types of individual samples on the basis of major cations and anions determined from their concentrations in milliequivalents per liter.

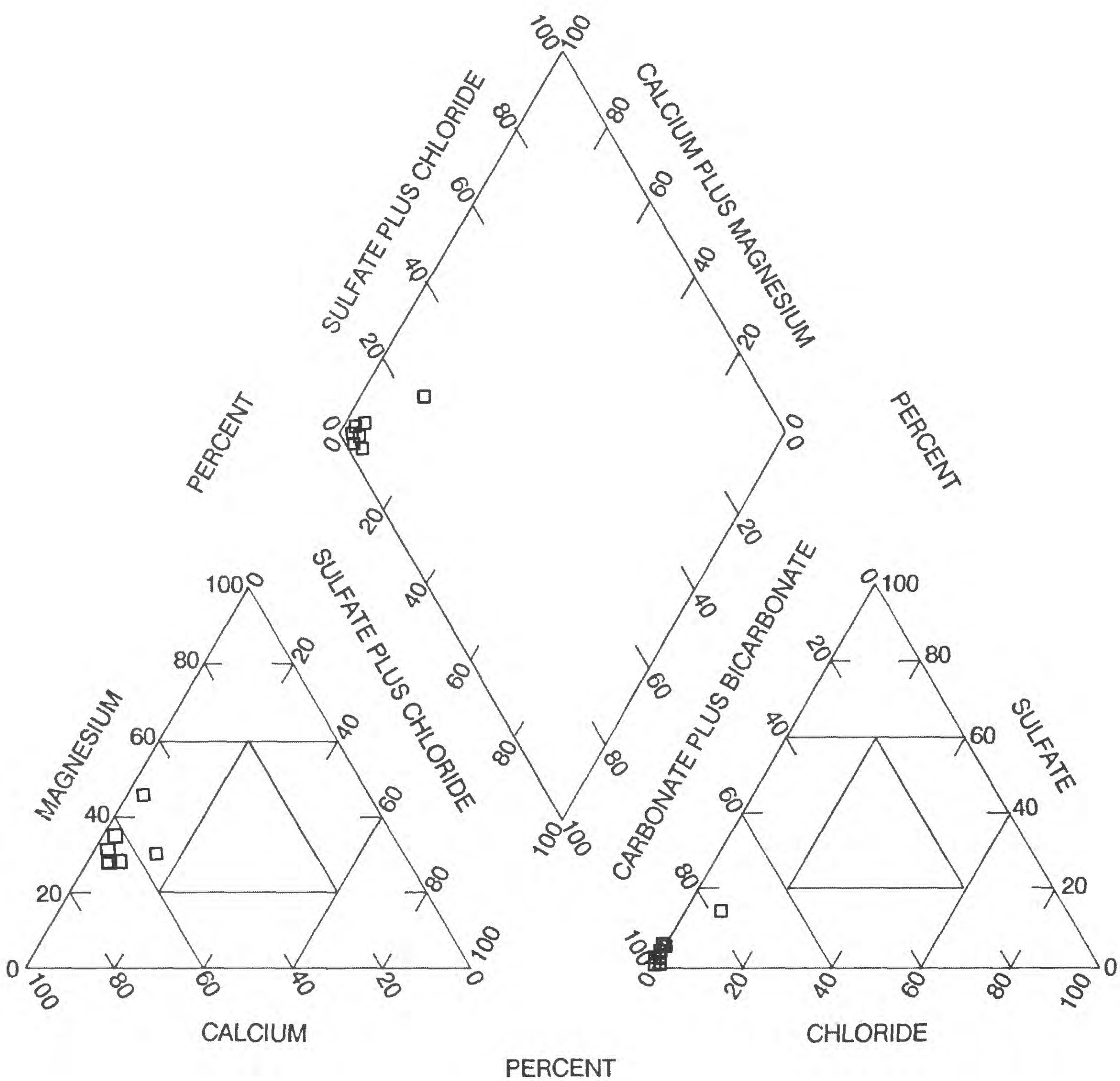


Figure 15.--Percentage of total milliequivalents per liter of major ions in samples collected from unconfined-drift aquifers in the White Earth Indian Reservation.

EXPLANATION

Diagram shows water types of individual samples on the basis of major cations and anions determined from their concentrations in milliequivalents per liter.

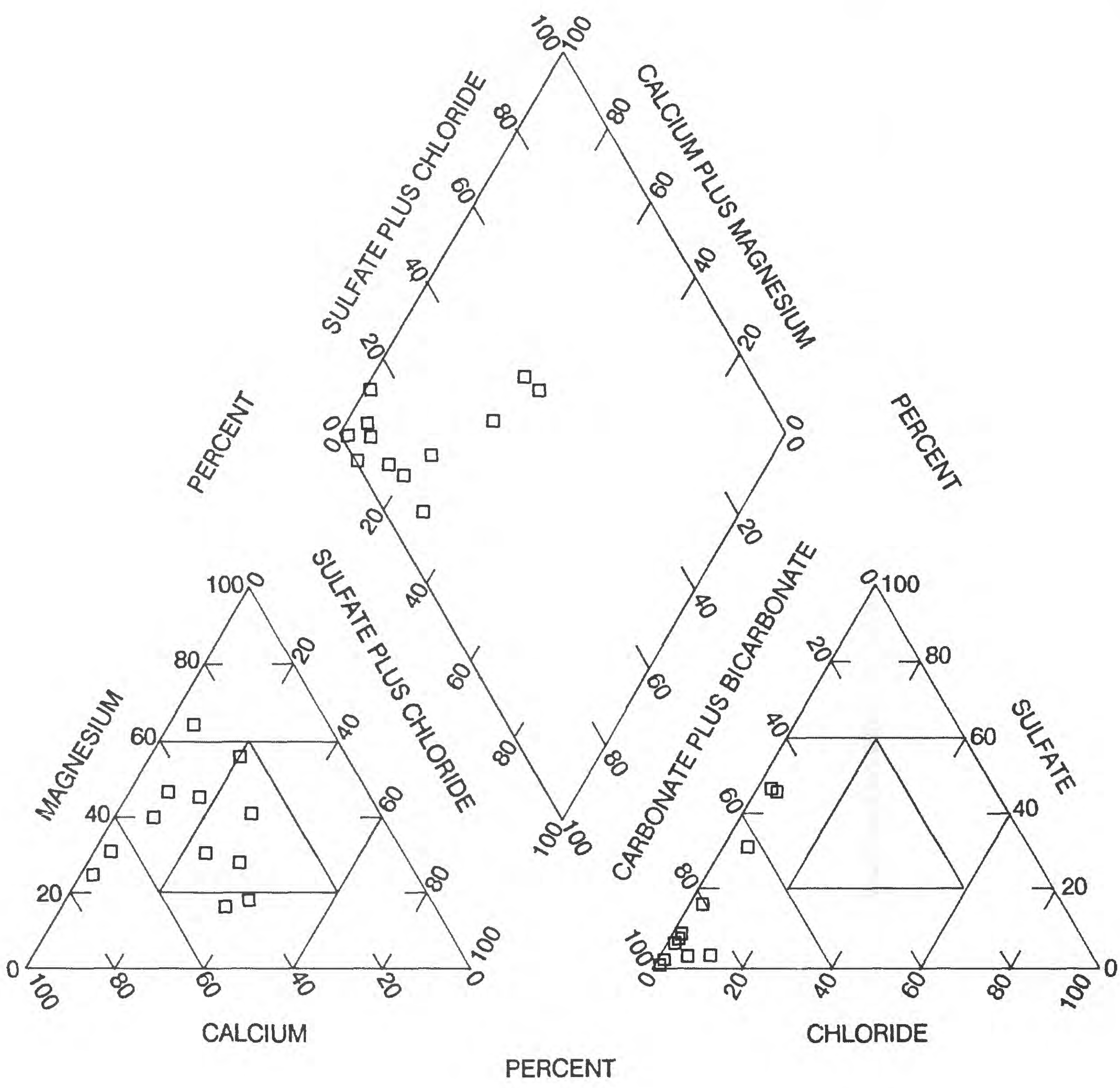
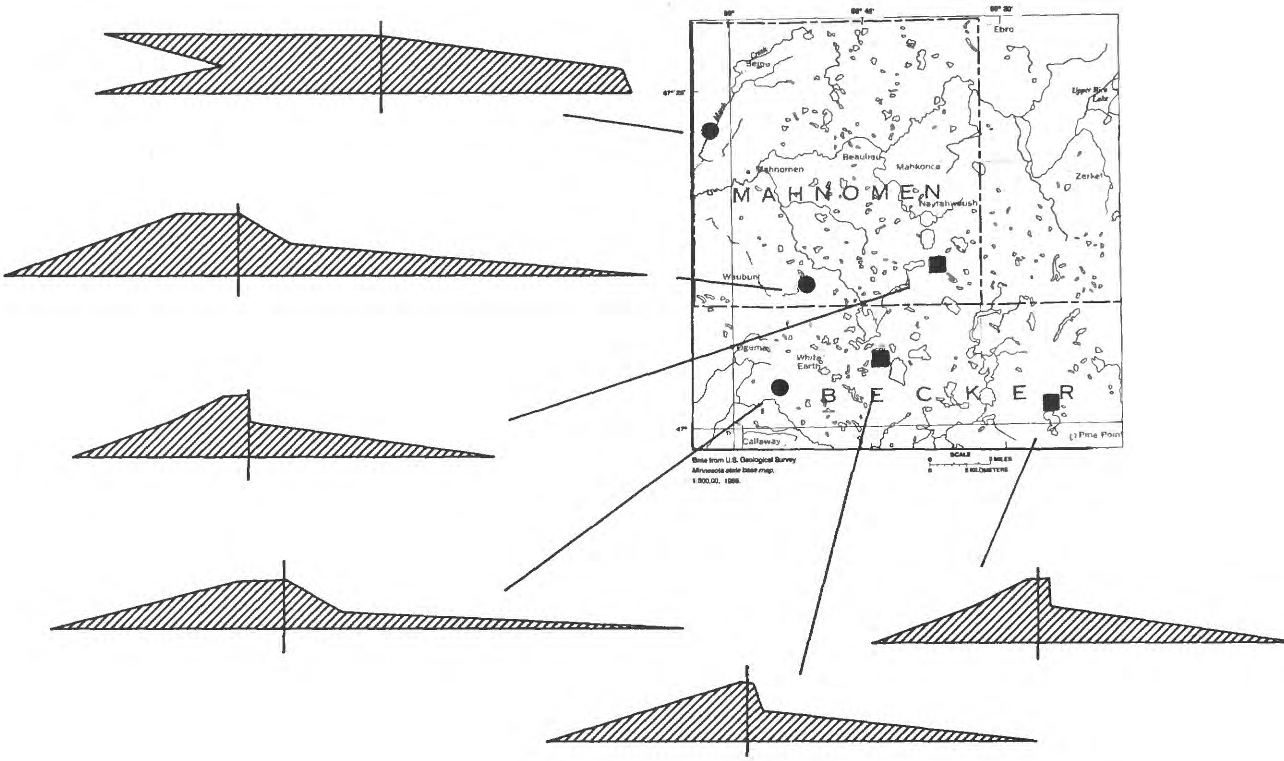
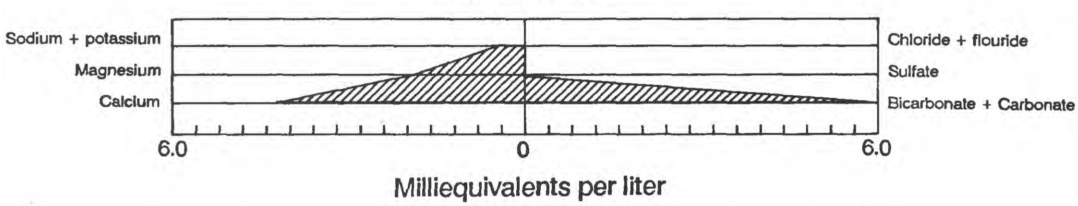


Figure 16.--Percentage of total milliequivalents per liter of major ions in samples collected from confined-drift aquifers in the White Earth Indian Reservation.



EXPLANATION



Stiff diagrams based on an analysis of one sample collected at the located site. The size of the diagram is directly proportional to the dissolved-solids concentration.

■ Unconfined-drift-aquifer site

● Confined-drift-aquifer site

Figure 17.--Ionic composition of water samples collected from unconfined- and confined-drift aquifers in the White Earth Indian Reservation.

The elevated concentrations of these constituents are likely to result from contamination by livestock animal wastes, septic systems, municipal treatment plant cesspools, or fertilizers applied to croplands.

The high concentration of sodium in ground water from the confined-drift aquifers results from interaction of water with sediments of Cretaceous age, incorporated in the deep drift, that contain clay minerals with high exchange capacities. Base-exchange reactions elevate the sodium concentration and reduce the calcium and magnesium concentrations. The elevated concentration of sulfate results mainly from solution of sulfate-bearing minerals in sediments of Cretaceous age. The concentrations of sodium and sulfate increase toward the northwestern part of the Reservation where sediments of Cretaceous age become more abundant. The variation in the concentration of these two minerals reflects the overall increase in mineralization across the Reservation from southeast to northwest (fig. 18).

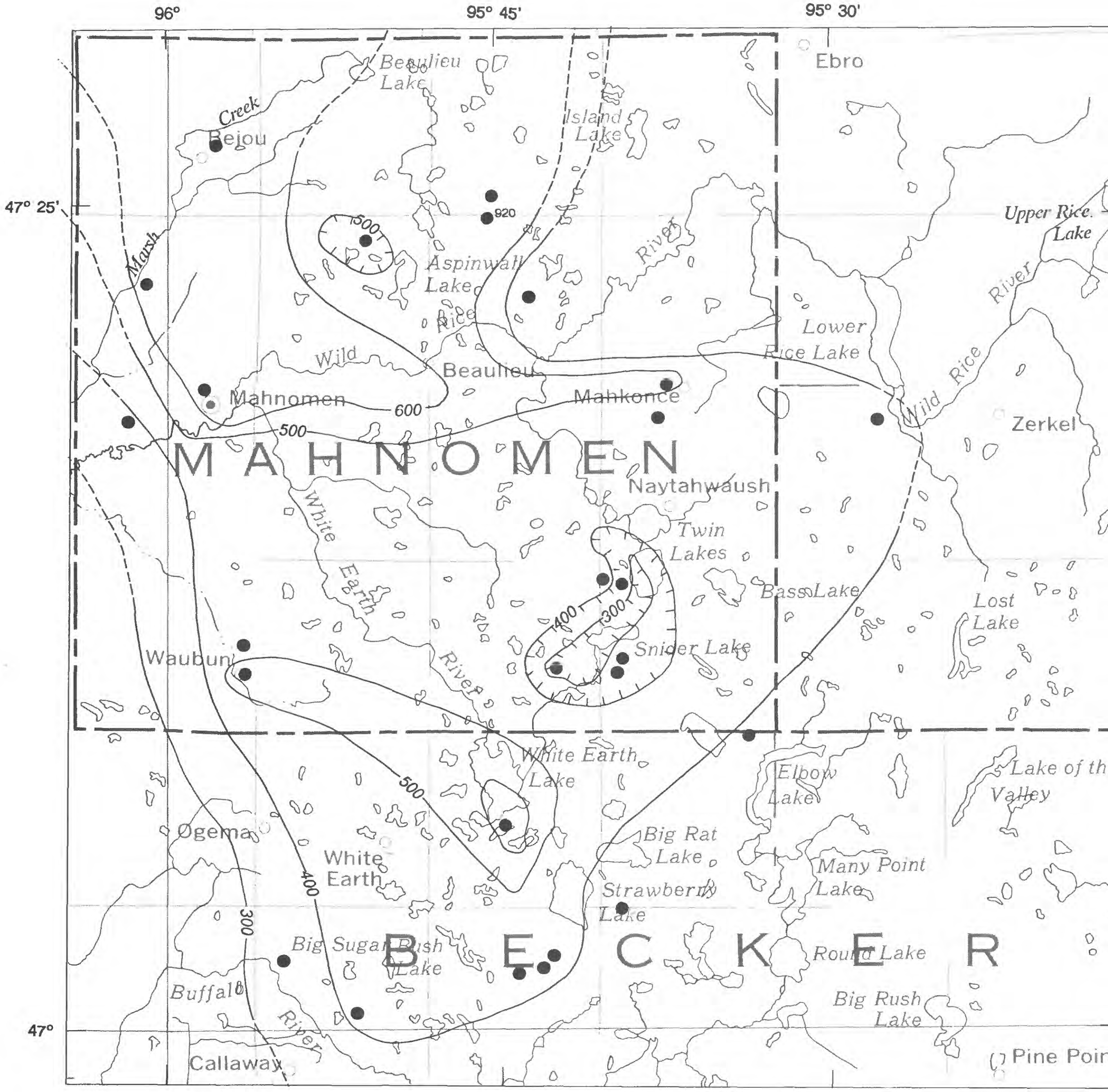
Surface Water

Many lakes, wetlands, prairie potholes, and streams comprise the surface-water features in the Reservation. The shallow lakes and prairie potholes, generally located in the lake plain and morainal areas, provide waterfowl habitat and produce wild rice. Larger and deeper lakes, which are in the eastern part of the Reservation, support walleye and northern pike fishing and other recreational uses, such as boating and swimming. Shoreline development of summer cabins, permanent residences, and resorts is extensive on some of these lakes. The Wild Rice River drains a basin that extends over approximately 60 percent of the Reservation. The Buffalo, Otter Tail, Red Lake, and Straight Rivers drain smaller basins in the Reservation (fig. 3).

Streamflow Characteristics

Stage-discharge relations were established at gaging stations on four streams near the Reservation boundary (fig. 5) during the 1985 water year (October 1, 1984, to September 30, 1985). The frequency of discharge measurements was approximately once a month. Observers recorded the stage from staff or wire-weight gages an average of three to six times per week during the open-water part of the year, and daily discharges were estimated from the stage-discharge relation.

The discharge hydrographs in figures 19 through 22 show variations in flow of four streams in the Reservation during the 1985 water year (October 1, 1984, to September 30, 1985). The hydrographs assume constant low-flow conditions during the winter months when readings of the gages were temporarily discontinued. The seasonal pattern of the streamflow for the 1985 water year was above normal on the basis of precipitation data. Annual precipitation measured at the Mahnomen weather station was 29.05 inches, which was nearly 6 inches above the long-term mean for the preceding 25 years of record (National Oceanic and Atmospheric Administration, 1984).



Base from U.S. Geological Survey
Minnesota state base map,
1:500,00, 1985.

SCALE
0 5 MILES
0 5 KILOMETERS

EXPLANATION

—500--- Line of equal dissolved solids concentration, in milligrams per liter. Interval 100 milligrams per liter. Dashed where approximate.

● 920 Well location--number is value of dissolved-solids concentration where greater than that indicated by lines of equal dissolved-solids concentration.

Figure 18.--Concentration of dissolved solids in the confined-drift aquifers in the White Earth Indian Reservation, 1965-86

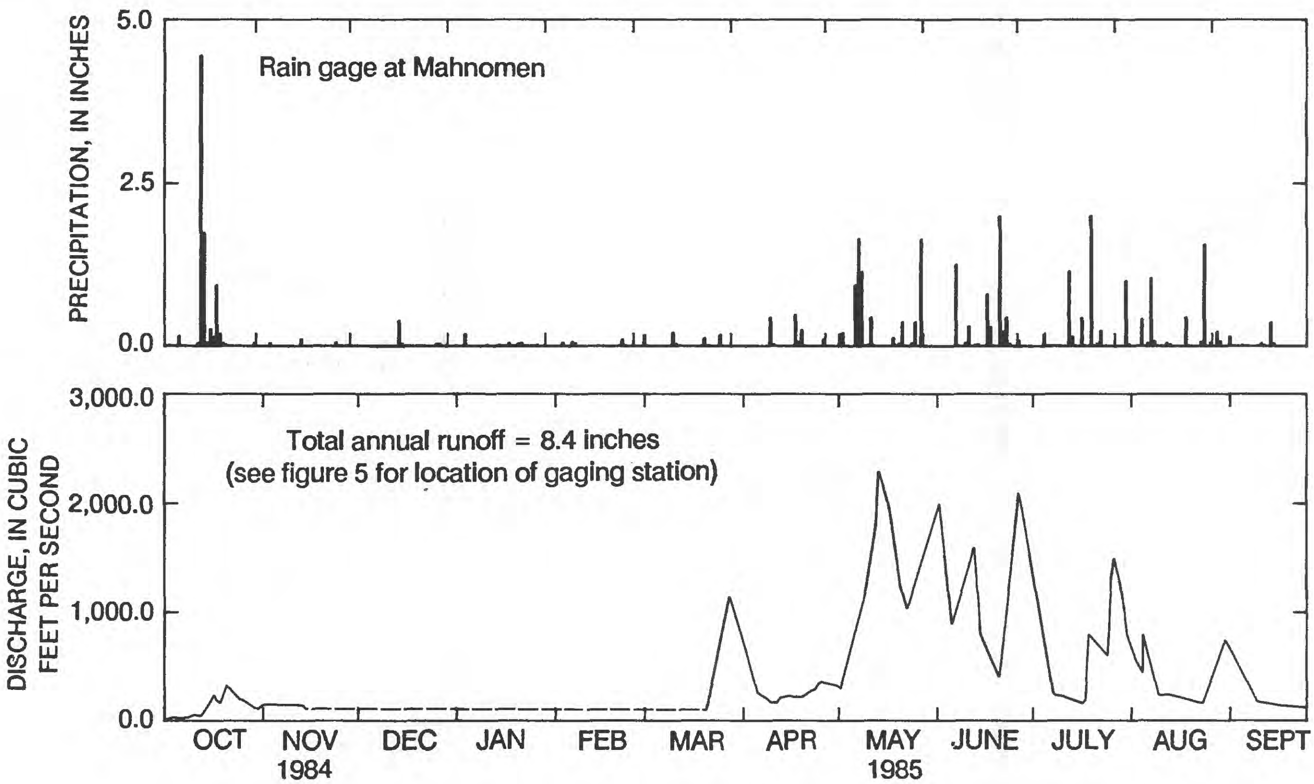


Figure 19.--Discharge of the Wild Rice River at the western boundary of the White Earth Indian Reservation, 1985 water year, October 1984 - September 1985

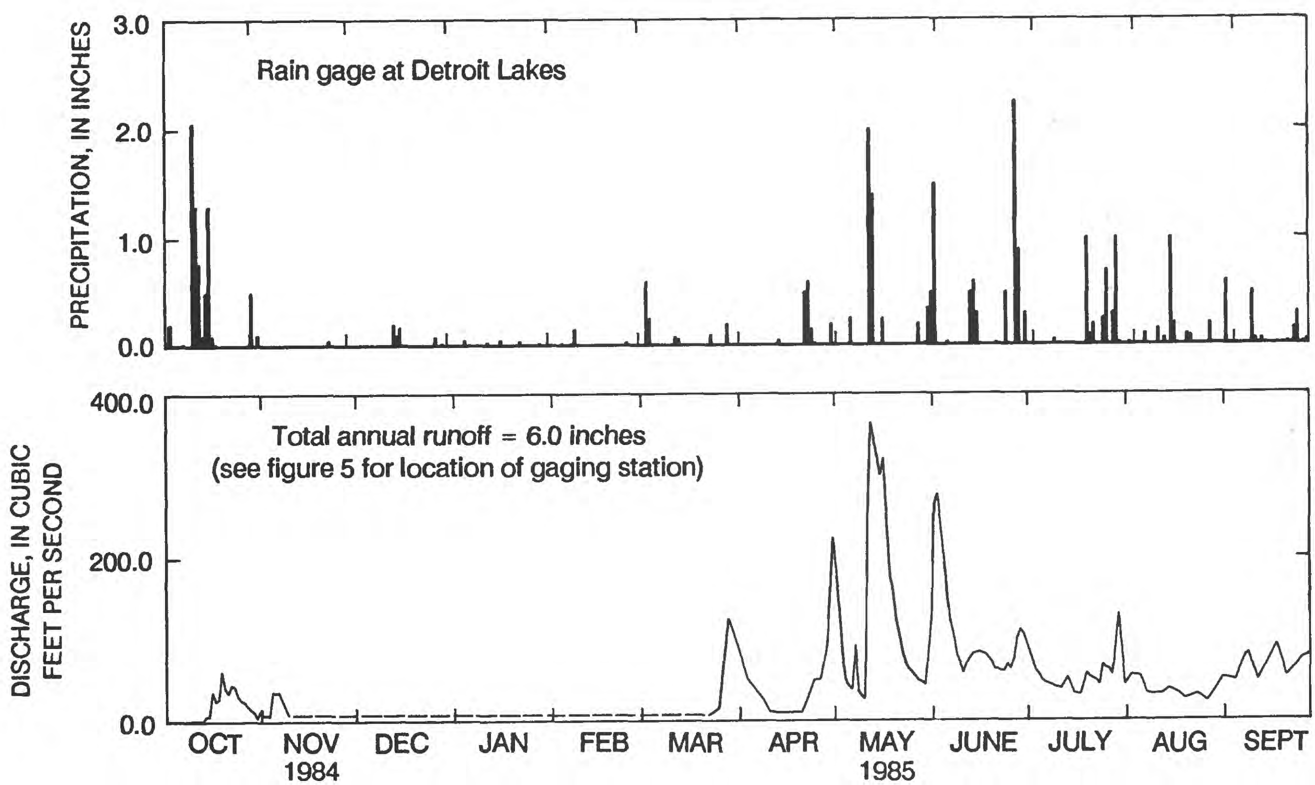


Figure 20.--Discharge of the Buffalo River at the southern boundary of the White Earth Indian Reservation, 1985 water year, October 1984 - September 1985

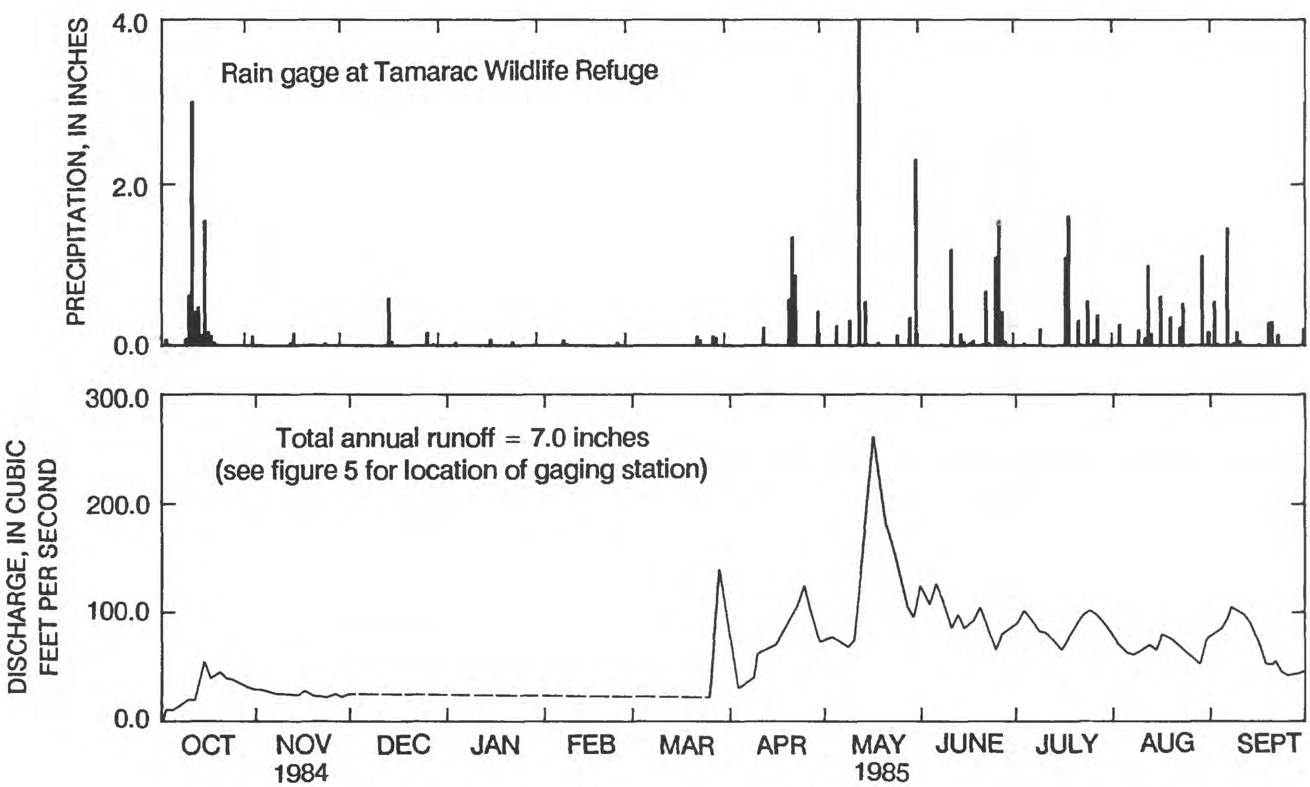


Figure 21.--Discharge of the Otter Tail River at the southern boundary of the White Earth Indian Reservation, 1985 water year, October 1984 - September 1985

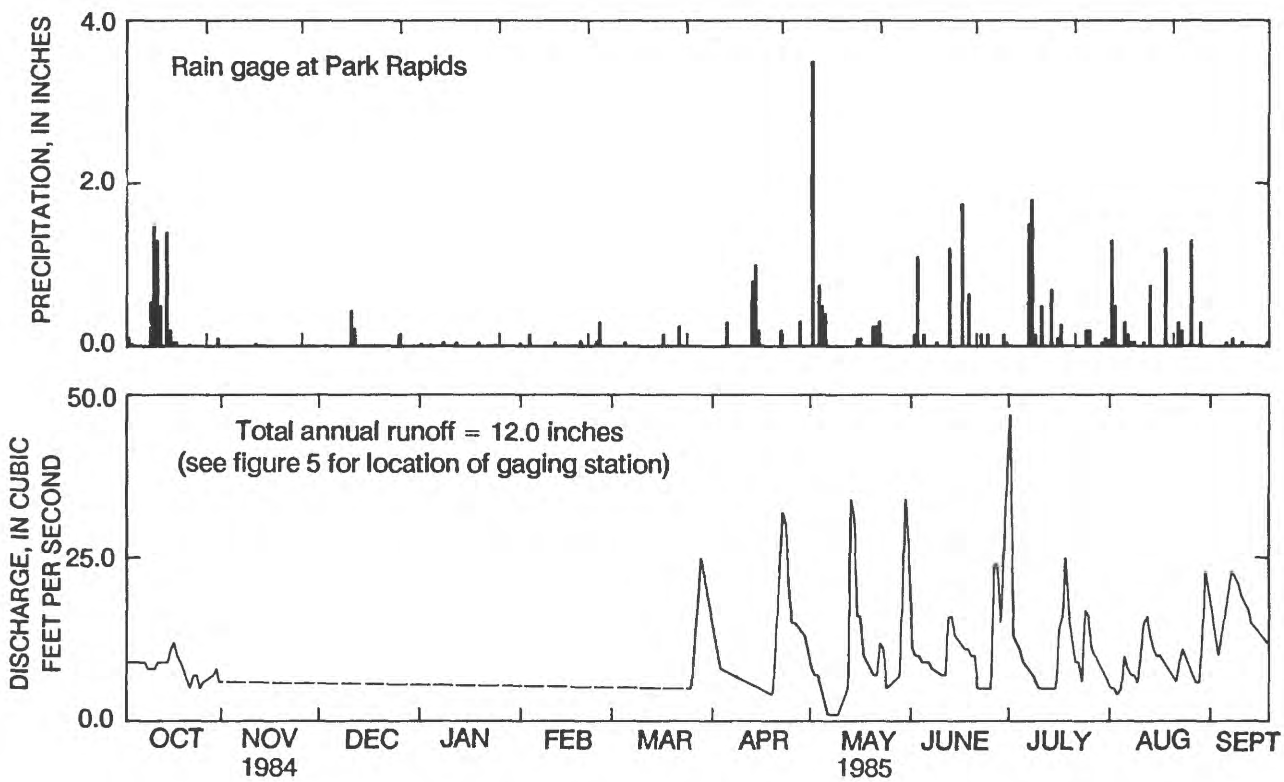


Figure 22.--Discharge of the Straight River at the southeastern boundary of the White Earth Indian Reservation, 1985 water year, October 1984 - September 1985

During October 1984, rainfalls of 2 to 5 inches caused observable increases in discharge in all four streams (figs. 19-22). Discharge increased in the Buffalo River in response to a storm in early November, and by mid-November, all of the streams had receded to base flow conditions that continued through winter. Snowmelt initiated the spring high-flow period in mid-March. The highest flows in the Wild Rice, Buffalo, and Otter Tail Rivers occurred in May after the first spring rainstorms. Peak flow in the Straight River followed nearly a month and a half later at the end of June and beginning of July.

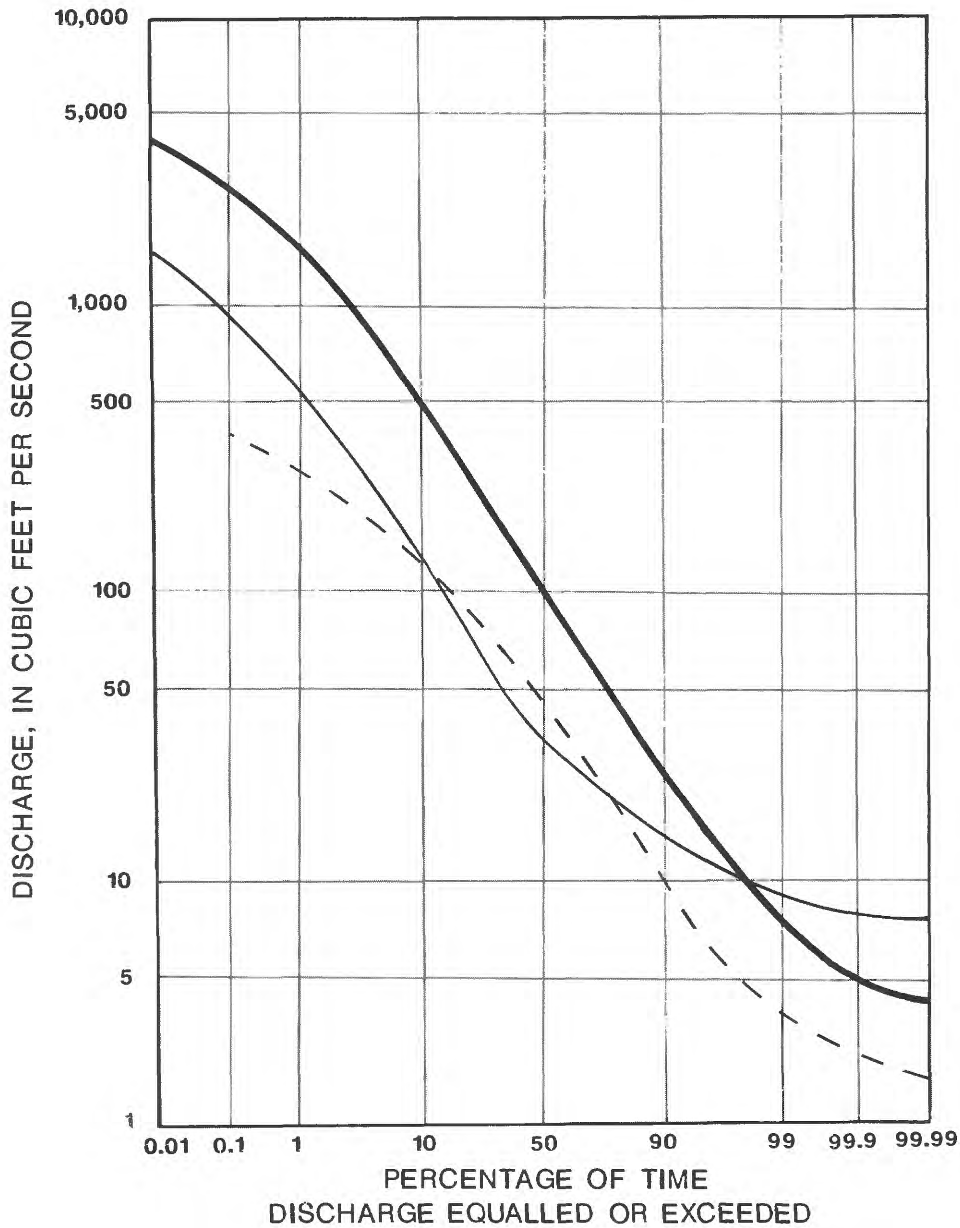
Discharge quickly receded in the streams following the peak flows in May and June, but rose sharply again following rainstorms in July, August, and September. The peaks that occurred during the final three months of the water year, however, were below the peaks of May and June. Soil-moisture conditions were very likely at field capacity immediately following snowmelt, and, as a consequence, the storms in May and June produced large volumes of runoff. By midsummer, soil-moisture conditions were less than field capacity because of evapotranspiration. The storms during this period produced smaller increases in runoff because of greater retention of the precipitation 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.

Basin Characteristics

Annual discharge from the Wild Rice, Buffalo, and Otter Tail River drainage basins during the 1985 water year expressed as equivalent inches of runoff was 8.4, 6.0, and 7.0 inches, respectively (figs. 19-21). Estimates of the average annual runoff, which includes base flow, from the headwaters area of these basins are 2.46, 3.02, and 2.65 inches (Winter and others, 1970; Winter and others, 1969; and Maclay and others, 1969). The runoff was higher than normal in 1985 because precipitation (measured at the Mahnomen weather station) was above normal (National Oceanic and Atmospheric Administration, 1985).

An estimate of the total runoff from the southeastern part of the Reservation that drains the headwaters area of the Crow Wing River basin is unavailable. However, runoff from the Straight River subbasin, which is one of several small ones in the headwaters area of the Crow Wing River basin, was estimated to be 12 inches in 1985 (fig. 22). Ground-water discharge may be a significant source of the stream discharge. The Straight River flows through a surficial outwash deposit that is potentially capable of transmitting a substantial quantity of water to the stream during dry or low-flow periods.

The numerous lakes and depressions in the morainal areas, and the potholes and marshes in the lake plain, all contribute to natural storage of surface-water runoff in the Reservation. The surficial outwash deposits also provide natural storage because the permeability of the sand and gravel allows precipitation and snowmelt to infiltrate rapidly through the soil zone and enter the upper part of the ground-water system. The outwash becomes a significant source of discharge to streams during low-flow periods. Flow duration curves based on discharge data collected at long-term gaging stations on the Wild Rice, Buffalo, and Otter Tail Rivers (fig. 5) reflect the storage characteristics of these basins (fig. 23). The lower ends of the curves



EXPLANATION

Wild Rice River at Twin Valley, 1945-65 water years

Buffalo River near Hawley, 1946-64 water years

Otter Tail River near Detoit Lakes, 1943-53 water years

Duration curves based on daily mean discharges. Hydrology from Winter and others, 1970; Winter and others, 1969; and Maclay and others, 1969.

Figure 23.--Flow duration curves of the Wild Rice, Buffalo, and Otter Tail Rivers

indicate that rates of base flow approach constant values during periods of low flow. Ground water from storage sustains base flows less than 10 ft^3/s in these streams.

Landscape features that contribute to basin storage also tend to limit peak flows during flooding. The natural storage in the lakes, marshes, and depressional areas in the morainal uplands, and the relatively high permeability of the surficial outwash deposits, limit flood runoff in the central and eastern parts of the Reservation. High flood peaks are more likely in the western lacustrine plain because of the nearly level topography, small capacity of the stream channels, and poor drainage characteristics of the soils.

The highest flows during the 1985 water year occurred in May and June in response to summer rainstorms (figs. 19-22). Significant maximum flows can occur anytime between March and October, particularly in small drainage areas that respond quickly to local, high-intensity rainstorms. High flows in the Reservation generally occur more frequently during spring snowmelt, particularly if rainstorms augment the runoff.

Quality

Lakes

Lakes in the Reservation generally are hard and alkaline, and are mesotrophic to eutrophic in terms of their productivity. The Reservation is in an area where potential evapotranspiration exceeds precipitation. Consequently the lakes tend to lose most of their water through evaporation rather than through surface-water outlets. Without continual flushing, the concentrations of soluble minerals increase. Ground water that discharges into these lakes from calcareous glacial drift is a calcium magnesium bicarbonate type, and the prevalent water type in the lakes also is calcium magnesium bicarbonate (fig. 24). Accumulation of these ions in the lake water elevates the hardness and alkalinity.

Analyses of water-quality samples collected from nine lakes are summarized in table 4. Tables 5 and 6 show the results of individual analyses summarized in table 4. The samples collected from the epilimnion were depth integrated within the upper 10 feet of the lake, and the samples collected from the hypolimnion were grabbed with a 2-liter Van Dorn water sampler within 3 feet of the bottom. The collection point for the samples was near the center of each lake. Additional sources of water-quality data were the White Earth Indian Reservation and the Minnesota Chippewa Tribe. Water-quality diagrams show strong similarity among samples from five lakes, which contain calcium magnesium bicarbonate-type water (fig. 25).

The quality of water in the lakes is suitable for aquatic life. Many of the deep cold-water lakes support viable populations of game fish, such as walleye and northern pike. The median concentrations of trace metals, with the exception of mercury, in samples collected from the epilimnia of selected lakes in the Reservation meet the limits recommended by the USEPA to protect against chronic effects on freshwater biota (table 4).

EXPLANATION

Diagram shows water types of individual samples on the basis of major cations and anions determined from their concentrations in milliequivalents per liter. Sodium concentrations are data from the White Earth Indian Reservation.

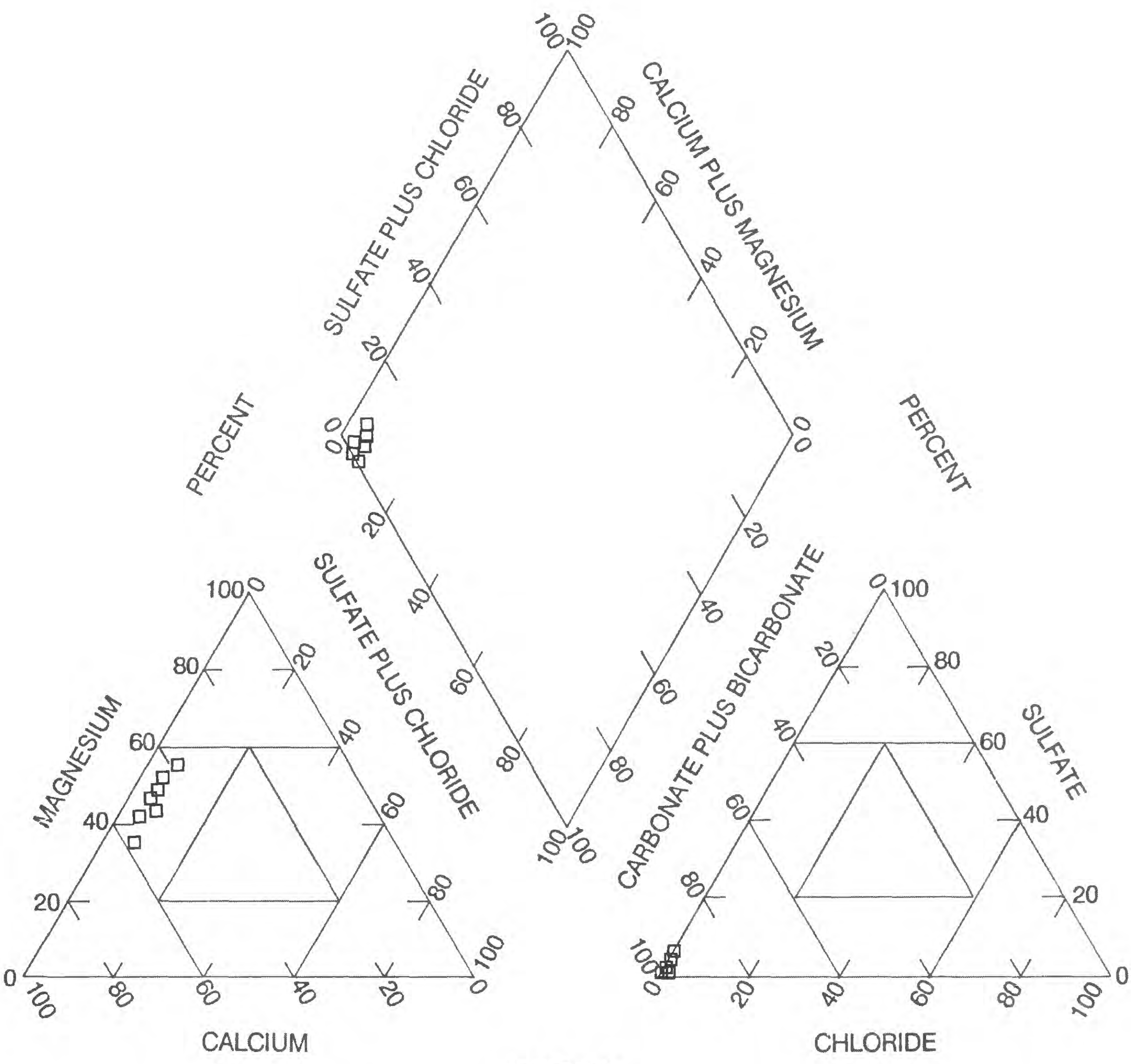


Figure 24.--Percentage of total milliequivalents per liter of major ions in samples collected from selected lakes in the White Earth Indian Reservation

Table 4.--*Summary of water-quality data for samples collected from the epilimnion and hypolimnion of selected lakes in the White Earth Indian Reservation, 1984-85*

The sampled lakes are Strawberry, White Earth, Lake of the Valley, Elbow, Many Point, Tullaby, Roy, North Twin, and Island. [Values in milligrams per liter except as indicated. N, number of samples; µg/L, micrograms per liter; --, no data; *, value of the constituent exceeds the limits recommended by U.S. Environmental Protection Agency (1986) to protect against chronic effects on freshwater life]

Property or constituent	Epilimnion				Hypolimnion			
	N	Minimum	Median	Maximum	N	Minimum	Median	Maximum
pH	9	8.6	8.6	8.9	5	7.7	8.0	8.5
Alkalinity (as $CaCO_3$)	6	120	154	167	--	--	--	--
Hardness (as $CaCO_3$)	8	111	151	168	--	--	--	--
Secchi disk transparency, in feet (summer)	5	3.6	4.8	5.9	--	--	--	--
Calcium, dissolved (as Ca)	8	15	29	36	5	24	35	45
Magnesium, dissolved (as Mg)	9	10	20	25	5	12	20	21
Solids, dissolved, as residue on evaporation at 180 degrees Celsius	9	133	176	197	5	144	197	221
Nitrite + nitrate, dissolved (as N)	9	<.10	<.10	.10	5	<.10	<.10	.10
Ammonia, total (NH_4 + NH_3) (as N)	9	<.01	<.01	<.01	5	<.01	.35	.50
Phosphate, total (as PO_4)	9	<.01	<.01	.04	5	<.01	.10	.19
Cyanide, total (as CN)	9	<.01	<.01	<.01	5	<.01	<.01	<.01

Table 4.--*Summary of water-quality data for samples collected from the epilimnion and hypolimnion of selected lakes in the White Earth Indian Reservation, 1984-85*--Continued

Property or constituent	Epilimnion				Hypolimnion			
	N	Minimum	Median	Maximum	N	Minimum	Median	Maximum
Arsenic, total (µg/L as As)	8	<1.0	1.5	3.0	4	<1	2	5
Barium, dissolved (µg/L as Ba)	9	<100	<100	<100	5	<100	<100	<100
Beryllium, total (µg/L as Be)	9	<10	<10	<10	5	<10	<10	<10
Cadmium, total (µg/L as Cd)	9	<1	<1	<1	5	<1	<1	1
Chromium, total (µg/L as Cr)	7	2.0	4.0	5.0	5	2	4	8
Copper, total (µg/L as Cu)	9	2	4	6	5	20	28	49
Iron, dissolved (µg/L as Fe)	9	<3	<10	20	5	5	100	1,700
Lead, total (µg/L as Pb)	9	<5	<5	5	5	5	12	18
Mercury, total (µg/L as Hg)	9	<.1*	.1*	.3*	5	<.1*	.4*	3.5*
Nickel, total (µg/L as Ni)	9	<1	3	5	5	<1	1	2
Selenium, total (µg/L as Se)	9	<1	<1	<1	4	<1	<1	<1
Silver, total (µg/L as Ag)	9	<1	<1	1	5	<1	<1	1

Table 5.--*Chemical analyses of samples from the epilimnion of selected lakes in the White Earth Indian Reservation, 1986*

Lake	USGS identification number	Lake name	Lake	USGS identification number	Lake name	Lake	USGS identification number	Lake name
1	470405095420001	Strawberry Lake near Ponsford	4	470830095330001	Elbow Lake near Ponsford	7	471530095383001	North Twin Lake near Naytahwausch
2	470500095323001	Many Point Lake near Ponsford	5	470830095363001	Tullaby Lake near Ponsford	8	471900095330001	Roy Lake near Naytahwausch
3	470730095450001	White Earth Lake near Ponsford	6	470800095233001	Lake of the Valley near Ponsford	9	472700095390001	Island Lake near Ponsford

[µs/Cm, Microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsuis; <, less than; --, not determined]

			Nitrogen (mg/l as N)						
Lake	Date	pH, laboratory (standard units)	Ammonia, total	Nitrate plus nitrite, total	Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)	Alkalinity (mg/L as $CaCO_3$)	Magnesium, dissolved (mg/L as Mg)	Arsenic, total (µg/L as As)
1	08/06/86	8.7	<0.01	<0.10	<0.01	24	--	20	1
2	08/12/86	8.6	<.01	<.10	<.01	29	155	19	2
3	08/06/86	8.7	<.01	<.10	<.01	--	163	20	--
4	08/07/86	8.6	<.01	<.10	<.01	36	167	19	1
5	08/13/86	8.7	<.01	<.10	<.01	29	--	20	2
6	08/07/86	8.6	<.01	.10	<.01	28	120	10	<1
7	08/13/86	8.6	<.01	<.10	<.01	29	--	21	3
8	08/13/86	8.9	<.01	<.10	<.01	15	153	25	2
9	08/03/86	8.6	<.01	<.10	<.01	27	130	20	1

Table 5.--*Chemical analyses of samples from the epilimnion of selected lakes in the White Earth Indian Reservation, 1986*--Continued

Lake	Date	Barium, dissolved (µg/L as Ba)	Beryllium, total recoverable (µg/L as Be)	Cadmium, total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Nickel, total recoverable (µg/L as Ni)
1	08/06/86	55	<10	<1	5	4	7	<5	<1
2	08/12/86	<100	<10	<1	3	6	20	5	3
3	08/06/86	<100	<10	<1	--	3	<10	<5	2
4	08/07/86	59	<10	<1	--	4	6	<5	4
5	08/13/86	<100	<10	<1	4	3	<10	<5	3
6	08/07/86	59	<10	<1	4	2	<3	<5	1
7	08/13/86	<100	<10	<1	4	6	<10	<5	4
8	08/13/86	<100	<10	<1	3	4	10	<5	5
9	08/03/86	<100	<10	<1	2	2	<10	<5	4

Lake	Date	Hardness, as $CaCO_3$ (mg/L)	Secchi disk transparency (feet)	Silver, total recoverable (µg/L as Ag)	Selenium, total (µg/L as Se)	Solids, residue at 180° C, dissolved (mg/L)	Phosphorus ortho, total (mg/L as P)	Mercury, total recoverable (µg/L as Hg)	Specific conductance laboratory (µs/Cm)
1	08/06/86	142	--	<1	<1	162	0.04	0.3	286
2	08/12/86	151	5.5	<1	<1	176	<.01	<.1	281
3	08/06/86	--	--	<1	<1	176	<.01	.2	301
4	08/07/86	168	--	<1	<1	180	<.01	.2	309
5	08/13/86	155	4.8	1	<1	180	<.01	<.1	285
6	08/07/86	111	--	<1	<1	133	.01	.2	234
7	08/13/86	159	3.7	<1	<1	197	<.01	.1	295
8	08/13/86	140	3.6	1	<1	169	<.01	<.1	284
9	08/03/86	150	5.9	<1	<1	187	<.01	<.1	286

Table 6.-- *Chemical analyses of samples from the hypolimnion of selected lakes in the White Earth Indian Reservation, 1986*

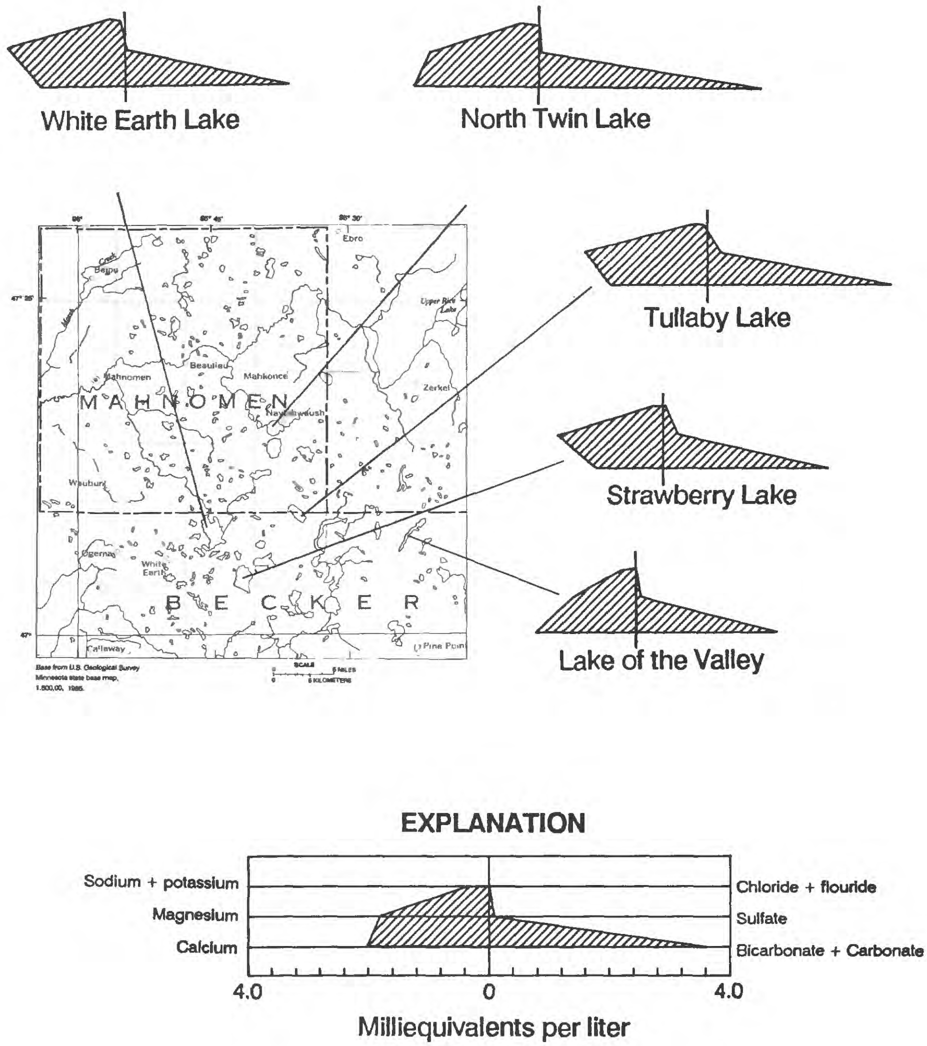
Lake	USGS identification number	Lake name	Lake	USGS identification number	Lake name
1	470405095420001	Strawberry Lake near Ponsford	4	470830095330001	Elbow Lake near Ponsford
2	470500095323001	Many Point Lake near Ponsford	5	470800095233001	Lake of the Valley near Ponsford
3	470730095450001	White Earth Lake near White Earth			

[µs/Cm, Microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsuis; <, less than; --, not determined]

Lake	Date	pH, laboratory (standard units)	Nitrogen (mg/l as N) Ammonia, total	Nitrogen (mg/l as N) Nitrate plus nitrite, total	Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Arsenic, total (µg/L as As)
1	08/06/86	8.5	<0.01	<0.10	<0.01	24	21	2
2	08/12/86	8.1	.42	<.10	<.01	38	19	--
3	08/06/86	8.0	.02	<.10	<.01	35	20	2
4	08/07/86	7.7	.50	.10	<.01	45	20	5
5	08/07/86	7.8	.35	<.10	<.01	33	12	<1

Lake	Date	Barium, dissolved (µg/L as Ba)	Beryllium, total recoverable (µg/L as Be)	Cadmium, total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)
1	08/06/86	55	<10	<1	8	44	5	18
2	08/12/86	<100	<10	<1	4	27	1700	5
3	08/06/86	71	<10	<1	2	20	100	12
4	08/07/86	89	<10	1	3	49	1100	15
5	08/07/86	68	<10	<1	4	28	13	8

Lake	Date	Nickel, total recoverable (µg/L as Ni)	Silver, total recoverable (µg/L as Ag)	Selenium, total (µg/L as Se)	Solids, residue at 180° C, dissolved (mg/L)	Phosphorus, ortho, total (mg/L as P)	Mercury, total recoverable (µg/L as Hg)	Specific conductance, laboratory (µs/Cm)
1	08/06/86	1	<1	<1	168	0.19	0.4	291
2	08/12/86	2	1	--	216	.10	<.1	332
3	08/06/86	<1	<1	<1	197	<.01	.4	334
4	08/07/86	2	<1	<1	221	.10	3.5	373
5	08/07/86	1	<1	<1	144	.01	.3	268



Stiff diagrams based on an analysis of one sample collected at the located site. The size of the diagram is directly proportional to the dissolved-solids concentration. Sodium concentrations data from the White Earth Indian Reservation.

Figure 25.--Ionic composition of water samples collected from selected lakes in the White Earth Indian Reservation

The median concentration of total recoverable mercury was 0.1 μg/L, which exceeds the recommended limit of 0.012 μg/L for the dissolved organic form (U.S. Environmental Protection Agency, 1986). This limit represents a 4-day average that USEPA recommends not be exceeded more than once during a 3-year period. Methylmercury, which is the dissolved organic form of the metal, is the most toxic form of mercury. In the absence of the dissolved organic concentration, USEPA recommends applying the limit to the total recoverable amount. If a lake fails to meet the criterion, USEPA recommends the edible portions of consumed species of fish from that lake be analyzed to determine the residue of methylmercury in the fish tissue. Long-term consumption of fish with residue levels that exceed 0.50 μg/g poses a human-health concern.

The concentration of total recoverable mercury is likely to exceed 0.012 μg/L in many lakes and streams in Minnesota. Deposition onto surface water of mercury released to the atmosphere from smelting and combustion of fossil fuels probably accounts for the widespread increase in concentration (Hem, 1985). Jenkins (1981) 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 is 0.200 μg/L (Smith and others, 1987). Exceedance of the recommended limit for dissolved organic mercury in surface water, therefore, appears to be widespread.

The potential problem posed by mercury contamination of fish is likely to be less serious in the White Earth Indian Reservation than other parts of the State because of the chemical characteristics of the lakes. A recent study of mercury levels in fish noted that the bioaccumulation of the most toxic form of mercury appears to occur less readily in alkaline lakes that have high levels of calcium (Helwig and Heiskary, 1985). This study also reported that mercury in northern pike and walleye in the north-central and western parts of the State seldom exceeded 0.20 μg/g, -- a level below the 0.50 μg/g-level that is considered to be unsafe for human consumption.

Values of pH in the sampled lakes are within limits recommended by USEPA for fresh-water aquatic habitat. The pH ranged from 8.4 to 8.6 in the epilimnion and 7.7 to 8.5 in the hypolimnion (table 4). Values of pH below 6.5 adversely affect walleye reproduction, increase the toxicity of some compounds, and possibly increase the solubility of harmful metals in bottom sediments (U.S. Environmental Protection Agency, 1986). The pH of the lakes tends to remain stable because of their high alkalinity, which protects against the potentially harmful effects of acid deposition. Alkalinities of susceptible lakes range from 16 to 30 mg/L (as $CaCO_3$) (Heiskary and Helwig, 1985). The alkalinity in the epilimnion of sampled lakes ranged from 120 to 167 mg/L (as $CaCO_3$) (table 4).

The productivity of the lakes stems from the fertility of the soils and active biological communities in the Reservation watersheds. Nutrients in inflowing water to the lakes are likely to be more concentrated than in the water in the lakes. Nutrients accumulate in the lakes and recycle between the biota and bottom sediments, where they become part of a permanent "nutrient reservoir" that contributes to biological productivity.

The total organic carbon produced in White Earth and Strawberry Lakes was estimated to be 226 and 321 grams per square meter per year ($g/m^2/yr$), respectively (Minnesota Chippewa Tribe, 1986). These values are characteristic of lakes that are intermediate between mesotrophic and eutrophic levels of productivity (Wetzel, 1975, p. 349-351). The summer Secchi disk transparency, which is an indirect measure of the biomass in the epilimnion, ranged from 3.7 to 5.9 feet in Reservation lakes (table 4). Eutrophic lakes in Minnesota tend to have Secchi disk transparencies that range from 1.5 to 6.5 feet (Heiskary and Helwig, 1985).

Lakes in the Reservation undergo seasonal and vertical changes in water quality. These changes occur in response to a wide variety of factors, such as (1) changes in water temperature, (2) seasonal changes in aquatic biological activity, (3) shifts in solubility of inorganic constituents and trace metals, (4) increases or decreases in the loading of chemical constituents, (5) chemical interaction between lake water and the sediments, and (6) lake-water stratification. Water-quality data collected from selected lakes by the White Earth Indian Reservation during 1983-86 show that the concentration of many inorganic constituents and trace metals changed very little. The constituents calcium, sulfate, bicarbonate, and, to a lesser extent, barium and boron, were the most variable. Calcium, sulfate, and bicarbonate are ions that commonly undergo changes in concentration as a result of biochemical activity.

Vertical profiles of temperature, pH, specific conductance, and dissolved oxygen show the variation with depth of these properties and constituents in four selected lakes in the Reservation during late summer of 1986 (fig. 26). North Twin Lake, which is a representative shallow lake less than 20 feet deep, was very well mixed, and Lake of the Valley, Many Point, and Tullaby were stratified. The thermocline in the stratified lakes was approximately 20 feet deep.

The increased pH and dissolved-oxygen content observed in the epilimnion of these lakes commonly occur in eutrophic, hard-water lakes (Wetzel, 1975). Phytoplanktonic algae in the trophogenic zone use bicarbonate ions and release oxygen during photosynthesis. This process increases the pH and dissolved oxygen in the epilimnion. Organic matter accumulates in the hypolimnion of stratified lakes and undergoes biological decay. This process increases the concentration of bicarbonate and decreases the concentration of oxygen. The hypolimnion of eutrophic lakes is commonly anaerobic within several weeks after summer stratification.

The specific conductance profiles, which show an increase in specific conductance with depth, reflect the increase in bicarbonate concentration in the hypolimnion. Increased dissolved-calcium concentration in the hypolimnion also elevates the specific conductance. During summer months, dissolved calcium commonly precipitates out of the epilimnion as calcium carbonate, which then settles to the bottom where some resolubilizes in the hypolimnion.

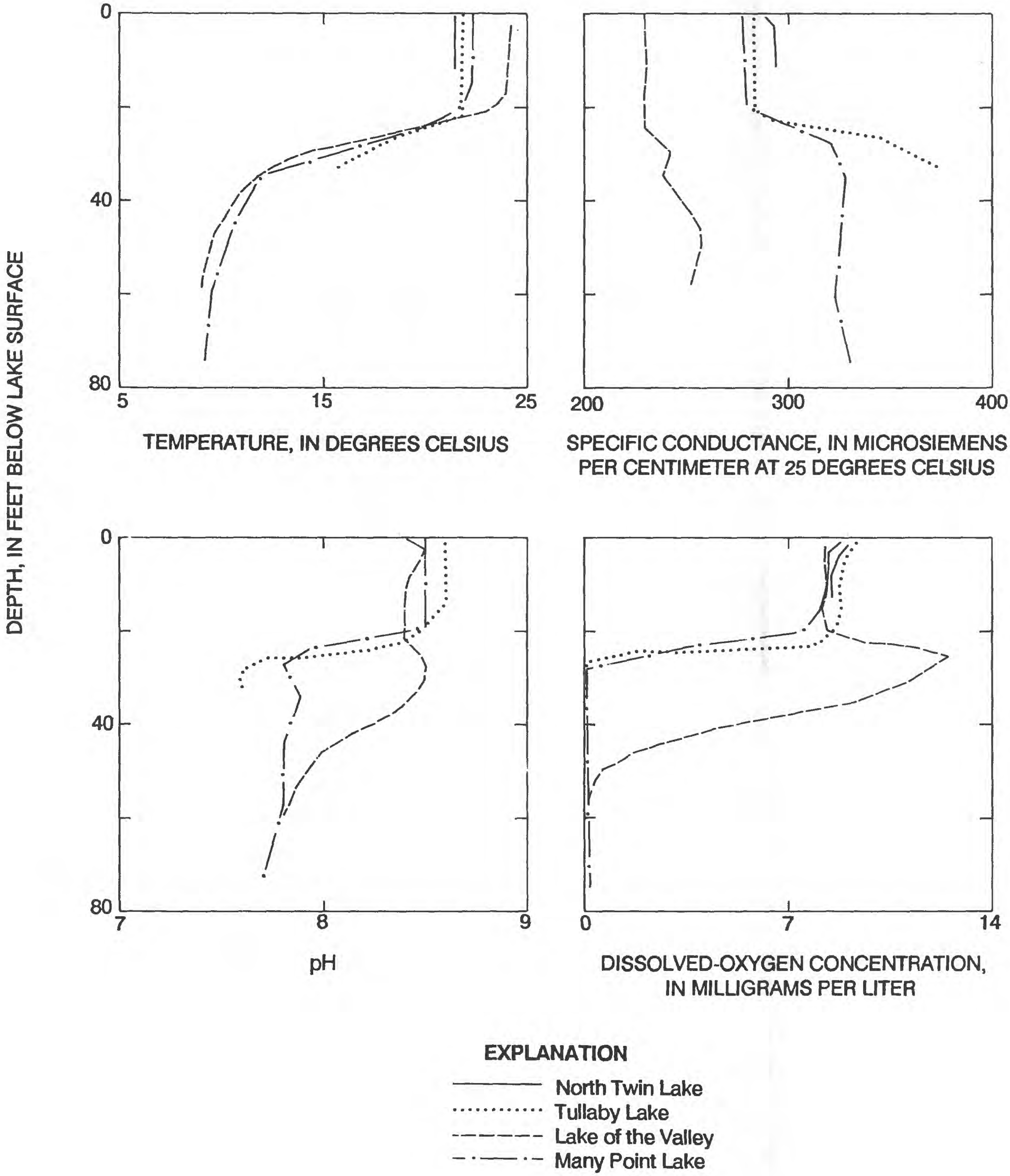


Figure 26.--Temperature, pH, specific conductance, and dissolved oxygen profiles in four lakes in the White Earth Indian Reservation during late summer of 1986

The concentration of nitrogen nutrients varies both vertically and seasonally. The median ammonium (NH_4+) concentration of 0.35 mg/L in the hypolimnion exceeded the median concentration of <0.01 mg/L in the epilimnion (table 4). The source of elevated NH_4+ in the hypolimnion of eutrophic lakes is organic matter that undergoes decomposition. The accumulation of NH_4+ accelerates as the hypolimnion becomes progressively anaerobic.

Orthophosphate, which is the most reactive form of inorganic phosphorus in lake water biota, also was high in the hypolimnion. The median concentration was 0.10 mg/L in the hypolimnion and 0.01 mg/L in the epilimnion (table 4). Lakes that become anaerobic in the hypolimnion commonly have a marked increase in phosphorus with depth, and much of the increase is due to release of soluble phosphorus from the sediments.

Orthophosphate commonly is a very small proportion of the total phosphorus in a lake. As much as 90 percent of the phosphorus is bound organically in living and nonliving particulate matter. The total phosphorus in samples collected from the epilimnia of Strawberry and White Earth Lakes in the summer of 1985 was 0.05 and 0.06 mg/L, respectively (Minnesota Chippewa Tribe Diagnostic Feasibility Study of Fishery Ecosystems, 1986). These concentrations are within or nearly within the range of 0.01 to 0.05 mg/L that is characteristic of most uncontaminated surface water (Wetzel, 1975, p. 217).

Some trace metals accumulated in the hypolimnion of the deeper lakes in the Reservation. Chemical-equilibrium conditions commonly favor the release of trace metals from bottom sediments into overlying water. The low pH and reducing conditions that commonly prevail in the hypolimnion of eutrophic lakes increase the solubility of many metal ions. These factors are likely causes of the elevated levels of arsenic, copper, iron, lead, and mercury (fig. 27).

Phytoplankton are a diverse assemblage of algae that photosynthesize organic matter required by many other organisms. Photosynthesis in phytoplankton occurs in the trophogenic zone, which is the upper stratum of lakes penetrated by sunlight sufficient to drive the biochemical reactions that produce organic matter. Growth of phytoplankton in temperate freshwater lakes commonly peaks in spring, decreases in summer, increases again in fall, and declines to a minimum in winter (Wetzel, 1975, p. 322-323). However, the seasonal pattern of growth and die-off of phytoplankton in individual lakes is highly variable. White Earth and Strawberry Lakes appear to have more growth of phytoplankton in fall than in spring. The seasonal variation of the concentration of chlorophyll *a*, which is a measure of the amount of phytoplankton biomass, was highest in the fall and lowest in the winter and summer (Minnesota Chippewa Tribe, 1986).

Most lakes in the Reservation have characteristics of both mesotrophic and eutrophic conditions. The moderately productive lakes that support nutrient-limited growth of algae are mesotrophic, and the more productive lakes that contain abundant nutrients and support prolific growth of algae are eutrophic. The productivity of the lakes is a key indicator of nutrient availability.

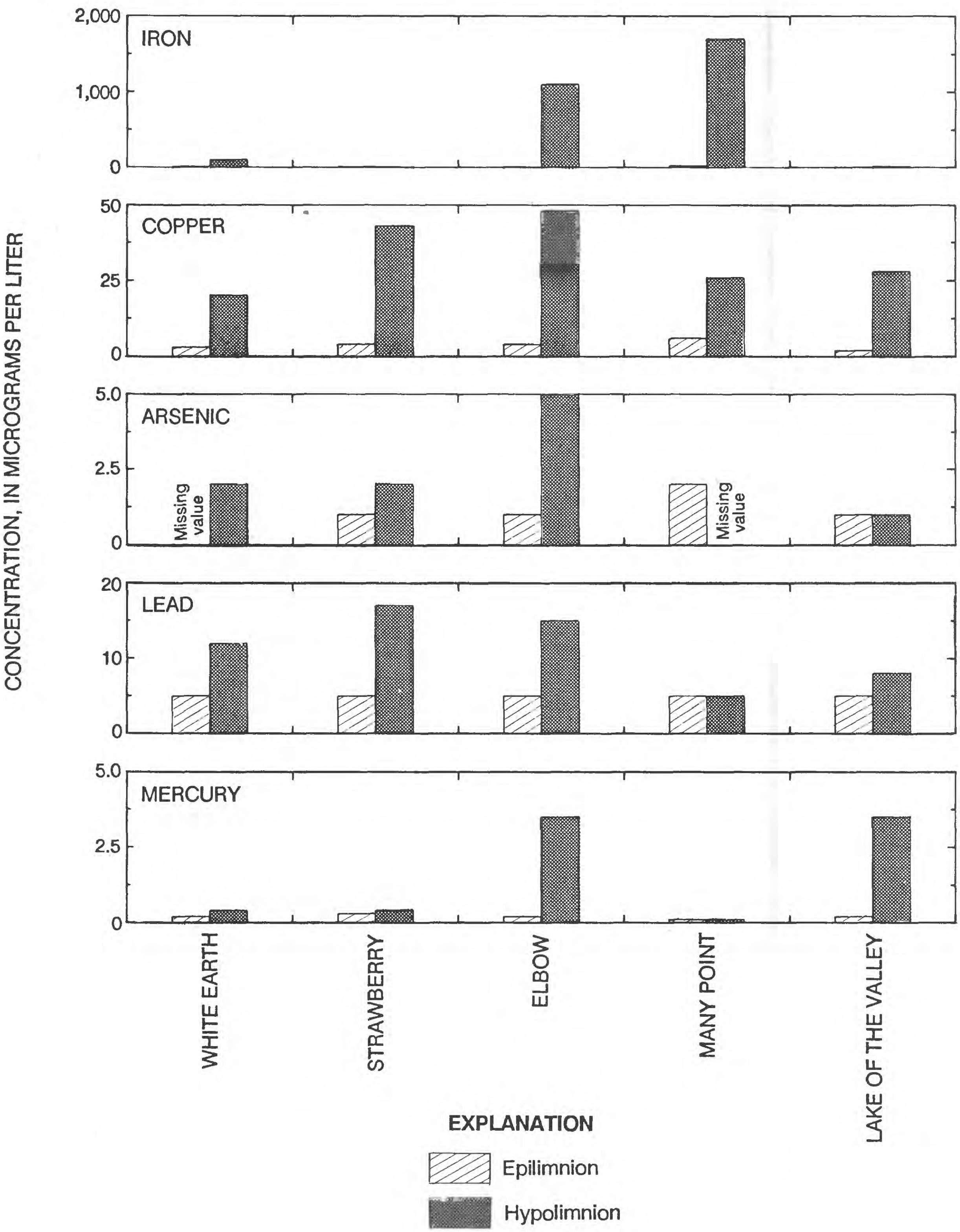


Figure 27,--Concentration of trace metals in the epilimnion and hypolimnion of selected lakes in the White Earth Indian Reservation

Figure 28 shows the proportions of the dominant types of phytoplankton in samples collected from nine lakes in the Reservation during late summer of 1986. The dominant algal associations were blue-green algae (Cyanophyta) and diatoms (Chrysophyta). These types of algae are characteristic of alkaline, eutrophic lakes. Dinoflagellates (Pyrrophyta) and euglenoids (Euglenophyta) were also present in some of the lakes sampled. Dinoflagellates are found in oligotrophic and mesotrophic lakes, although they are sometimes prolific in eutrophic lakes. Euglenoids are most common in eutrophic lakes that are organically enriched or polluted (Wetzel, 1975, p. 299).

The species diversity of phytoplankton in a lake is indicative of the fertility of the water. The species diversity is more likely to be low if the productivity of the lake is high, and vice versa. Productive eutrophic lakes commonly favor rapid growth of one or a small number of species that become dominant. Oligotrophic lakes, however, allow the coexistence of a wide variety of species with similar growth requirements (Wetzel, 1975, p. 330-331).

A species-diversity index calculated by a formula derived from Shannon shows the differences in the phytoplankton communities (Wetzel, 1975, p. 331). The indices were lowest in samples from Tullaby Lake and Lake of the Valley because of the dominance of three species of blue-green algae, Anabena spiroides, Chroococcus limneticus, and Oscillatoria tennis. The phytoplankton communities were slightly more diverse in the samples from North Twin, Island, and Strawberry Lakes. Diatoms, particularly Melosira granulata, were abundant in these samples. Species diversity was greatest in the sample from White Earth Lake. Sixteen different species were present, and the number of cells of each of these species comprised less than 20 percent of the total number. North Twin and Tullaby Lakes appear to be eutrophic because of the low species-diversity index, high cell count, and large amount of biomass of the phytoplankton in the samples from these lakes. Lake of the Valley, Many Point, Elbow, White Earth, Strawberry, Roy, and Island Lake are more likely to be mesotrophic lakes.

Streams

Quality of the streams in the Reservation is assessed on the basis of analyses of samples collected from the Wild Rice, Buffalo, Otter Tail, and Straight Rivers at the short-term gaging stations (fig. 5). Table 7 summarizes these data. Table 8 shows the results of individual analyses. The streams appear to be of acceptable quality for recreation and fishery habitat.

Water in the streams is the calcium magnesium bicarbonate type (fig. 29). Figure 29 shows that the proportions of the major ions in the Wild Rice, Buffalo, and Otter Tail Rivers are very similar, but those in the Straight River are slightly different because of high sodium concentration (fig. 30).

The median values of all the constituents and properties except turbidity meet the criteria established by the Minnesota Pollution Control Agency for surface water placed in a recreational- and fishery-use classification (table 7). The turbidity in the sample collected from the Otter Tail River, however, was 2.5 NTU, which is within the recommended limit.

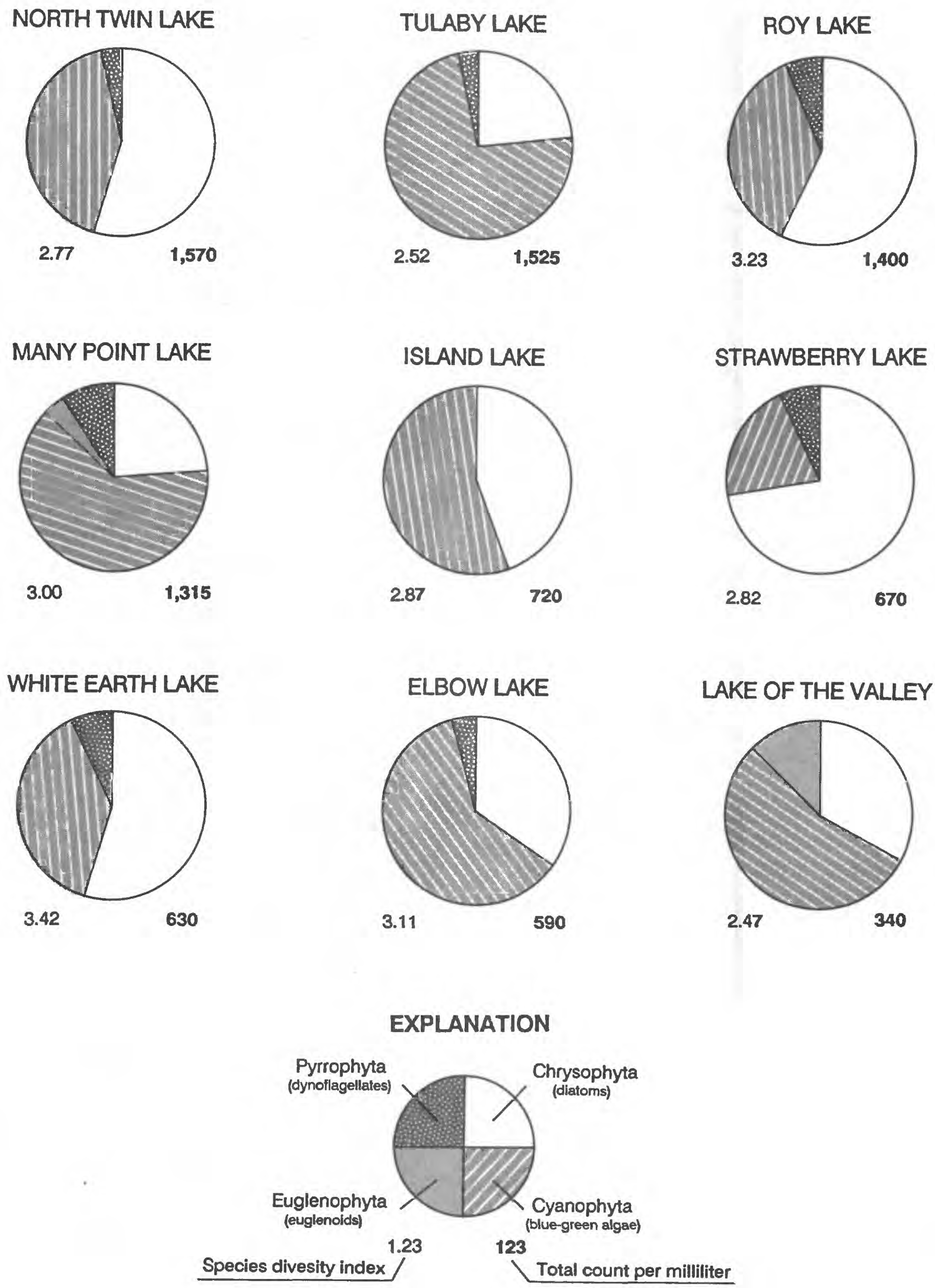


Figure 28.--Phytoplankton dominance and species diversity index of selected lakes in the White Earth Indian Reservation during late summer of 1986

Table 7.--*Summary of water-quality data for samples collected from the Wild Rice, Buffalo, Otter Tail, and Straight Rivers in the White Earth Indian Reservation, 1984-85*

[Values in milligrams per liter except as indicated. N, number of samples; NTU, nephelometric turbidity units; *, indicates the value exceeds the limit recommended by the Minnesota Pollution Control Agency for fisheries and recreation (Minnesota Pollution Control Agency, 1988); μs/cm, microsiemens per centimeter; μg/L, micrograms per liter]

Property or constituent	N	Minimum	Median	Maximum	Recommended limit or range for fisheries and recreation[1]
Specific conductance, μs/cm at 25 degrees Celsius	4	329	401	417	
pH	3	7.9	8.1	8.2	6.5-8.5
Alkalinity (as $CaCO_3$)	4	174	220	226	
Turbidity, NTU	4	2.5	103	180	10 NTUs
Calcium, dissolved (as Ca)	4	35	54	58	
Magnesium, dissolved (as Mg)	4	13	20	30	
Potassium, dissolved (as K)	4	1.2	2.1	3.3	
Sulfate, dissolved (as SO_4)	4	2.0	11	45	
Chloride, dissolved (as Cl)	4	1.5	2.9	50	

Table 7.--*Summary of water-quality data for samples collected from the Wild Rice, Buffalo, Otter Tail, and Straight Rivers in the White Earth Indian Reservation, 1984-85*--Continued

Property or constituent	N	Minimum	Median	Maximum	Recommended limit or range for fisheries and recreation[1]
Solids, dissolved, as residue on evaporation at 180 degrees Celsius	4	197	274	298	
Nitrite + nitrate, dissolved (as N)	4	<.10	<.10	.53	
Ammonia, total, (NH_4 + NH_3) (as N)	4	0.02	0.04	0.04	
Ammonia, un-ionized, (NH_3) (as N)	4	0.001	0.002	0.002	0.016 μg/L
Phosphorus, total (as P)	4	0.02	0.04	0.05	
Organic carbon, total (as C)	4	9.9	13.1	15.1	
Arsenic, dissolved (μg/L as As)	4	<1	1.5	2	
Barium, dissolved (μg/L as Ba)	4	65	100	100	

Table 7.--*Summary of water-quality data for samples collected from the Wild Rice, Buffalo, Otter Tail, and Straight Rivers in the White Earth Indian Reservation, 1984-85*--Continued

Property or constituent	N	Minimum	Median	Maximum	Recommended limit or range for fisheries and recreation[1]
Cadmium, dissolved (µg/L as Cd)	4	<1	1	1	
Chromium, dissolved (µg/L as Cr)	4	<10	<10	10	20 µg/L
Copper, dissolved (µg/L as Cu)	4	<1	1.5	2	10 µg/L
Cyanide, total (µg/L as CN)	4	<.01	<.01	<.01	20 µg/L
Lead, dissolved (µg/L as Pb)	4	<1	<1	1	
Manganese, dissolved (µg/L as Mn)	4	20	26	60	
Mercury, dissolved (µg/L as Hg)	4	.4*	.5*	.8*	
Selenium, dissolved (µg/L as Se)	4	<1	<1	<1	
Silver, dissolved (µg/L as Ag)	4	<1	<1	<1	
Zinc, dissolved (µg/L as Zn)	4	<10	17	40	

[1] Minnesota Pollution Control Agency, 1988, Standards for the protection of the quality and purity of the waters of the State, Minnesota Rules Chapter 7050.

Table 8.--*Chemical analyses of four streams in the White Earth Indian Reservation, 1984*

Stream	USGS identification number	Stream name	Stream	USGS identification numberLake	Stream name
1	471710096055201	Wild Rice River near Faith	3	465955095364201	Otter Tail River near Ponsford
2	465750096025701	Buffalo River near Lake Park	4	465858095170801	Straight River near Osage

[µs/Cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity unit; °C, degrees Celsuis; <, less than; --, not determined]

Stream	Date	Temperature water (°C)	Turbidity (NTU)	Specific conductance (µs/cm)	pH, laboratory (standard units)	Nitrogen (mg/L as N) Ammonia, total	Ammonia plus organic		Nitrate plus nitrite, dissolved
							Dissolved	Total	
1	05/23/84	18.0	180	419	8.2	0.04	0.30	1.70	<0.10
2	05/23/84	15.0	150	412	7.9	.04	.50	1.60	<.10
3	05/22/84	17.0	2.5	333	8.1	.02	.30	2.50	<.10
4	05/22/84	17.0	55	398	--	.04	.10	2.00	.53

Stream	Date	Phosphorus (mg/L as P)		Carbon, organic (mg/l as C)		Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)
		Total	Dissolved	Dissolved	Suspended		
1	05/23/84	0.04	0.03	14.0	0.6	<0.01	58
2	05/23/84	.04	.01	14.0	1.1	<.01	53
3	05/22/84	.02	.01	9.4	.5	<.01	35
4	05/22/84	.05	.02	9.1	2.5	<.01	54

Table 8.--*Chemical analyses of four streams in the White Earth Indian Reservation, 1984*
--Continued

Stream	Date	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)
1	05/23/84	20	2.4	50	45	2	100	70
2	05/23/84	30	3.3	3.0	19	2	100	60
3	05/22/84	19	1.7	1.5	2.0	1	65	40
4	05/22/84	13	1.2	2.8	3.1	<1	100	30

Stream	Date	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Silver, dissolved (µg/L as Ag)
1	05/23/84	1	10	<1	20	<1	20	<1
2	05/23/84	1	10	1	20	<1	30	<1
3	05/22/84	<1	<10	2	46	1	21	<1
4	05/22/84	1	<10	2	30	<1	60	<1

Stream	Date	Zinc, dissolved (µg/L as Zn)	Selenium, dissolved (µg/L as Se)	Solids, residue at 180 °C dissolved (mg/L)	Mercury, dissolved (µg/L as Hg)	Specific conductance laboratory (µs/cm)	Alkalinity, laboratory (mg/L as $CaCo_3$)
1	05/23/84	20	<1	298	0.8	415	225
2	05/23/84	<10	<1	292	.6	417	226
3	05/22/84	14	<1	197	.4	329	174
4	05/22/84	40	<1	256	.4	387	215

EXPLANATION

Diagram shows water types of individual samples on the basis of major cations and anions determined from their concentrations in milliequivalents per liter. Sodium concentrations are estimated values based on water-quality data reported by Winter and others, 1970.

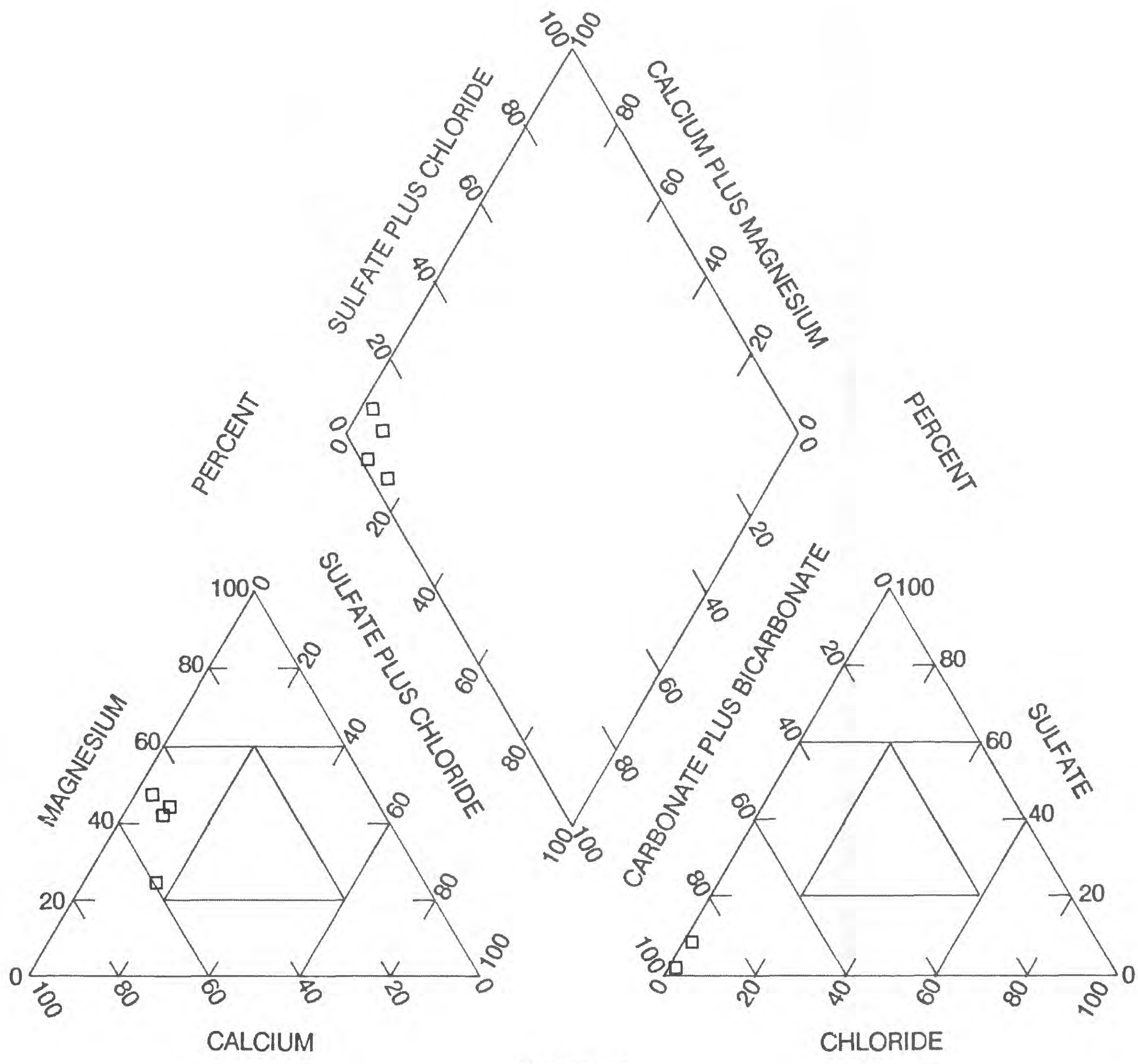
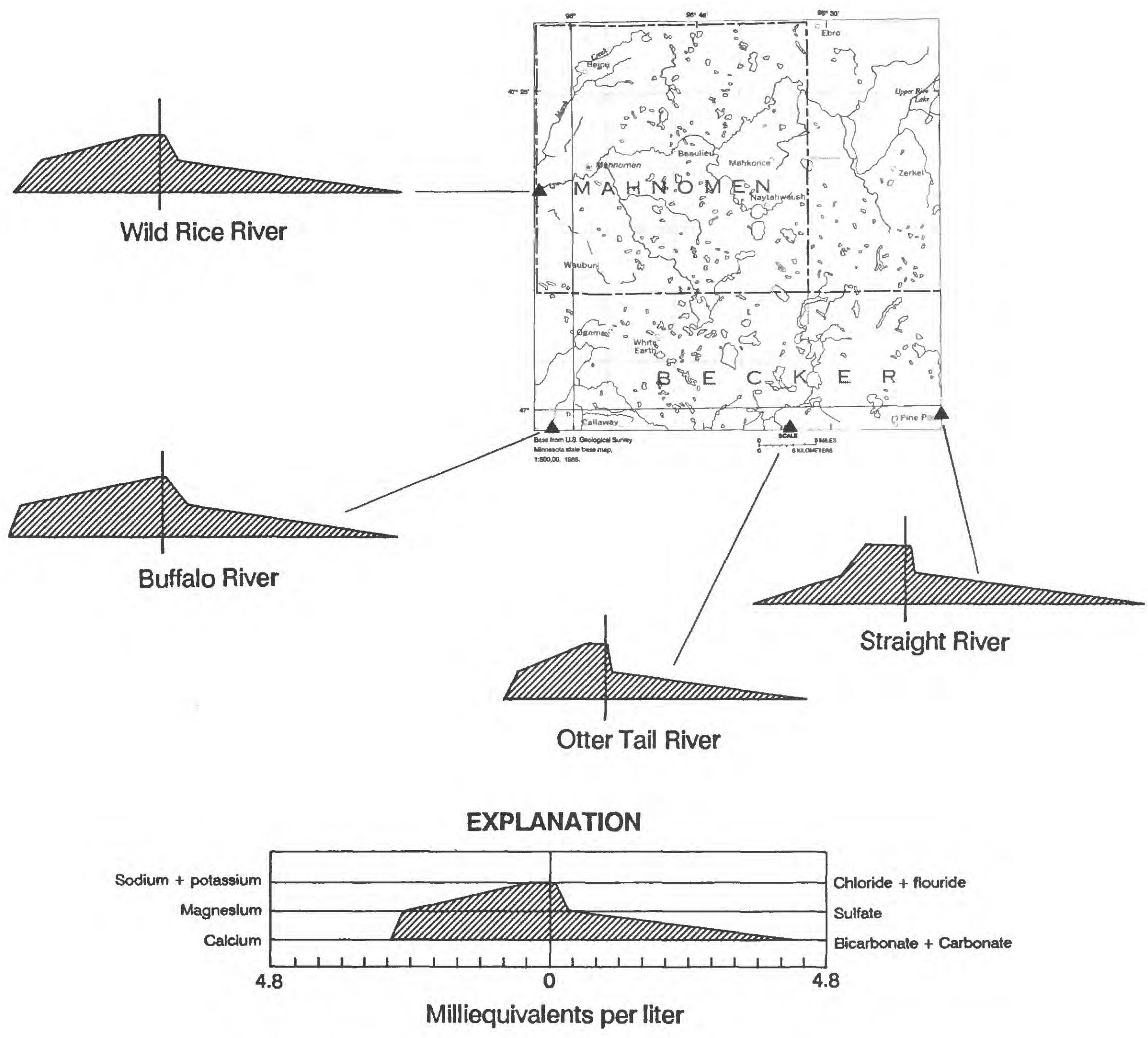


Figure 29.--Percentage of total milliequivalents per liter of major ions in water samples collected from the Wild Rice, Buffalo, Otter Tail, and Straight Rivers



Stiff diagrams based on an analysis of one sample collected at the located site. The size of the diagram is directly proportional to the dissolved solids concentration. Sodium concentrations are estimated values based on water-quality data reported by Winter and others, 1970.

Figure 30.--Ionic composition of water samples collected from four streams in the White Earth Indian Reservation

Turbidity is a measure of the optical property in water that causes light to be scattered and absorbed. High values of turbidity are due to suspended material--commonly, phytoplankton and sediment. Phytoplankton is abundant during the warm part of the year, and the sediment load generally is greatest during high-flow periods. Erosion and channel scour increase the sediment load in streams. Conditions that favor erosion commonly occur in cultivated areas during the early and late stages of the growing season. The high turbidity in the Wild Rice, Buffalo, and Straight Rivers may be related to erosion of the relatively large amount of cultivated area in these watersheds. In contrast, much of the land in the headwaters area of the Otter Tail River watershed is forest where erosion generally is negligible.

Seasonal changes in the dissolved-solids concentration in streamflow depend on the proportions of ground water and overland runoff that contribute to total streamflow. Overland runoff (precipitation or snowmelt that enters directly into the stream channel) is less mineralized than ground-water inflow because of the short period of time that overland runoff water is in contact with glacial materials. The overland runoff dilutes the ground-water inflow during high-flow periods and lowers the dissolved-solids concentration in the stream. Tornes (1980) reported that the dissolved-solids concentration in the Wild Rice River at Twin Valley was highest in fall and winter during low-flow conditions and lowest in spring during high-flow conditions. Although most inorganic constituents tend to be inversely related to flow, sulfate and chloride concentrations increased with flow in the Wild Rice River at Twin Valley, which suggests a surface-runoff origin (Tornes, 1980).

Water-quality data collected at Twin Valley during 1975-77 indicate that the dissolved-oxygen concentration ranged from 65 to 115 percent of saturation (Ford and others, 1979). Tornes (1980) presented diurnal profiles of the dissolved-oxygen concentration at Twin Valley that showed the variation during a 24-hour period was greatest in summer and lowest in winter. Daily values in summer ranged from as high as 9.5 mg/L in late afternoon to as low as 6.5 mg/L in early morning. The daily values in winter changed very little, however; concentrations remained near 8 mg/L. A reduction in the fluctuation of dissolved oxygen in winter reflects reduced rates of photosynthesis and respiration that results from a reduction in sunlight and water temperature. The observed dissolved-oxygen concentration was never below the recommended minimum concentration of 5.0 mg/L (Minnesota Pollution Control Agency, 1988).

The biochemical oxygen (BOD), which is a widely used indicator of stream pollution by animal wastes and sewage, also varies with season. Tornes (1980) reported that the 5-day BOD in the Wild Rice River at Twin Valley was highest in spring and lowest in winter. These findings indicate that more oxygen-demanding substances load the river during spring runoff than at other times of the year. The cause of much of this increase in BOD is plant material that undergoes biochemical decay in the streams.

The amount of total organic carbon in the Reservation streams ranged from 9.9 to 15.1 mg/L (table 7). Concentrations higher than 30 mg/L generally are above background levels and are indicative of polluted conditions (Wetzel, 1975, p. 542). Most of the organic carbon in streams is in the dissolved form, which is rapidly metabolized. The dissolved organic-carbon fraction in the four sampled streams was 3 to nearly 20 times greater than the suspended fraction. Decomposition of the larger, particulate material is very slow because the organic material is in a nonreactive form.

Nitrogen and phosphorus nutrients may lead to degraded quality of water in streams if present at high enough concentrations to support abundant growth of free-floating algae. Nutrient enrichment of a stream may occur because of cultural activities, such as use of fertilizers that contain nitrogen and phosphorus compounds, and direct discharge of sewage into streams. The potential for nutrient loading of streams in the Reservation from nonpoint sources is greatest in the eastern part where agriculture is prevalent. The available data, however, fail to show significant effects of agricultural nutrients in stream water on the capability of these streams to support freshwater life.

The concentration of nitrogen and phosphorus in the Reservation streams is comparable to other areas in the United States. Table 7 shows that the total phosphorus concentration ranged from 0.02 to 0.05 mg/L, which is within the range of that found in uncontaminated surface water and below the median concentration of 0.13 mg/L reported for streams throughout the United States (Smith and others, 1987). Tornes (1980) reported that the average total phosphorus concentration in the Wild Rice River at Twin Valley was 0.06 mg/L, and that the concentration generally increased at higher flow. The concentration of nitrate was less than the detection limit of 0.10 mg/L (as N) in the Wild Rice, Buffalo, and Otter Tail Rivers, and was 0.53 mg/L in the Straight River (table 8). These concentrations are less than or similar to the median nitrate concentration of 0.42 mg/L for streams throughout the United States (Smith and others, 1987). The nitrate concentrations in small and medium-sized streams in agricultural areas may be as high as 2.3 mg/L at times (Hem, 1985).

SUMMARY

This report is an appraisal of the water resources of the White Earth Indian Reservation in northwestern Minnesota. The Reservation extends over a 1,300-square mile area that is forested in the eastern part and cultivated in the western part. Approximately one-fifth of the Reservation is pasture land, open water, wetlands, and urban and rural residential areas. Morainal areas and till plains in the central and western parts of the Reservation, lacustrine plains in the western part, and outwash deposits in the central and southeastern parts, form the major landscape features.

Much of the water from precipitation and snowmelt that infiltrates the land surface quickly returns to the atmosphere as evapotranspiration or enters local flow systems and discharges into nearby wetlands, lakes, or streams. Some of this water, however, infiltrates deeper into the subsurface and recharges the ground-water reservoir. Ground-water recharge in the Reservation generally ranges from 2 to 4 inches. Ground water in the Reservation generally moves along regional flow paths from southeast to northwest. The upland morainal areas in the eastern part of the Reservation are regional recharge areas, and the lake plain in the western part is a regional discharge area.

Ground water is stored in glacial-drift aquifers that consist of permeable deposits of sand and gravel. These aquifers comprise two types: (1) unconfined-drift aquifers, and (2) confined-drift aquifers. Most of the pumped water comes from the confined-drift aquifers, which consist of discontinuous deposits of sand and gravel overlain by clay or till. These aquifers differ in size from several square miles to tens of square miles. The aquifers may be hydraulically connected, but they are more likely separated hydraulically by till. The unconfined-drift aquifers in the Reservation are two surficial outwash plains. One trends along a north-south strip through the central part of the Reservation, and the other occupies the southeastern part.

The saturated thickness of the unconfined-drift aquifers ranges from 10 to 50 feet in the central outwash plain and from 50 to 125 feet in the southeastern outwash plain. The southeastern unconfined-drift aquifer is more heavily used than the central unconfined-drift aquifer. The permeability and saturated thickness of the southeastern aquifer indicates that wells completed in this aquifer are potentially capable of producing 500 to 1,000 gal/min. Estimates of the yield from wells completed in confined-drift aquifers range from 100 gal/min in a large part of the Reservation to 1,000 gal/min in local areas of the Reservation.

Quality of the ground water in the Reservation is suitable for drinking and other household uses. Ground water is commonly a calcium magnesium bicarbonate type. The concentrations of inorganic constituents in surface water and shallow ground water from unconfined-drift aquifers are very similar. Quality of water in the deeper confined-drift aquifers differs from that in the shallow aquifers because of increased mineralization. The concentration of dissolved solids in the confined-drift aquifers is highest in the northwestern part of the Reservation because of increased concentrations of sodium and sulfate.

The surface-water resources in the Reservation consist of many lakes, prairie potholes, wetlands, and streams. The larger and deeper lakes support populations of game fish, such as northern pike and walleye, and provide recreational opportunities for swimming and boating. The shallower lakes and potholes are important as waterfowl habitat and for production of wild rice. Most of the streams in the Reservation drain basins that are part of the Red River of the North drainage system. The Wild Rice River basin, which includes the Marsh Creek and Sand Hill River subbasins, extends over the northern three-fourths of the Reservation, and the Buffalo and Otter Tail River basins extend across the southern part. The southeastern part of the Reservation is part of the Crow Wing River basin, which is the only basin in the Reservation that is part of the upper Mississippi River drainage system.

Estimated runoff from the Wild Rice, Buffalo, and Otter Tail River basins during the 1985 water year was 8.4, 6.0, and 7.0 inches, respectively; these values exceeded the long-term average runoff values of 2.46, 3.02, and 2.65 inches, respectively. The large volume of runoff in 1985 was caused by an abnormally large amount of precipitation that totaled nearly 6 inches more than the mean for the previous 25 years of record. The high flows during 1985 occurred in May and June in response to summer rainstorms.

Lakes and depressions in the morainal areas and potholes and marshes in the lake plain provide natural storage of surface-water runoff. The surficial outwash retains runoff because water rapidly infiltrates the permeable sand and gravel. The nearly level segment of the lower part of the flow-duration curves of the Wild Rice, Buffalo, and Otter Tail Rivers is characteristic of basins that sustain streamflow from ground-water storage during dry periods. Base flow in these streams is at least 10 ft^3/s during 90 percent of the time.

The lakes in the Reservation generally contain elevated concentrations of dissolved minerals and are hard and alkaline. The trophic state of the lakes is intermediate between mesotrophic and eutrophic. The concentrations of trace metals, except for mercury, are within limits recommended by USEPA to protect against chronic effects on freshwater life. The concentration of total recoverable mercury in samples from the trophogenic zone of nine lakes was as high as 0.3 μg/L, which is above the USEPA recommended 4-day average concentration of 0.012 μg/L for the dissolved organic form of mercury. However, exceedance of this limit appears to be widespread in surface water. At present the amount of mercury in the edible tissue of fish from alkaline lakes of northwestern Minnesota seldom exceeds 0.20 μg/g, which is below the 0.50 μg/g limit recommended by the MPCA for human consumption.

River quality in the Reservation appears to be acceptable for recreation and fish and wildlife habitat. The concentrations of constituents and values of water-quality properties in samples from four of the major streams in the Reservation meet criteria established by the MPCA for surface water placed in a recreation and fishery-use classification. The amount of total organic carbon in the streams ranged from 9.9 to 15.1 mg/L, which is within the range commonly observed in uncontaminated surface water. The concentration of nitrate in samples from the four streams ranged from less than the detection limit of 0.10 to 0.53 mg/L (as N). These concentrations are less than or very near to the median nitrate concentration of 0.42 mg/L for streams throughout the United States.

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