Water Resources of the Grand Portage Indian Reservation, Northeastern Minnesota

By James F. Ruhl

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Grand Portage Indian Reservation Tribal Council

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U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
2280 Woodale Drive
Mounds View, MN 55112

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Conversion Factors, Vertical Datum, and Abbreviations

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter
foot (ft)	.3048	meter
mile (mi)	1.609	kilometer
acre	4.047×10^{-3}	square kilometer
square mile (mi^2)	2.590	square kilometer
foot squared per day (ft^2/d)	.09290	meter squared per day
cubic foot per second (ft^3/s)	.02832	cubic meter per second
gallon (gal)	3.785	liter
gallon per minute (gal/min)	.06309	liter per second
degree Fahrenheit (°F)	5/9 x (°F - 32)	degree Celsius

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.

Chemical concentrations are 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.

Definition of Terms

Alkalinity: Capacity for neutralizing acid and commonly reported as an equivalent amount of calcium carbonate. This property is attributed mostly to dissolved species of carbon dioxide if the pH of the water is less than 9.5. Noncarbonate constituents such as silicate ions are potential sources of alkalinity in water with a pH greater than 9.5 (Hem, 1985, p. 106).

Argillite: A compact, weakly metamorphosed rock derived from mudstone or shale.

Base flow: Streamflow sustained by ground-water discharge.

Confined aquifer: An aquifer bound above and below by confining units. Synonymous with a buried aquifer where hydraulic head rises above the top of the aquifer in a tightly cased well.

Discharge: The volume of water that passes a given point along a stream channel as streamflow in the channel within a given period of time.

Dissolved: The amount of a given constituent carried in solution that passes through a 0.45-micrometer membrane filter.

Dissolved solids: Total amount of mineral constituents dissolved in the water and is expressed in mg/L.

Evapotranspiration: Water discharge to the atmosphere by evaporation from water and land surfaces and by plant transpiration of soil moisture.

Extrusive: Term applied to igneous rock that has erupted onto the land surface. Includes basalt formed by overland lava flows.

Glacial drift: All material (clay, sand, gravel, pebbles, and boulders) transported and deposited by glacial ice or meltwater.

Graywacke: Generally dark colored, hard, coarse-grained sandstone that consists of poorly sorted angular to subangular grains of quartz and feldspar in a clayey matrix.

Ground water: Subsurface water that is in the saturated zone.

Hardness: The soap-consuming capacity of water that is generally attributable to calcium and magnesium. This property is commonly reported as an equivalent concentration of calcium carbonate. Water that ranges in hardness from 0 to 60 mg/L (as calcium carbonate) is soft, from 61 to 120 mg/L is moderately hard, from 121 to 180 mg/L is hard, and greater than 180 mg/L is very hard (Hem, 1985, p. 159).

Hydraulic conductivity: The capacity of a water-bearing formation to transmit water under pressure (expressed in feet per day in this report).

Hydraulic diffusivity: The ratio of the transmissivity to the storage coefficient; a measure of the rapidity that effects of hydrologic stresses are propagated throughout a ground-water system. Used in descriptions of ground-water systems in a gross areal or regional setting (expressed in feet squared per day in this report).

Intrusive: Rock formed within existing rock by emplacement of magma or injection of sedimentary rock. This includes gabbro and diabase.

pH: A measure of the hydrogen ion activity of water that is expressed in terms of the concentration of hydrogen ions in solution. A pH of 7.0 indicates a neutral solution, pH values lower than 7.0 indicate acidity, and pH values greater than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH, although excessively alkaline water also can be corrosive. The pH generally indicates the status of equilibrium reactions that include water as a participant. The pH of natural water generally ranges from 6.0 to 8.5 (Hem, 1985, p. 64).

Regolith: Entire layer of loose, fragmented, and unconsolidated materials that overlies solid and coherent bedrock. It includes weathered rock, volcanic ash, glacial drift, alluvium, peat, and mineral soil.

Runoff in inches: The depth to which the drainage area would be covered if all the runoff for a given time period were uniformly distributed on it.

Slate: A compact, fine-grained metamorphic rock typically formed from shale or volcanic ash.

Specific capacity: The well yield per unit of water-level drawdown (expressed in gallons per minute per foot in this report).

Specific conductance: The capacity of water to conduct an electric current. This property generally is proportionate to the dissolved solids content in most dilute natural water.

Storage coefficient: The volume of water released from or taken into storage in a unit surface area of an aquifer when the head is changed a unit distance (dimensionless).

Streamflow: The discharge that occurs in a natural channel.

Total constituent: The entire amount of a given constituent in a representative water sample. This term is used only when the analytical procedure assures measurement of at least 95 percent of the constituent.

Total recoverable: Refers to the amount of a given constituent in a water sample after digestion by a method (usually using a dilute acid solution) that results in dissolution of readily soluble substances. Complete dissolution of all particulate matter often is not achieved by the digestion method, thus determination of the concentration represents less than the total amount (that is, less than 95 percent) of the constituent in the dissolved and suspended phases of the sample.

Transmissivity: The rate that water is transmitted through a unit width of a water-bearing formation under a unit hydraulic gradient. It is equal to the hydraulic conductivity multiplied by the thickness of the water-bearing formation. (Expressed in feet squared per day in this report).

Unconfined aquifer: An aquifer that consists of a water-bearing formation that is not completely filled with water. Under this condition the top surface of the saturated zone usually is the water table.

Well drawdown: The vertical distance that the static (nonpumping) water level in the well is lowered by pumping.

WATER RESOURCES OF THE GRAND PORTAGE INDIAN RESERVATION, NORTHEASTERN MINNESOTA

By James F. Ruhl

Abstract

The Grand Portage Indian Reservation Tribal Council needs information about the availability and quality of the ground water in the Reservation to develop, protect, and manage this resource for future use. The U.S. Geological Survey, in cooperation with the Grand Portage Indian Reservation Tribal Council, did a three-year study of the ground water in the Reservation to provide this needed information. This report presents the results of that study.

Presently, ground water from bedrock is the principal source of supply for municipal, commercial, and residential water use. The bedrock aquifers are the (1) North Shore Volcanic Group basalt, (2) Keweenawan Volcanic and intrusive rocks, which are gabbro and diabase, and (3) Rove Formation argillite, slate, and graywacke. Sand and gravel aquifers are a small source of ground water.

The storage coefficient of the bedrock aquifers was estimated to be 1×10^{-4}, which is a small value typical of confined, fractured rock aquifers. The median estimate of transmissivity determined from data for 17 wells completed in bedrock was 20 feet squared per day; the range was from 3 to 500 feet squared per day. Reported yield of 19 wells completed in bedrock had a range of 1 to 100 gallons per minute and a median of 7 gallons per minute. The median yield of 11 wells completed in the North Shore Volcanic Group was 16 gallons per minute; the median yield of 8 wells completed in the Keweenawan Volcanic and intrusive rocks and Rove Formation was 4 gallons per minute.

Geophysical logs and televiewer images of two wells completed in bedrock indicated the boreholes penetrated many fractures. Hydrofracturing of the two wells increased their yield from about 0.05 and 0.25 gallons per minute to about 1.5 and 1.2 gallons per minute, respectively. Although the estimated yield from the two wells was increased by 30 and by nearly 5 times after hydrofracturing, the well yield after hydrofracturing was still small.

Water types determined from analyses of water from nine wells completed in bedrock were sodium-chloride, calcium-chloride, sodium-bicarbonate, and calcium-bicarbonate. Water from three wells had concentrations of dissolved solids (800 to 3,110 milligrams per liter) and dissolved chloride (410 to 1,600 milligrams per liter) that were higher than their respective Secondary Maximum Contaminant Levels of 500 and 250 milligrams per liter established by the U.S. Environmental Protection Agency. Water from two wells had concentrations of dissolved iron (1,600 and 1,300 micrograms per liter) that were higher than the Secondary Maximum Contaminant Level of 300 micrograms per liter. Water from an observation well located about 200 feet downgradient from an abandoned landfill and screened from 79 to 84 feet below land surface in a gravel aquifer had a trace amount of toluene (0.2 micrograms per liter). The presence of toluene suggested possible contamination.

Introduction

The Grand Portage Indian Reservation (hereinafter referred to as the Reservation) is located in extreme northeastern Minnesota along the north shore of Lake Superior (fig. 1). The Reservation has an area of about 56,000 acres and is mostly forest. Total population of the Reservation is about 350 people (Rick Novitsky, Grand Portage Indian Reservation Tribal Council, oral commun., 1994). Most homes, businesses, tourist and historical attractions, are located in the community of Grand Portage, along Highway 61, and along Highway 17 east of Mineral Center.

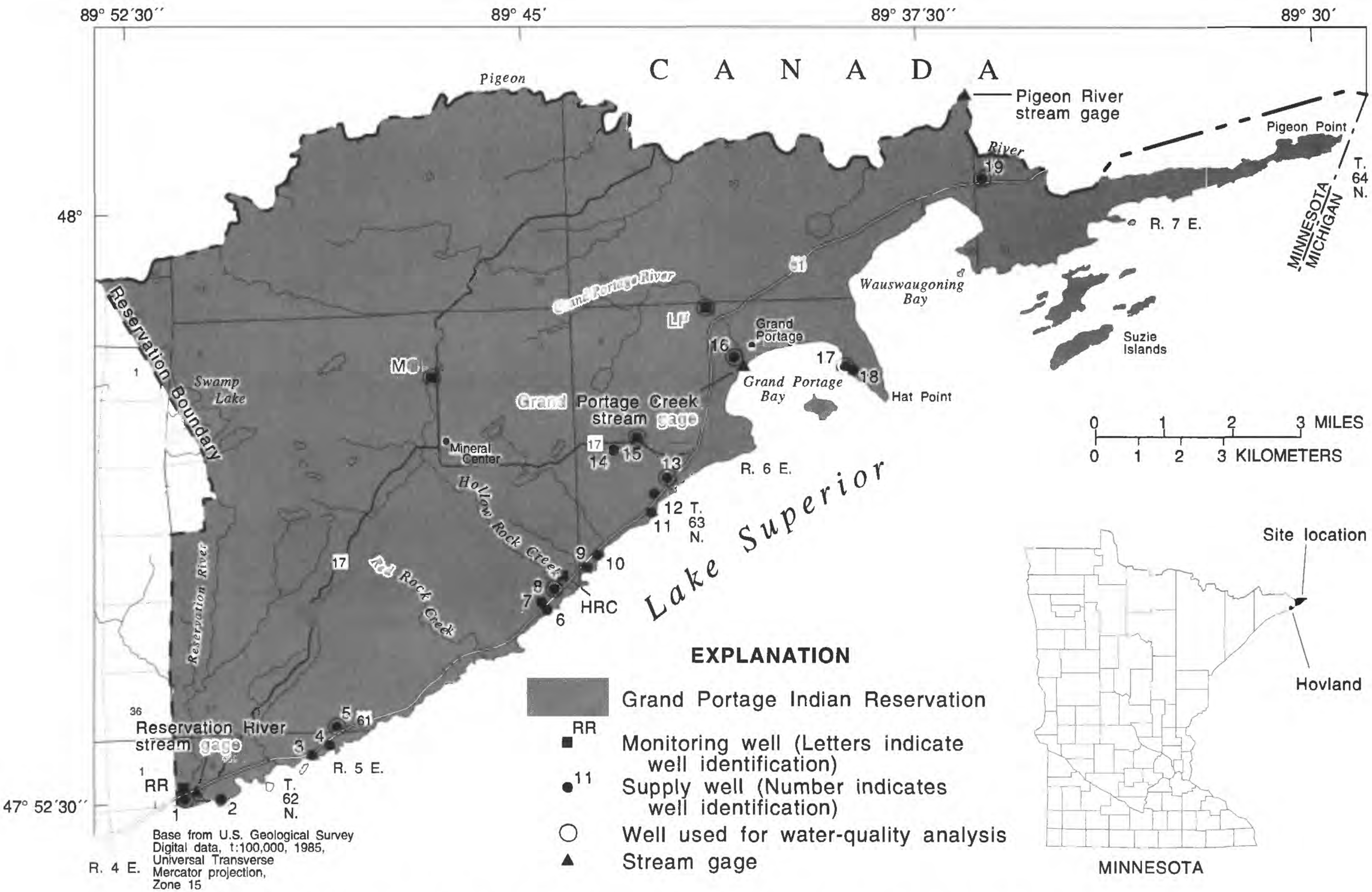


Figure 1. Location of the Grand Portage Indian Reservation in northeastern Minnesota, stream-gage stations, and wells used for collection and analysis of water quality and well-log data.

The Reservation Tribal Council has identified efficient development of ground-water supplies for commercial and residential use as an important natural resource issue. Residents of the Reservation depend on ground water for drinking and general household supply. The Tribal Council needs information about the ground water to effectively manage and protect this resource. The U.S. Geological Survey and the Reservation Tribal Council cooperated in a study to improve the understanding of the ground-water resources and to provide information needed for future water development and planning on the Reservation. Objectives of the study were to (1) describe the general hydrology, (2) identify and delineate the aquifers, (3) evaluate the water-bearing characteristics of the aquifers, and (4) describe the general quality of the ground water.

Purpose and Scope

The purpose of this report is to describe the streamflow characteristics and availability and quality of ground water in the Reservation. The report spans a three-year (1991-93) period of study of the entire Reservation that covers (1) streamflow characteristics, (2) estimates of aquifer transmissivity, (3) reported well yields, (4) effects of hydrofracturing on well yield, and (5) general physical and chemical properties of the ground water.

Methods of Investigation

Information about climate and geology was summarized from the literature. Streamflow data were collected from the Pigeon, Reservation, and Grand Portage Rivers. Peak streamflows of the Reservation and Grand Portage Rivers were estimated from basin characteristics. The hydrology and aquifer properties were described from (1) reconnaissance geologic mapping, (2) records from 23 well logs, (3) streamflow data for the Reservation and Grand Portage Rivers, and (4) geophysical logs, televiewer images, flow measurements, and hydrofracturing of two observation wells completed in bedrock. Quality of the ground water was described from analyses of water from nine wells completed in bedrock and from one well completed in gravel.

Streamflow was described from stage and discharge data collected at temporary stream-gage stations near the mouth of the Reservation River and at the mouth of the Grand Portage River (fig. 1) during the 1992 water year (October 1, 1991 through September 30, 1992). Streamflow also was described from stage and discharge data collected at a long-term stream-gage station located near the mouth of the Pigeon River. The stream discharge measurements were made about once a month by the U.S. Geological Survey and by the Canadian Water Survey (Pigeon River only). An automatic stage recorder operated at 15 minute intervals at the Reservation and Pigeon River stations; an observer read the stage about five times a week at the Grand Portage River station. The stage data were converted to daily-mean stream discharge. Stage readings were discontinued from about the beginning of November to about the middle of April because of freeze-up. Streamflow was estimated from three stream discharge measurements each at the stations on the Pigeon, Reservation, and Grand Portage Rivers and from local weather records during the time stage readings were discontinued. Recurrence interval 2-, 5-, 10-, 25-, 50-, and 100-year peak streamflows for the Reservation and Grand Portage Rivers were estimated from the relation of peak streamflows to basin characteristics.

The availability of ground water was described from estimates of the storage coefficient, of the transmissivity of the aquifers, and from reported well yields. The storage coefficent is a measure of the capacity of an aquifer to take water into or release water from storage. Transmissivity is a measure of the capacity of an aquifer to allow water to flow through it.

The relation of the storage coefficient to the transmissivity of the bedrock aquifers was estimated from the hydraulic diffusivity. The hydraulic diffusivity of bedrock aquifers in the Reservation River Basin was estimated from streamflow recession and basin characteristics. The hydraulic diffusivity also was used to describe the rate that hydrologic stresses are propagated through the bedrock aquifers. The method used to estimate hydraulic diffusivity was developed by Rorabaugh and Simmons (1966, p. 12) and later applied by Trainer and Watkins (1975, p. 31).

The storage coefficient of the aquifers was estimated based on values typical of confined, fractured rock aquifers. Transmissivity was estimated from data for 18 wells (table 1 and fig. 1). The method used to estimate transmissivity was developed and described by Theis and others (1963) and was later applied by Trainer and Watkins (1975) in a study of bedrock terrain similar to that in the Reservation. Well yields were reported in gal/min (gallons per minute) for 19 wells completed in bedrock and for 2 wells completed in sand and gravel.

The depth, structure, weathering, and permeability of bedrock fractures that intersected the boreholes of observation wells RR and HRC were analyzed from geophysical logs, televiewer images, and flow measurements of the two wells (Paillet, 1994). The two observation wells were hydrofractured by pressurizing isolated intervals of the boreholes with water. Geophysical logs, televiewer images, and flow measurements of the two observation wells from before and after hydrofracturing, were compared to determine the effectiveness of hydrofracturing as a method to increase well yield.

The quality of ground water from nine wells completed in bedrock and from one well completed in gravel was compared to U.S. Environmental Protection Agency (USEPA) drinking-water standards (U.S. Environmental Protection Agency, 1986). These standards include (1) Maximum Contaminant Levels (MCLs), which are maximum permissible concentrations of contaminants in water delivered to a public water supply system; and (2) Secondary Maximum Contaminant Levels (SMCLs), which are nonenforceable standards established for contaminants that may adversely affect the odor or appearance of water.

Collection methods and treatment of ground-water samples are described by Fishman and Friedman (1989). Prior to collection of samples, wells were pumped for about 20 minutes while temperature, pH, and specific conductivity were measured. Samples were collected when these properties stabilized. Samples were analyzed at the U.S. Geological Survey Central Laboratory in Denver, Colorado.

Well-Numbering and Location System

The system used to number and locate wells in this report is based on the Federal system of land subdivision (township (T), range (R), and section (Sec.)) (fig. 2). The first number of a well designation indicates the township (the N after the township number is an abbreviation for north); the second, the range (the letter E after the range number is an abbreviation for east); and the third, the section. Uppercase letters after the section number indicate location within the section; the first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. Letters A, B, C, and D are assigned in a counterclockwise direction, beginning in the northeast corner of each tract. The number of uppercase letters indicates accuracy of the location number. For instance, if a point can be located within a 10-acre tract, three uppercase letters are shown in the location number. The well number 62N05E06CCC, shown in figure 2, indicates the well is located in SW 1/4 SW 1/4 SW 1/4, Sec. 06, T.62 N., R.05 E.

Geologic Setting

Proterozoic bedrock underlies glacial drift. The Rove Formation of the Animikie Group consists of argillite, slate, and graywacke from the early Proterozoic Era. The Rove Formation is present in the northern half of the Reservation (fig. 3). During the middle Proterozoic Era, the Puckwunge Formation of the Keweenawan Supergroup (Green, 1982) was formed as a sedimentary clastic sandstone interbedded within igneous, crystalline bedrock. The Puckwunge Formation crops out along a narrow east-west strip through the center of the Reservation. The igneous Proterozoic bedrock includes (1) the North Shore Volcanic Group of the Keweenawan Supergroup; (2) the Logan intrusion of the Keweenawan Supergroup, and (3) Keweenawan volcanic and intrusive rocks, also of the Keweenawan Supergroup (Green, 1982) and hereinafter referred to as Keweenawan intrusives. The North Shore Volcanic Group is extrusive basalt that is present throughout the southwestern one-half of the Reservation. The Logan intrusion is a diabase sill that subcrops in a small area of the northwestern part of the Reservation. The Keweenawan intrusives are gabbro and diabase that are present throughout the Reservation.

Bedrock structure controlled the formation of the major slopes, ridges, and valleys. Glaciation, weathering, stream erosion, and wave action of Lake Superior, have resulted in the formation and deposition of unconsolidated materials on top of the bedrock. The unconsolidated materials consist mainly of glacial drift

Table 1.--Summary of hydrogeologic characteristics and well data in the Grand Portage Indian Reservation, Minnesota

[NSV, North Shore Volcanic Group; KI, Keweenawan intrusives, RAG, Rove Formation; UNC, unconsolidated sand and gravel; --, undetermined because data are unavailable; ft, feet; min, minute; gal/min, gallons per minute; gal/min/ft, gallons per minute per foot; ft^2/d, feet squared per day]

Well index letters or number[1]	Aquifer unit	Depth of well (ft)	Depth below land surface to bottom of casing (ft)	Depth below land surface to bedrock (ft)	Depth below land surface to water (ft)	Depth into bedrock penetrated by well (ft)	Borehole interval open to aquifer below static water level (ft)	Pump test period (min)	Reported well yield (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)	Estimated transmissivity (ft^2/d)
1	KI	230	46	40	5	190	184	120	3	195	$1.5x10^{-2}$	3
2	UNC	39	35	--	4	0	4	120	2	28	$7.1x10^{-2}$	10
3	KI	225	26	1	0	225	199	120	2	97	$2.1x10^{-2}$	4
4	KI	168	25	8	30	160	138	120	4	120	$3.3x10^{-2}$	6
5	KI	404	25	5	46	399	358	60	4	49	$8.2x10^{-2}$	20
6	NSV	302	25	0	14	302	277	60	16	52	$3.1x10^{-1}$	70
7	NSV	179	25	0	18	179	154	60	17	8	$2.1x10^{0}$	500
8	NSV	104	35	5	8	99	69	60	16	8	$2.0x10^{0}$	500
9	NSV	147	35	26	[2]+2	121	112	120	14	52	$2.7x10^{-1}$	60
10	NSV	225	40	27	6	198	185	120	2	204	$1.0x10^{-2}$	20
11	NSV	85	26	4	10	81	59	120	22	0	--	--
12	NSV	225	44	10	[2]+2	215	181	180	13	82	$1.6x10^{-1}$	40
13	NSV	350	35	34	0	316	315	10	16	100	$1.6x10^{-1}$	30
14	NSV	302	25	0	12	302	277	60	5	56	$8.9x10^{-2}$	20
15	NSV	285	20	6	--	279	265	--	--	--	--	--
[3]16	RAG	155	150	92	--	63	5	1,800	50	100	$5.0x10^{-1}$	100
17	RAG	115	105	104	28	11	10	120	7	47	$1.5x10^{-1}$	30
18	RAG	310	46	46	45	264	264	60	5	255	$2.0x10^{-2}$	3
19	RAG	--	--	--	--	--	--	--	--	--	--	--
RR[4]	KI	345	50	49	24	296	295	100	[5]1	20	$5.0x10^{-2}$	9
MC[4]	NSV	275	28	23	22	253	247	--	100	--	--	--
HRC[4]	NSV	265	85	85	13	180	180	75	[5]1	33	$3.0x10^{-2}$	5
LF[4]	UNC	84	79	--	[2]+4	0	5	--	10	--	--	--

[1] Location of wells shown by index number or letters on figure 1.
[2] Plus sign indicates water level is above land surface.
[3] Community well number 1.
[4] Indicates monitoring well.
[5] Yield estimated for 50 feet of drawdown after hydrofracturing.

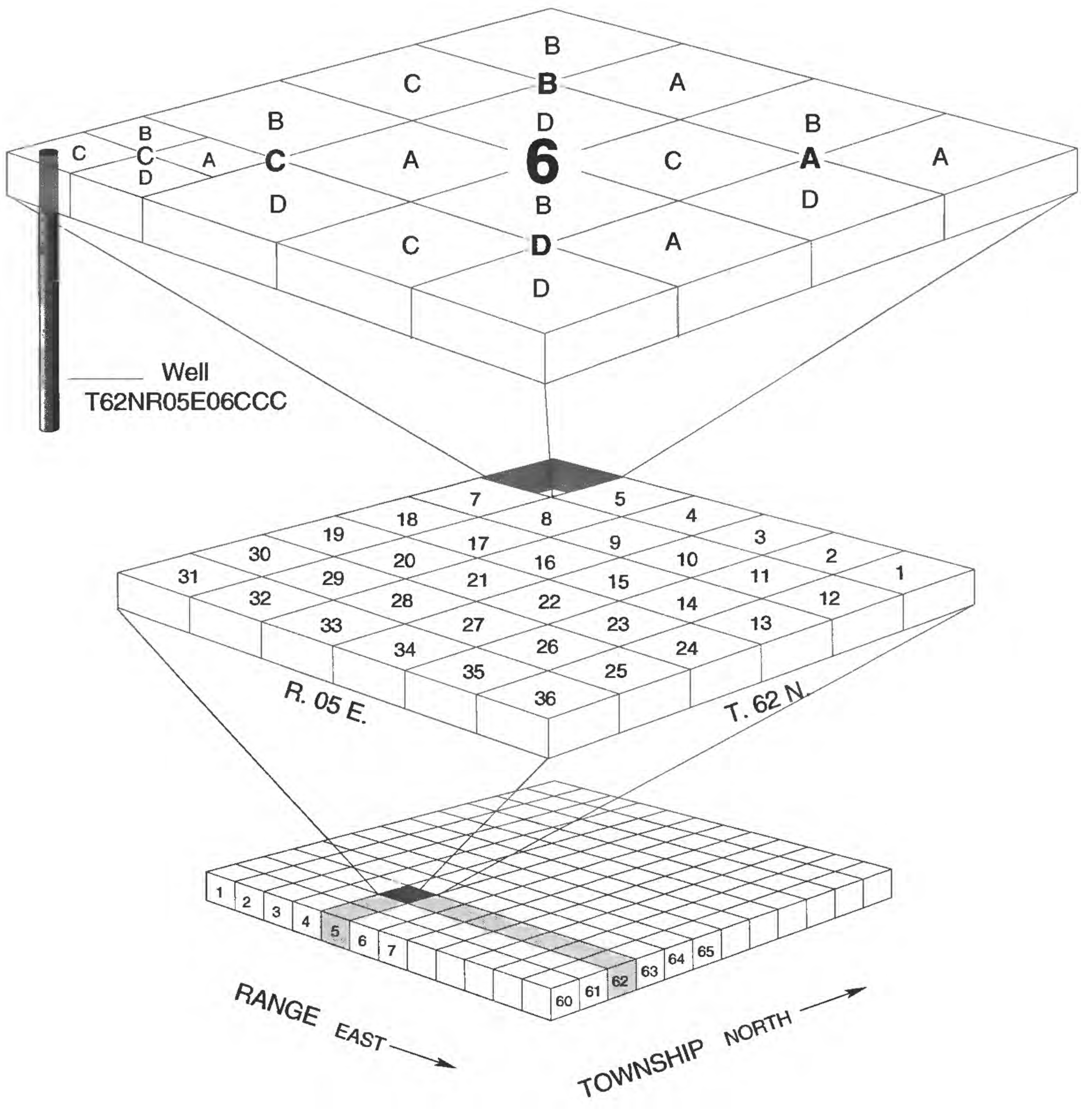


Figure 2. Well-numbering and location system.

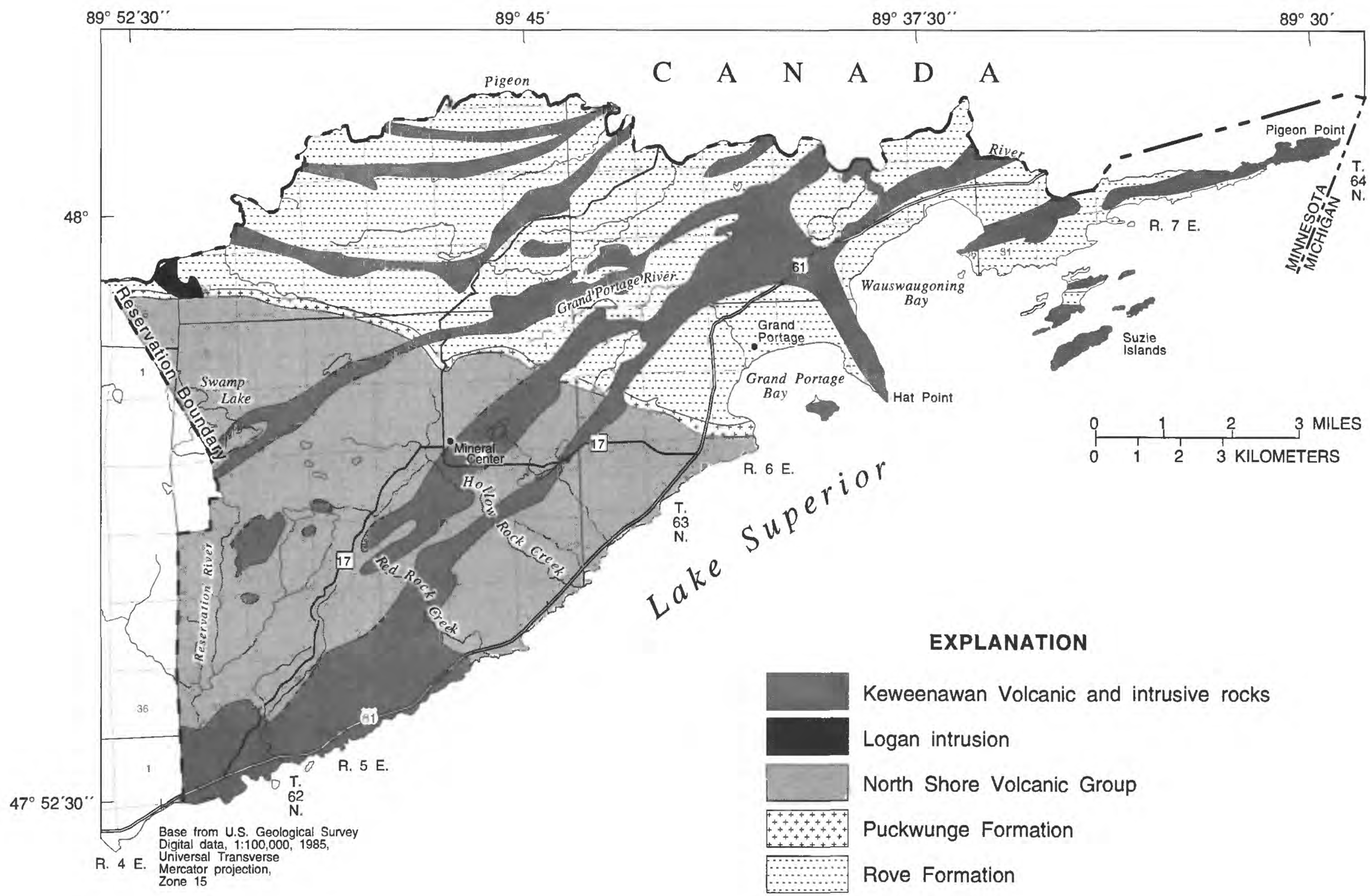


Figure 3. Bedrock geology of the Grand Portage Indian Reservation, Minnesota. (Geology modified from Green, 1982)

but include post-glacial alluvium, beach deposits, and peat. The thickness of the unconsolidated materials generally is less than 50 ft, but can be as much as 100 ft.

Four major glaciers advanced across the area during the Pleistocene Epoch, which ended about 10,000 years ago. During the Pleistocene Epoch ground moraines of till and moderately to well sorted sand and gravel were deposited in all but about one fourth of the Reservation in the north-central part (Hobbs and Goebel, 1982).

During the retreat of the last glacier into the present Lake Superior Basin, lakes around the margins of the basin coalesced to form Glacial Lake Duluth. The elevation of Glacial Lake Duluth stabilized at about 500 ft above the present level of Lake Superior. Melting of continental ice sheets to the northeast lowered Glacial Lake Duluth to the present level of Lake Superior.

Beach deposits formed in upland areas in T.63 N, R.05 E, section 26, and in T.63 N, R.06 E, section 8, as the level of Glacial Lake Duluth declined (Green and others, 1977, p. 21-22). Sediments that settled out of Glacial Lake Duluth formed broad, gently sloping lake plains of silt and clay and smaller amounts of sand, gravel, and boulders. The lake plains are present in about one-fourth of the Reservation in the north-central part (Hobbs and Goebel, 1982).

Bedrock that remained following glaciation formed ridges that are between 1,600 and 1,700 ft above sea level, and islands along the shore of Lake Superior, such as the Susie Islands east of Grand Portage (fig. 1). Beaches formed along the shore of Lake Superior where bedrock protects against excessive wave erosion. These beaches are common between the Reservation River and Hat Point (Green and others, 1977, p. 21-22). Water filled numerous depressions that became lakes and ponds in upland moraines and in lake plains. Plant material accumulated in the lakes and ponds and decomposed into peat, and converted the former lakes and ponds into bogs and swamps.

Hydrologic Setting

The climate is continental; average monthly temperature ranges from about 8°F during January to about 62°F during July (Baker and others, 1985). Average annual precipitation is about 29 in. based on a period of record from 1941 to 1970 (Baker and Kuehnast, 1978). About two thirds of precipitation is rain that falls from April through November. The other one-third is snowfall that falls from December through March.

During normal years slightly less than one-half of the precipitation in basins in the Reservation becomes runoff; the remainder of the precipitation returns to the atmosphere by evapotranspiration. A generalized annual water budget of the north shore region of Lake Superior is (Olcott and others, 1978):

$$P = RO + \Delta S + U + ET \qquad (1)$$

where P = precipitation in inches (28 in.),

RO = runoff in inches (13 in.);

ΔS = change in storage in inches (0 in.);

U = underflow in inches (0 in.);

and ET = evapotranspiration in inches (15 in.).

Change in storage is assumed to be negligible. Ground water discharges to Lake Superior as underflow. The amount of underflow probably is a small portion of the total hydrologic budget of basins in the north shore region of Lake Superior (Olcott and others, 1978).

Streamflow Characteristics

About 42 mi of perennial and 29 mi of intermittent streams flow through or bound the Reservation. These streams and tributaries drain into Lake Superior and generally flow along steeply graded channels incised into bedrock. The Pigeon and Reservation Rivers flow along the northern and western boundaries, respectively. The Pigeon River Basin has a total drainage area of about 600 mi^2 (more than half of this area is in Canada) and encompasses the northern one-third of the Reservation. Minor drainage basins range from about 2 to about 17 mi^2 (fig. 4).

Annual runoff from the Grand Portage, Reservation, and Pigeon River Basins during the 1992 water year was 15.50, 17.00, and 12.50 in., respectively. Runoff from the Pigeon River Basin during the 1992 water year was slightly higher than the mean annual runoff of 11.41 in. determined for the Pigeon River Basin for water years 1921-1992 (Gunard and others, 1992, p. 37). Runoff from the Pigeon River Basin during the 1992 water year

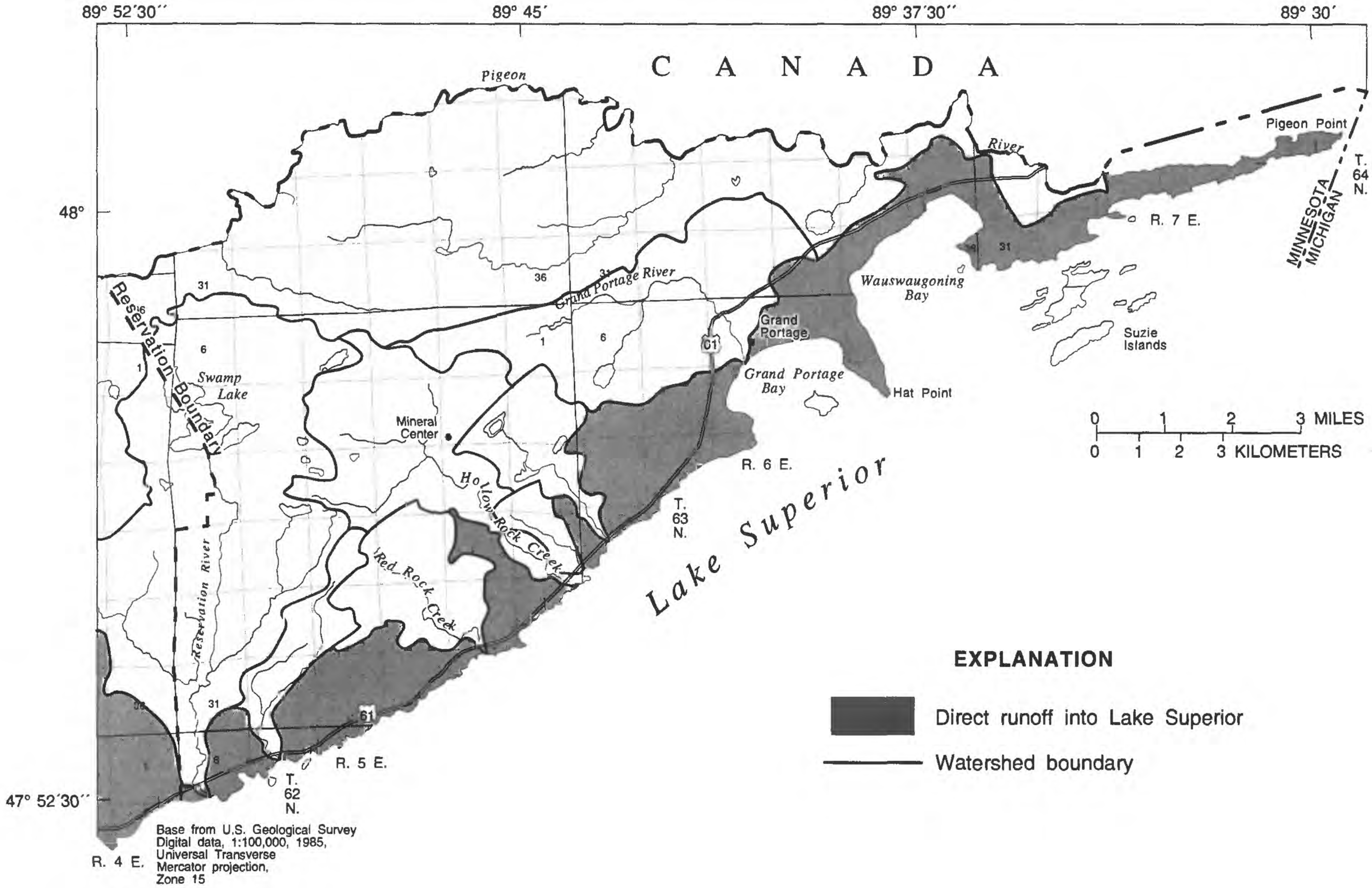


Figure 4. Watersheds in the Grand Portage Indian Reservation, Minnesota.

may have been slightly higher than normal because precipitation at Grand Portage during the 1992 water year was 30.0 in. (National Oceanic and Atmospheric Administration, 1991 and 1992), which was slightly higher than the long-term (1941-1970) mean annual precipitation of 29 in. determined for the Reservation (Baker and Kuehnast, 1978).

Seasonal climatic changes controlled the variation in streamflow in the Pigeon, Reservation, and Grand Portage Rivers during the 1992 water year (fig. 5). Peak streamflows occurred in late April and in early May from snowmelt and spring rain. Precipitation at Grand Portage from April 20 to April 22 was 2.40 in. and on May 12 was 1.68 in. (National Oceanic and Atmospheric Administration, 1992). Evapotranspiration reduced the amount of precipitation available for runoff in July and August, which normally are the warmest months of the year (Baker and others, 1985). Streamflows decreased to base-flow conditions by late summer except for streamflow peaks in early July and in early August following rainstorms. Precipitation at Grand Portage from June 28 to July 3 was 2.31 inches and from August 7 to August 8 was 3.04 in. (National Oceanic and Atmospheric Administration, 1992). Streamflows increased in September because of reduced evapotranspiration and increased precipitation. Precipitation at Grand Portage from September 2 to September 3 was 2.37 in., from September 8 to September 10 was 1.00 in., and from September 16 to September 18 was 0.85 in. (National Oceanic and Atmospheric Administration, 1992). Streamflows decreased in late September to base-flow conditions, which normally last from late fall until spring in basins of the north shore region of Lake Superior (Olcott and others, 1978).

Multiple-linear regression techniques were used to define relations of peak streamflows to basin characteristics for the Grand Portage and Reservation Rivers. The following equations (Jacques and Lorenz, 1988) were used to estimate peak streamflows for recurrence intervals of 2, 5, 10, 25, 50, and 100 years:

$$Q_2 = 20.3A^{0.856}(St + 1)^{-0.327}S^{0.288} \quad (2)$$

$$Q_5 = 24.1A^{0.851}(St + 1)^{-0.339}S^{0.383} \quad (3)$$

$$Q_{10} = 24.3A^{0.852}(St + 1)^{-0.338}S^{0.451} \quad (4)$$

$$Q_{25} = 23.0A^{0.855}(St + 1)^{-0.333}S^{0.536} \quad (5)$$

$$Q_{50} = 21.4A^{0.858}(St + 1)^{-0.326}S^{0.599} \quad (6)$$

$$Q_{100} = 19.7A^{0.862}(St + 1)^{-0.318}S^{0.660} \quad (7)$$

where Q_T is the T-year peak streamflow estimate, in cubic feet per second (ft^3/s), for the point of interest (here, the point of interest is the stream-gage site);

A is area, in mi^2, of the drainage basin above the point of interest (A is 7.34 and 17.25 mi^2 for the Grand Portage and Reservation River Basins, respectively);

St is storage area, which consists of all lakes, ponds, and wetlands in the drainage basin above the point of interest, expressed as a percentage of the basin area (St is 0.48 and 2.49 for the Grand Portage and Reservation River Basins, respectively); and

S is mean slope, in ft/mi, of the stream channel upstream from the point of interest to the basin divide computed between points 10 and 85 percent of the main channel length (S is 65 and 112 ft/mi for the Grand Portage and Reservation River Basins, respectively).

Peak streamflows were plotted in terms of their exceedance probability, which is the probability expressed as a percent that the streamflow will be exceeded in any given year. Thus peak streamflow determined for a 2-year recurrence interval has an exceedance probability of 50 percent, and peak streamflow for a 100-year recurrence interval has an exceedance probability of 1 percent. Estimated peak streamflows for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals range from 327 to 1,520 ft^3/s for the Grand Portage River at Grand Portage, Minnesota, and from 601 to 3,470 ft^3/s for the Reservation River near Hovland, Minnesota (fig. 6).

Ground-Water Availability

Presently, ground water is the only source of supply for residential, municipal, and commercial use on the Reservation. The principal sources of ground water are Proterozoic bedrock aquifers. The bedrock aquifers are

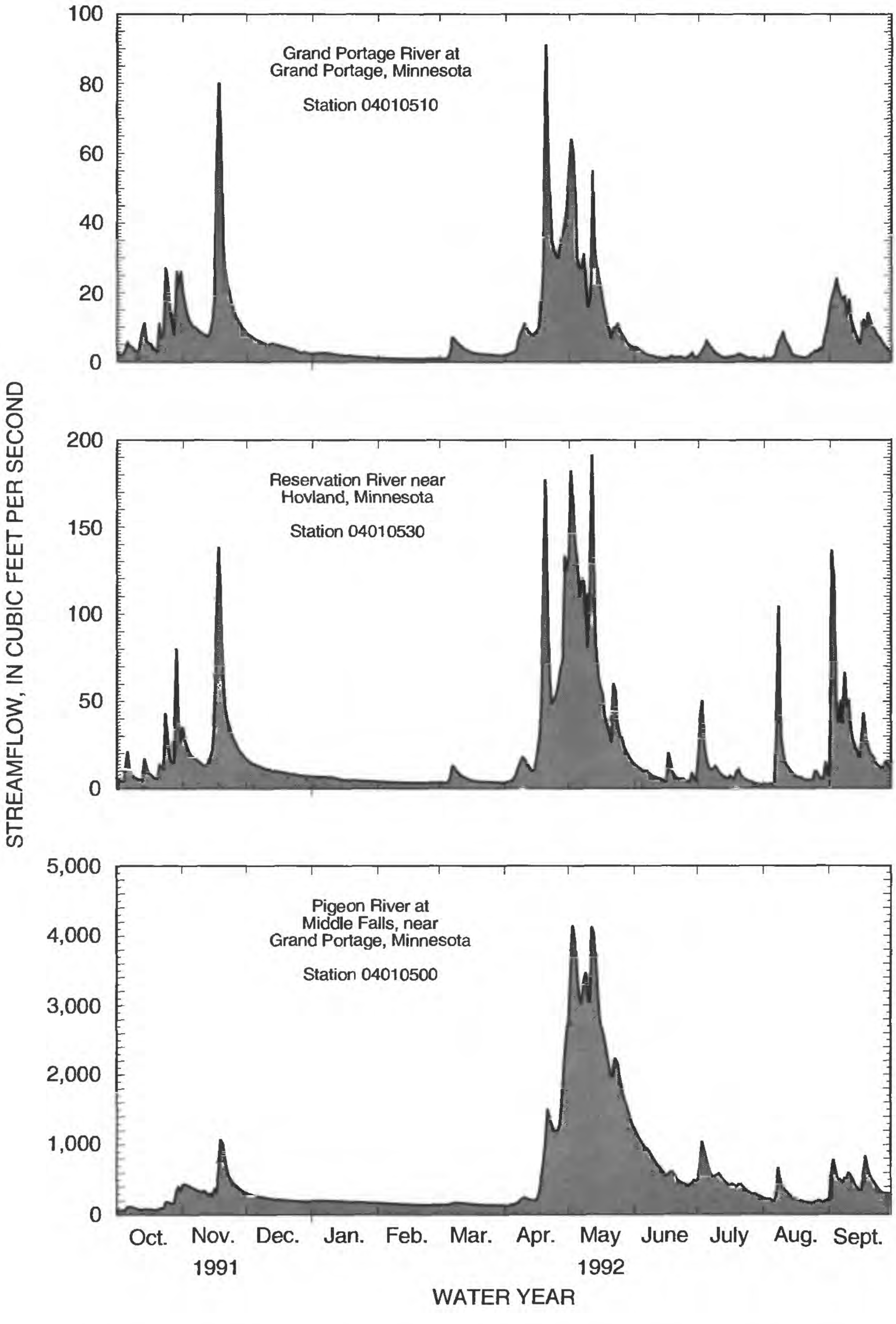
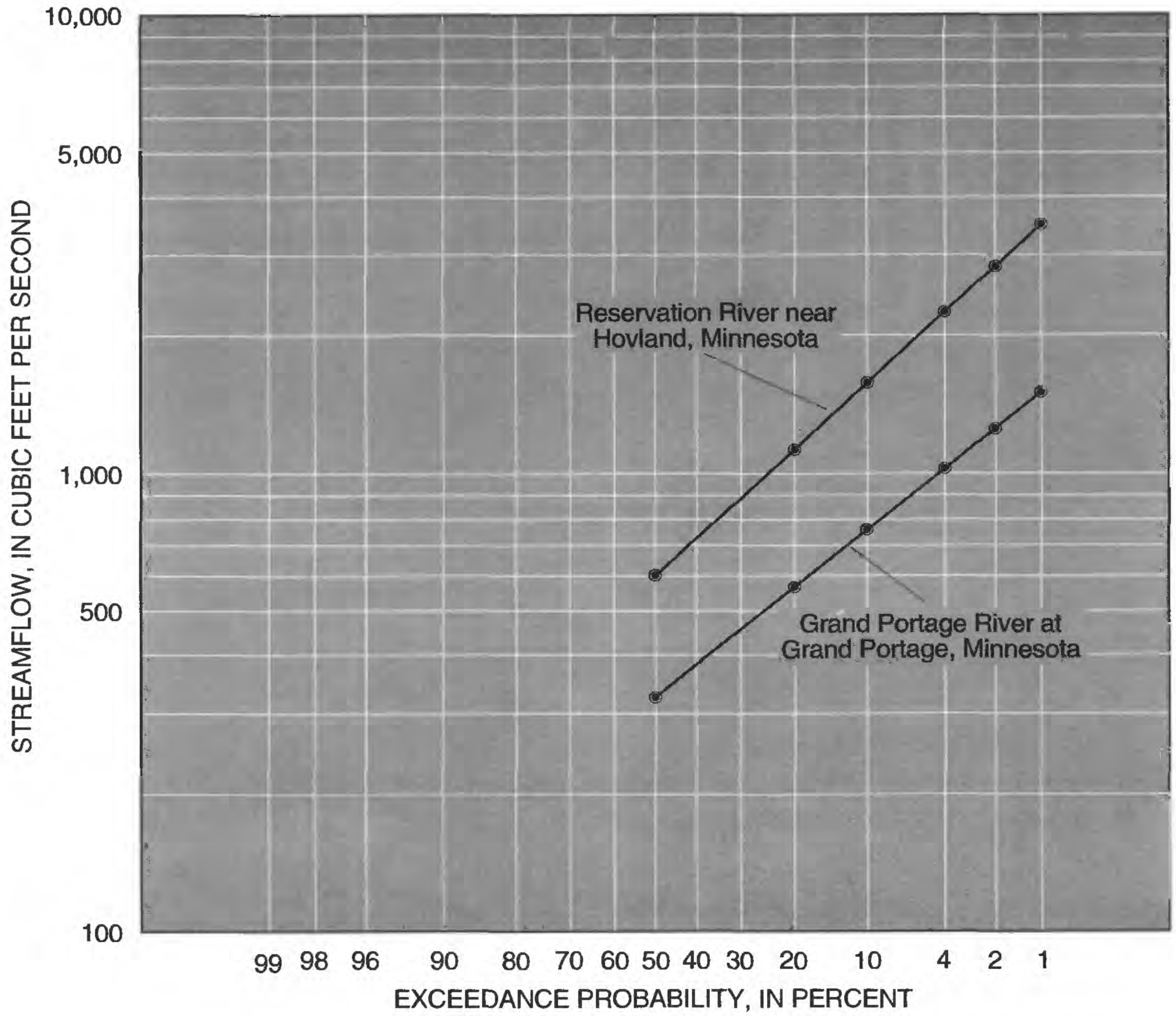


Figure 5. Streamflow of the Pigeon, Reservation, and Grand Portage Rivers for the 1992 water year, Grand Portage Indian Reservation, Minnesota .



		Reservation River near Hovland, Minnesota	Grand Portage River at Grand Portage, Minnesota
Exceedance probability, in percent	Recurrence interval, in years	Estimated peak streamflow, in cubic feet per second	Estimated peak streamflow, in cubic feet per second
50	2	601	327
20	5	1,080	569
10	10	1,510	764
4	25	2,170	1,040
2	50	2,770	1,270
1	100	3,470	1,520

Figure 6. Peak streamflow frequency plots of the Reservation and Grand Portage Rivers, Grand Portage Indian Reservation, Minnesota.

the (1) North Shore Volcanic Group basalt, (2) Keweenawan Volcanic and intrusive rocks, which are gabbro and diabase, and (3) Rove Formation argillite, slate, and graywacke. Sand and gravel aquifers are a small source of ground water. Of 19 domestic and municipal wells analyzed in this study, 10 were completed in the North Shore Volcanic Group, 4 were completed in the Keweenawan intrusives, 4 were completed in the Rove Formation, and 1 was completed in sand and gravel.

Ground-water flow in the bedrock aquifers is through openings created by fractures; fractures are visible in bedrock exposures along Minnesota Highway 61 (fig. 7). Density, size, and connectivity of fractures determine the bedrock permeability. The fracture permeability of crystalline bedrock generally decreases with depth below land surface (Freeze and Cherry, 1979, p. 159). Topographic conditions may indicate locations of fractures. Fracture permeability generally is greater in valleys and in ravines than along crests of ridges and hill tops (Freeze and Cherry, 1979, p. 160).

Storage Coefficient

The storage coefficient of the bedrock aquifers was estimated to be 1×10^{-4}, which is a small value within the range of 1×10^{-5} to 1×10^{-3} that is typical of aquifers under confined conditions. The bedrock aquifers appeared to be confined because the static water level in 11 bedrock wells was higher than the top of the bedrock (table 1). This estimate of the storage coefficient is within an order of magnitude of the average storage coefficient of 5×10^{-3} estimated by Trainer and Watkins (1975, p. 39) in a study of bedrock terrain similar to that in the Reservation.

An estimate of the hydraulic diffusivity, T/S, of the bedrock aquifers that discharge ground water to the Reservation River indicated that the storage coefficient of these aquifers is very small relative to the transmissivity. The hydraulic diffusivity of these bedrock aquifers was estimated from the following equation (Rorabaugh and Simmons, 1966, p. 12):

$$T/S = (a^2)(0.933)/(\Delta t) \qquad (8)$$

where T = transmissivity, in ft^2/d, of the bedrock aquifers;

S = storage coefficient, (dimensionless), of the bedrock aquifers;

a = mean lateral distance, in feet, from the stream to the basin divide; and

Δt = time, in days, required for stream discharge to decline during streamflow recession through one log cycle.

Equation 8 is valid when the logarithm of streamflow decreases exponentially with time to define a straight-line recession that theoretically occurs after a critical time has elapsed following recharge. The critical time is approximately equal to about one-fifth the time of Δt (Trainer and Watkins, 1975). The application of equation 8 assumed that the effects of direct overland runoff and evapotranspiration on the slope of the streamflow recession used to estimate Δt were small.

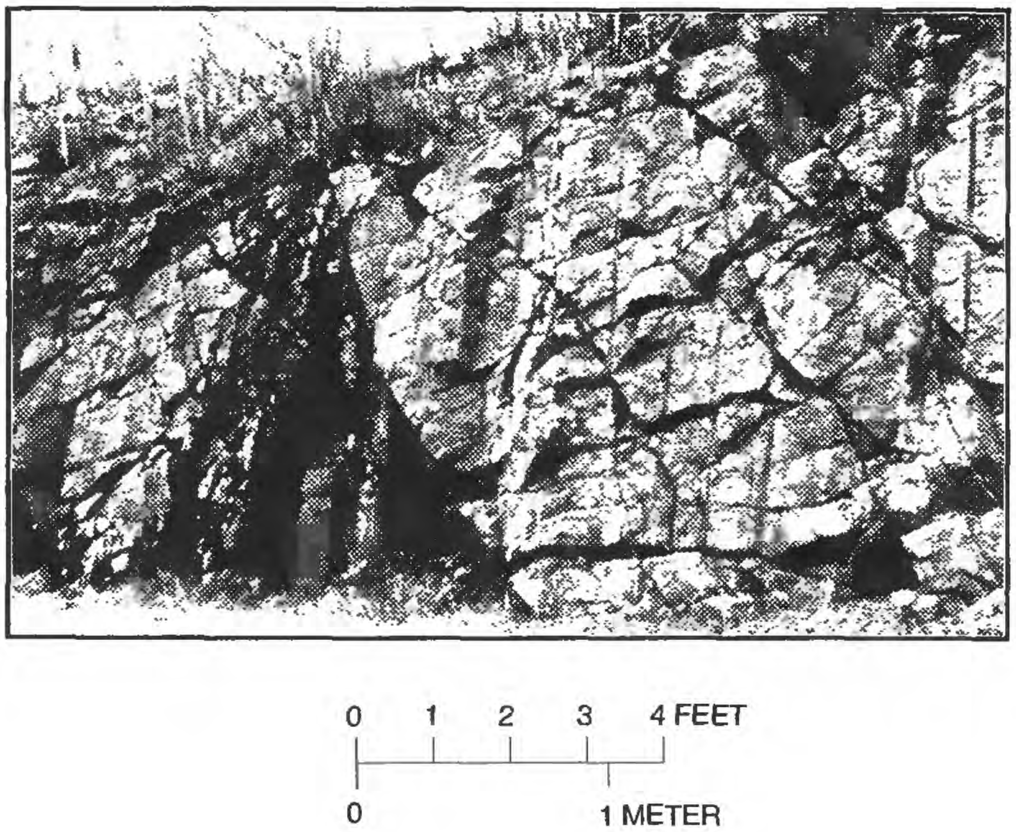
The calculation of hydraulic diffusivity for the Reservation River Basin by equation 8 follows:

$$T/S = 0.933\,(4.7 \times 10^3 ft)^2/23\ d = 9.0 \times 10^5\ ft^2/d.$$

The estimate of Δt was determined to be 23 days from the straight-line extension of the streamflow recession episode shown on figure 8. A value of 4.7×10^3 ft for the mean lateral distance from the stream to the basin divide (a) was calculated from the relation A = 2aL, where A (17.25 mi^2) is area of the basin and L (9.7 mi) is total length of the stream channel. The estimate of hydraulic diffusivity applies to the bedrock aquifers that discharged ground water to the Reservation River. The principal bedrock aquifer in the Reservation River Basin is the North Shore Volcanic Group, but Keweenawan intrusives also are present (fig. 3). In addition to the small storage coefficient relative to the transmissivity, the high estimated hydraulic diffusivity of 9.0×10^5 ft^2/d indicates that effects from hydrologic stresses, such as ground-water withdrawals or recharge from rain storms, are propagated rapidly in these aquifers.

Transmissivity

Transmissivity was estimated from data for 17 wells completed in bedrock and for one well completed in sand and gravel using the method of Theis and others (1963). The equations used in the method of Theis and others (1963) were solved by a computer program



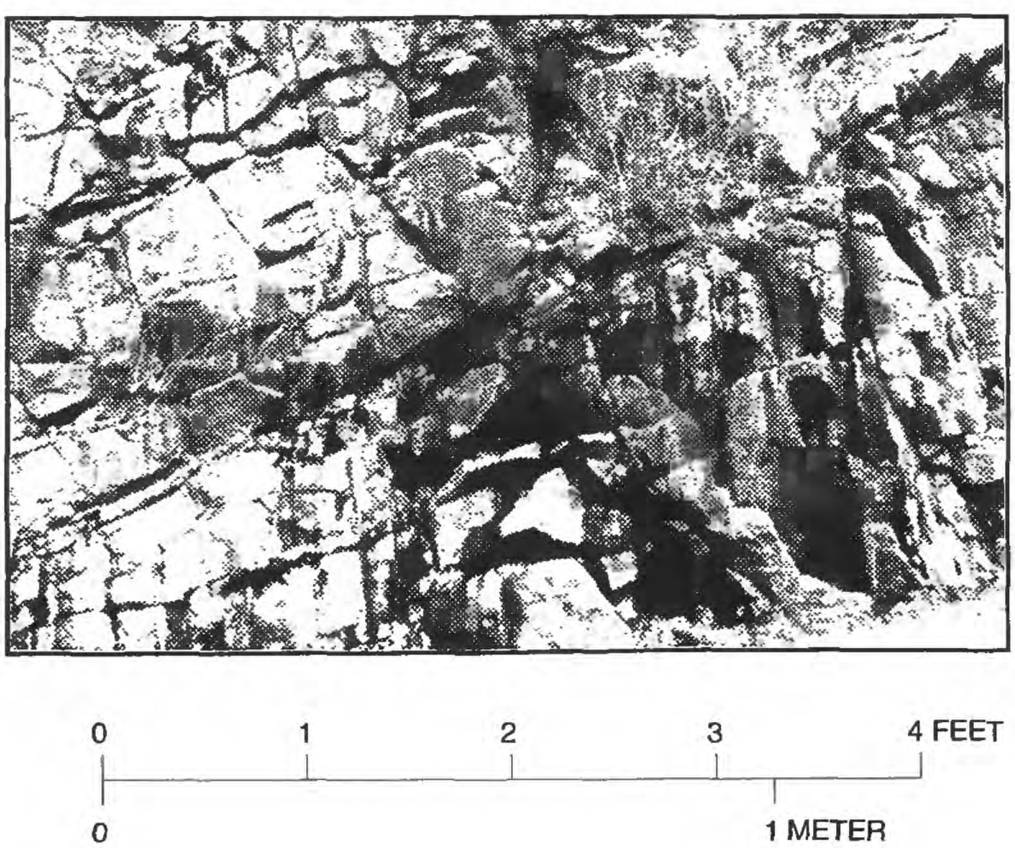


Figure 7. Fractured Keweenawan intrusive gabbro exposed at two sites along Minnesota Highway 61 about one-half mile northeast of the RR monitoring well in the Grand Portage Indian Reservation, Minnesota.

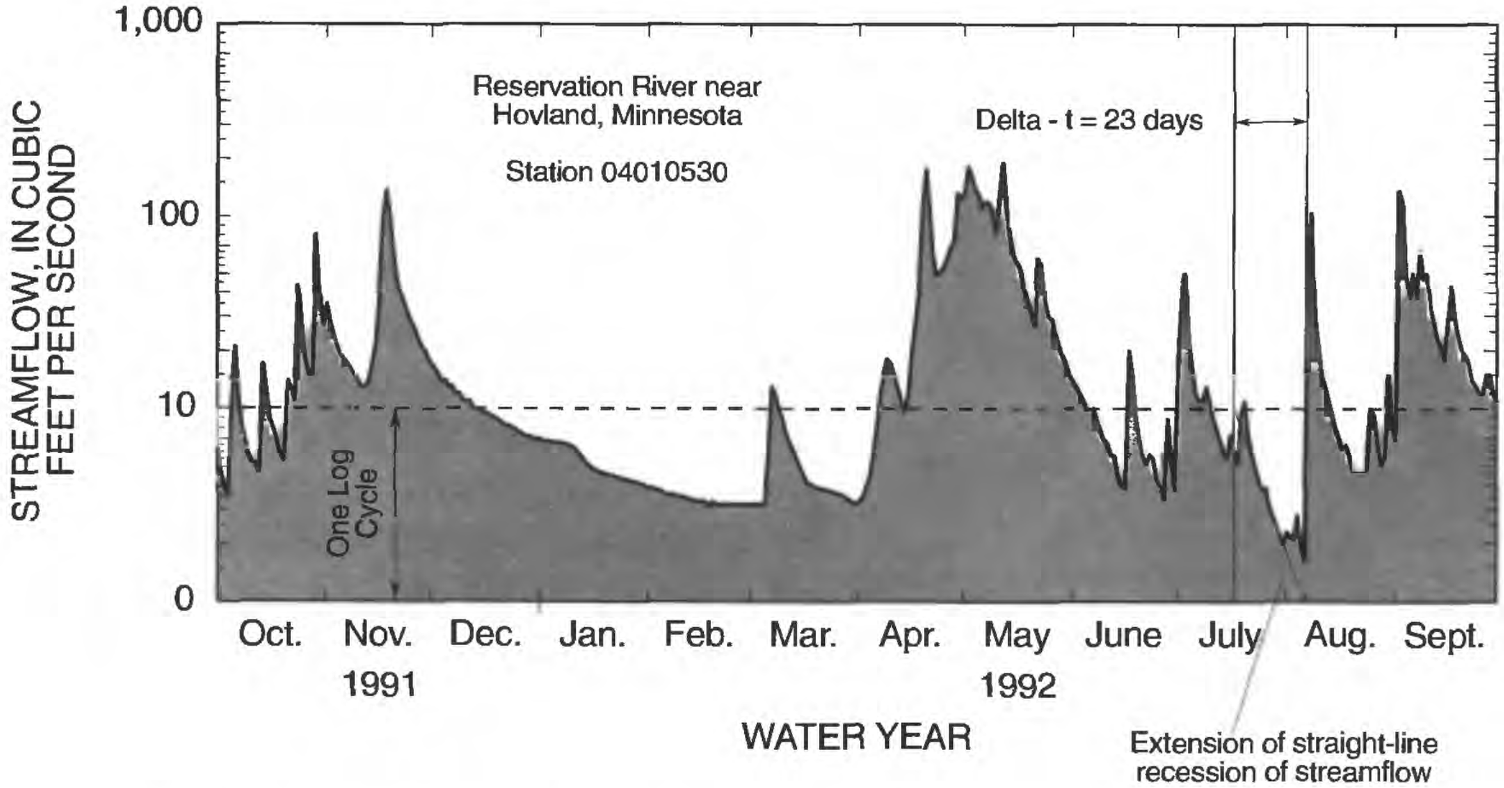


Figure 8. Streamflow for the Reservation River near Hovland, Minnesota for the 1992 water year, Grand Portage Indian Reservation, Minnesota.

developed for hand-held programmable calculators (Czarnecki and Craig, 1985). Input data required for this program (Czarnecki and Craig, 1985) are (1) diameter and specific capacity of the well, (2) length of time of pumping that was done to determine the specific capacity, (3) an initial storage coefficient for an ideal unconfined or ideal confined aquifer, and (4) an estimate of the storage coefficient of the aquifer that yields water to the well. The method of Theis and others (1963) requires simplifying assumptions: (1) the aquifer is homogeneous and isotropic; (2) the well is 100 percent efficient; and (3) the well is open to the full saturated thickness of the aquifer. The estimates of transmissivity are given in table 1.

The casing in all of the wells listed in table 1 penetrates the surficial, unconsolidated materials and as much as 35 ft of bedrock (except for wells 2 and LF); the remainder of the well boreholes are open to the bedrock aquifers. The estimated transmissivities of the bedrock aquifers apply to the part of the aquifers in contact with the open borehole below the static water level.

The specific capacity, time of pumping, and well diameter used to estimate transmissivity were determined from drillers' logs and Paillet (1994). The specific capacities were computed from the drawdown measured during pumping from one to two hours at rates that ranged from 1 to 50 gal/min. Eight wells were pumped at variable stepped down rates; all the other wells were pumped at constant rates. The diameter of all the wells is 6 in.

An initial storage coefficient of 2×10^{-4} was specified for wells completed in the bedrock aquifers because these aquifers appeared to be confined. An initial storage coefficient of 2×10^{-1} was specified for the well completed in the sand and gravel aquifer because this aquifer was unconfined. The estimate of the bedrock aquifer storage coefficient was 1×10^{-4}. The estimate of the sand and gravel aquifer storage coefficient was 2×10^{-1}, which is typical of unconfined aquifers (Heath, 1987, p. 28).

Transmissivity estimated from data for 17 wells completed in the bedrock aquifers ranged from 3 to 500 ft^2/d and had a median value of 20 ft^2/d (table 1). Well 11 was pumped at 22 gal/min for two hours without measurable drawdown, therefore the specific capacity and transmissivity could not be determined. Well 11 was completed in the North Shore Volcanic Group and penetrated at least one very productive fracture system. The transmissivity of 10 ft^2/d estimated for well 2 is the

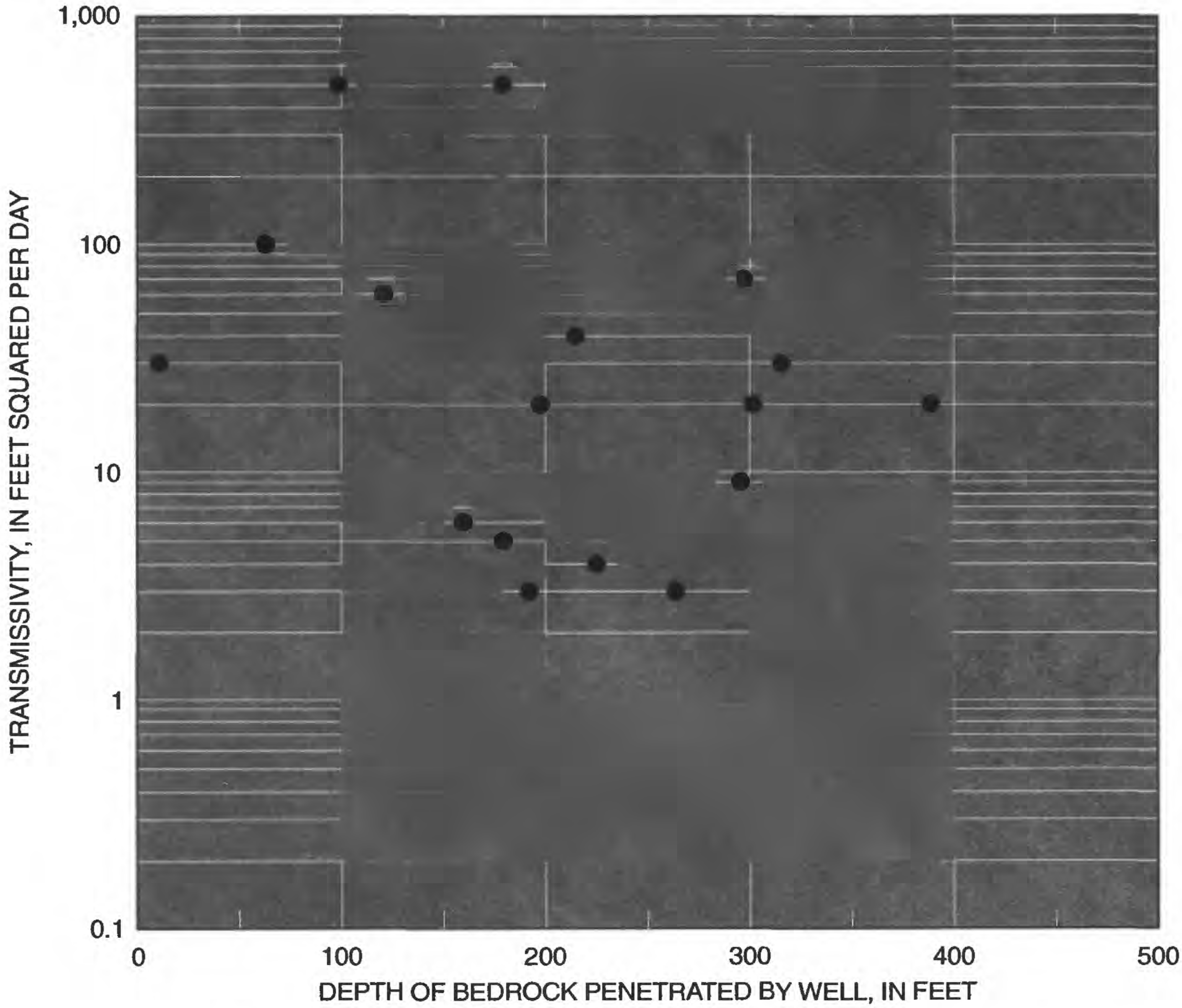


Figure 9. Relation of transmissivity to depth of bedrock penetrated by well borehole, Grand Portage Indian Reservation, Minnesota.

only estimate available for wells completed in sand and gravel.

The transmissivity estimates determined for wells completed in bedrock do not show a clear trend of variation with depth of bedrock penetrated by the well borehole (fig. 9). Results of this study indicate that the transmissivity of the bedrock aquifers cannot be predicted from the depth of bedrock penetration by wells.

Well Yield

Yield reported for 19 wells completed in the bedrock ranged from 1 to 100 gal/min (table 1). The median reported well yield was 7 gal/min. The yield generally was higher in wells completed in the North Shore Volcanic Group (basalt), where the median yield reported for 11 wells was 16 gal/min, than in the Keweenawan intrusives (gabbro and diabase) and in the Rove Formation (argillite, slate, and graywacke), where the median yield reported for 8 wells was 4 gal/min (fig. 10). Reported yield of two wells completed in the sand and gravel aquifers was 2 and 10 gal/min.

Along the north shore of Lake Superior, basaltic bedrock generally contains more closely-spaced fractures than does the intrusive diabasic and gabbroic bedrock (Green and others, 1977, p. 58). This different

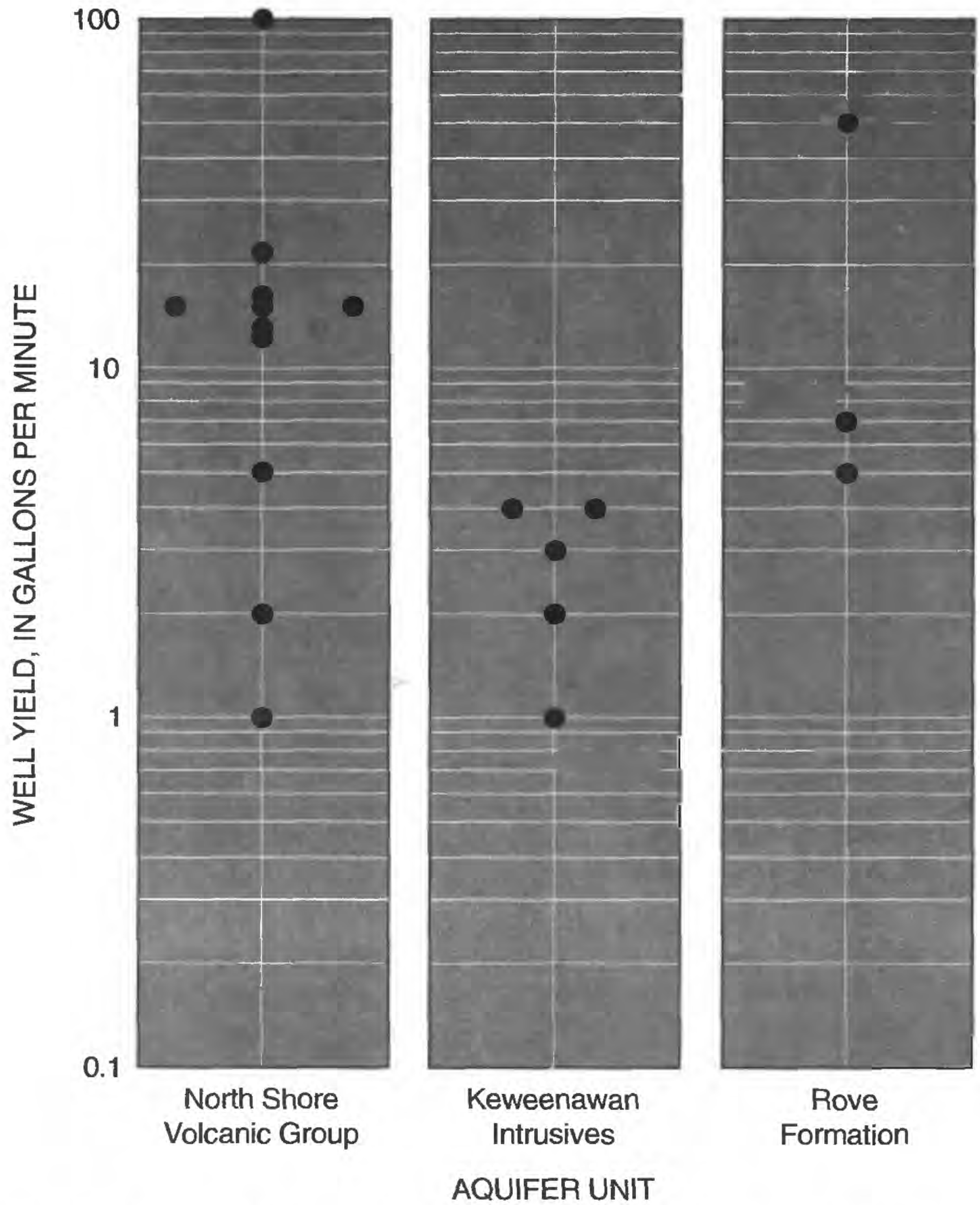


Figure 10. Well yield grouped by bedrock aquifer, Grand Portage Indian Reservation, Minnesota.

structural characteristic may make the North Shore Volcanic Group basalt more permeable than the Keweenawan intrusive gabbro and diabase.

Effect of Hydrofracturing on Well Yield

The depth interval, structure, and alteration from weathering of fractures that intersect the boreholes of observation wells RR and HRC were described before and after hydrofracturing from photograph-like images of the well boreholes produced by televiewing, and from geophysical logs of the well boreholes (Paillet, 1994). The geophysical logs included (1) caliper (borehole diameter), (2) single point resistivity (electrical resistivity of the formation and ground water), and (3) long and short normal resistivity (electrical resistivity of the formation and ground water). The permeability of fractures that intersect the boreholes of observation wells RR and HRC was described before and after hydrofracturing from flowmeter measurements that determined vertical profiles of flow during pumping (table 2).

Well RR was completed in Keweenawan intrusive gabbro and diabase, and well HRC was completed in North Shore Volcanic Group basalt. The boreholes of these wells were assumed to penetrate typical samples

Table 2.--Summary of inflow zones in monitoring wells Reservation River (RR) and Hollow Rock Creek (HRC) in the Grand Portage Indian Reservation, Minnesota (from Paillet, 1994)
[<, less than; --, percentage could not be computed because total inflow was too small to measure]

Depth interval, below top of casing (feet)	Before hydrofracturing		After hydrofracturing	
	Normalized inflow[1]	Percentage of total	Normalized inflow	Percentage of total
		Reservation River borehole		
75-80	[2]<0.02	--	0.20	34
85-90	<.02	--	.12	21
130-140	<.02	--	.05	9
138-188	<.02	--	.12	21
190-200	<.02	--	.02	3
210-215	<.02	--	.02	3
235-238	<.02	--	.05	9
		Hollow Rock Creek borehole		
[3]85-90	.10	100	.10	20
108-120	<.02	0	.06	12
130-135	<.02	0	.03	6
167-180	<.02	0	.14	29
235-240	<.02	0	.03	6
250-255	<.02	0	.03	6
Below 260	<.02	0	.10	20

[1] Inflows, in gallons per minute, normalized to a drawdown of 20 feet.

[2] No inflow detected during experiment (limit of detection was about 0.01 gallons per minute).

[3] This interval was not treated because of possible borehole instability.

of fracture frequency in the crystalline bedrock of the Reservation.

Wells RR and HRC were hydrofractured by injection of water pressurized from about 1,000 to nearly 3,000 pounds per square inch into isolated intervals of the well boreholes. The purpose of the hydrofracturing was to increase the permeability of fractures in the bedrock immediately surrounding the boreholes, thus increasing the yield from the wells.

Caliper logs and televiewer images of wells RR and HRC indicated that the boreholes of these wells penetrated many fractures (Paillet, 1994). Resistivity logs and televiewer images indicated more extensive weathering of the rocks penetrated by borehole HRC than by borehole RR.

Televiewer images show increased roughness along the boreholes after hydrofracturing (fig. 11). This effect probably was caused by spalling of rock from intervals where multiple fractures intersected the borehole wall. The spalling produced from hydrofracturing had little effect on permeability of the fractures. No new fractures in either borehole were produced by hydrofracturing (Paillet, 1994).

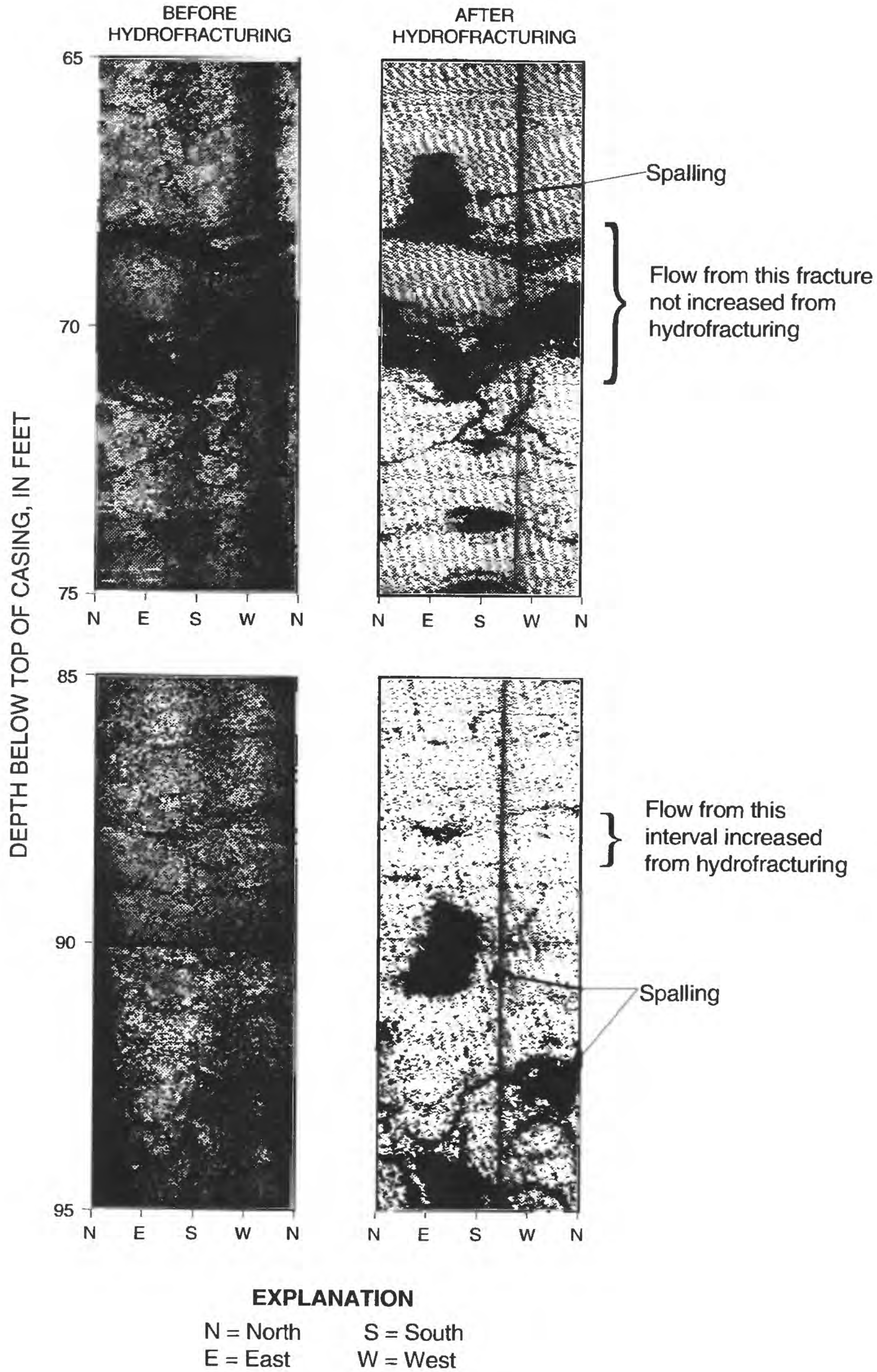


Figure 11. Televiewer images obtained before and after hydrofracturing well RR borehole, Grand Portage Indian Reservation, Minnesota (From Paillet, 1994).

Flowmeter measurements were made to determine sources of inflow to wells RR and HRC. The wells were pumped at about 1 gal/min to about 20 to 35 ft of drawdown before and after hydrofracturing (table 2). The source of inflow to well RR prior to hydrofracturing could not be determined. After hydrofracturing about three-fourths of the inflow to well RR was from 75 to 90 ft and from 138 to 188 ft below the top of the casing. The source of inflow to well HRC prior to hydrofracturing was from 85 to 90 ft below the top of the casing. After hydrofracturing about four-fifths of the inflow to well HRC was from 85 to 120 ft, from 167 to 180 ft, and from more than 260 ft, below the top of the casing (Paillet, 1994).

The yield from wells RR and HRC estimated for 50 ft of drawdown was 0.05 and 0.25 gal/min, respectively, before hydrofracturing, and was 1.5 and 1.2 gal/min, respectively, after hydrofracturing (Paillet, 1994). The yield estimated for wells RR and HRC was 30 (RR) and nearly 5 (HRC) times higher after hydrofracturing than before hydrofracturing. The well yield after hydrofracturing, however, was still small.

Ground-Water Quality

Alkalinity, pH, hardness, specific conductance, and concentrations of dissolved solids, major ions, and trace metals, were determined in water from seven domestic wells (1, 5, 8, 13, 15, 17, and 19), from one community well (16), and from one observation well (MC), that were completed in bedrock. The same properties and chemical constituents, and dissolved organic carbon, nitrate, and volatile organic compounds, were analyzed in water from well LF, which was completed in a gravel aquifer near an abandoned landfill.

Physical and Chemical Properties and Major Ions in Water from Nine Wells Completed in Bedrock

The laboratory pH had a median of 8.2 and a range of 7.4 to 10.0 (table 3). The laboratory pH in water from wells 5, 15, 17, and 19 was greater than the SMCL of 8.5 (U.S. Environmental Protection Agency, 1986). Total hardness ranged from soft, 0 to 60 mg/L $CaCO_3$, in water from wells 15, 17, 19, and MC, to very hard, as much as 180 mg/L $CaCO_3$, in water from wells 1, 13, and 16. The laboratory alkalinity had a median of 53 mg/L and a range of 9 to 210 mg/L as $CaCO_3$.

The dissolved solids concentration in water from wells 1, 5, and 13 ranged from 800 to 3,110 mg/L and exceeded the SMCL of 500 mg/L (U.S. Environmental Protection Agency, 1986). The dissolved solids concentration in water from wells 1 and 13 was saline (greater than 1,000 mg/L). The dissolved solids/specific conductance ratio ranged from 0.54 to 0.62 and averaged 0.58. Therefore, the dissolved solids concentration in water from wells completed in bedrock can be estimated from the specific conductance by multiplying the specific conductance by 0.58.

Water types determined from percentages of total milliequivalents of major ions were (1) sodium-chloride, (2) calcium-chloride, (3) sodium-bicarbonate, and (4) calcium-bicarbonate (fig. 12). Calcium, sodium, bicarbonate, and chloride ranged from 2 to 490 mg/L, from 1.6 to 460 mg/L, from 21 to 256 mg/L, and from 1.1 to 1,600 mg/L, respectively. The chloride concentrations 1,600, 410, and 1,400 mg/L, in water from wells 1, 5, and 13, respectively, exceeded the SMCL of 250 mg/L (U.S. Environmental Protection Agency, 1986).

Trace Metals in Water from Nine Wells Completed in Bedrock

The concentrations of dissolved arsenic, barium, chromium, copper, silver, zinc, and selenium were less than their respective SMCLs and MCLs (U.S. Environmental Protection Agency, 1986). The dissolved cadmium concentration of 10 µg/L in water from wells 1 and 13 exceeded the MCL of 5 µg/L (U.S. Environmental Protection Agency, 1986). The dissolved cadmium concentration in water from seven wells was less than the U.S. Geological Survey Central Laboratory's 10 µg/L detection limit. The dissolved lead concentration in water from the nine wells was less than the 100 µg/L detection limit. The dissolved iron concentration in water from wells 16 and MC was 1,300 and 1,600 µg/L, respectively, which exceeded the SMCL of 300 µg/L (U.S. Environmental Protection Agency, 1986). The dissolved manganese concentration in water from well 16 was 59 µg/L, which exceeded the SMCL of 50 µg/L (U.S. Environmental Protection Agency, 1986).

Quality of Water from Observation Well LF

Monitoring well LF is located about 200 ft from an abandoned landfill near the Grand Portage River (fig. 13). The screened interval of the well is from 79 to 84 ft below land surface and is open to a gravel aquifer. Depth below

Table 3.--Water-quality data from wells in the Grand Portage Indian Reservation, Minnesota, 1992

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

Date	USGS identification number	Local number	Well index letters or number	Depth of well, total (ft)	Pump or flow period prior to sampling (min)	Specific conductance at 25°C (µS/cm)		pH (standard units)		Temperature, water (°C)
						field	lab	field	lab	
09/15/92	475229089520701	T62NR5E06CCC	1	230	20	5,250	5,210	--	7.5	7.0
09/16/92	475325089491001	T63NR5E33CCD	5	404	20	--	1,480	8.8	8.7	8.0
09/15/92	475505089444501	T63NR5E25ABA	8	104	20	825	716	7.4	7.7	9.0
09/14/92	475618089423801	T63NR6E17CAB	13	350	20	4,650	4,540	8.2	8.2	9.0
09/16/92	475650089425501	T63NR6E07DDD	15	285	20	--	183	10.0	10.0	7.0
09/15/92	475755089410501	T63NR6E04CDA	16	155	20	860	709	7.6	7.9	6.5
09/14/92	475710089390001	T63NR6E10AAA	17	115	20	315	317	8.8	8.8	6.5
09/15/92	480002089360501	T64NR7E30BCB	19	--	20	--	458	8.6	8.6	11.0
09/16/92	475719089465201	T63NR5E03CCC	MC	275	20	--	94	--	7.4	6.5
09/16/92	475827089413501	T63NR6E04BBC	LF	84	20	--	--	7.9	8.1	6.5

Well index letters or number	Hardness, total, (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate[1], dissolved (mg/L as HCO_3)	Alkalinity, total (mg/L as $CaCO_3$)		Sulfate, dissolved (mg/L as SO_4)
							field	lab	
1	1,200	490	1.6	460	2	21	17	9	43
5	130	52	.3	240	2	59	48	49	61
8	100	35	3.4	95	.6	63	52	53	34
13	1,100	440	.6	400	.7	23	19	14	19
15	6	2	.3	36	.2	--	78	78	5.4
16	300	66	33	38	4	256	210	210	91
17	27	8	1.8	57	2	122	100	100	22
19	55	14	4.8	66	4	104	85	87	41
MC	44	12	3.3	1.6	.3	54	44	44	5.1
LF	220	56	19	91	5	81	66	67	17

Table 3.--Water-quality data from wells in the Grand Portage Indian Reservation, Minnesota, 1992--Continued

Well index letters or number	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Dissolved solids, residue at 180 °C, (mg/L)	Nitrogen, dissolved (mg/L as N)		Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)
				nitrite	nitrite plus nitrate						
1	1,600	0.9	3,110	--	--	<1	<100	10	2	10	100
5	410	1.7	800	--	--	1	54	<10	<1	<10	<3
8	170	.5	394	--	--	<1	18	<10	<1	<10	37
13	1,400	.6	2,760	--	--	<1	500	10	<1	10	30
15	3.6	.6	107	--	--	<1	7	<10	<1	<10	30
16	73	.8	450	--	--	3	33	<10	<1	<10	1,300
17	23	3.4	179	--	--	<1	25	<10	<1	<10	19
19	64	1.8	255	--	--	<1	64	<10	<1	<10	36
MC	1.1	<.1	58	--	--	<1	7	<10	<1	<10	1,600
LF	240	1.0	531	<0.01	<0.05	3	110	<10	<1	<10	170

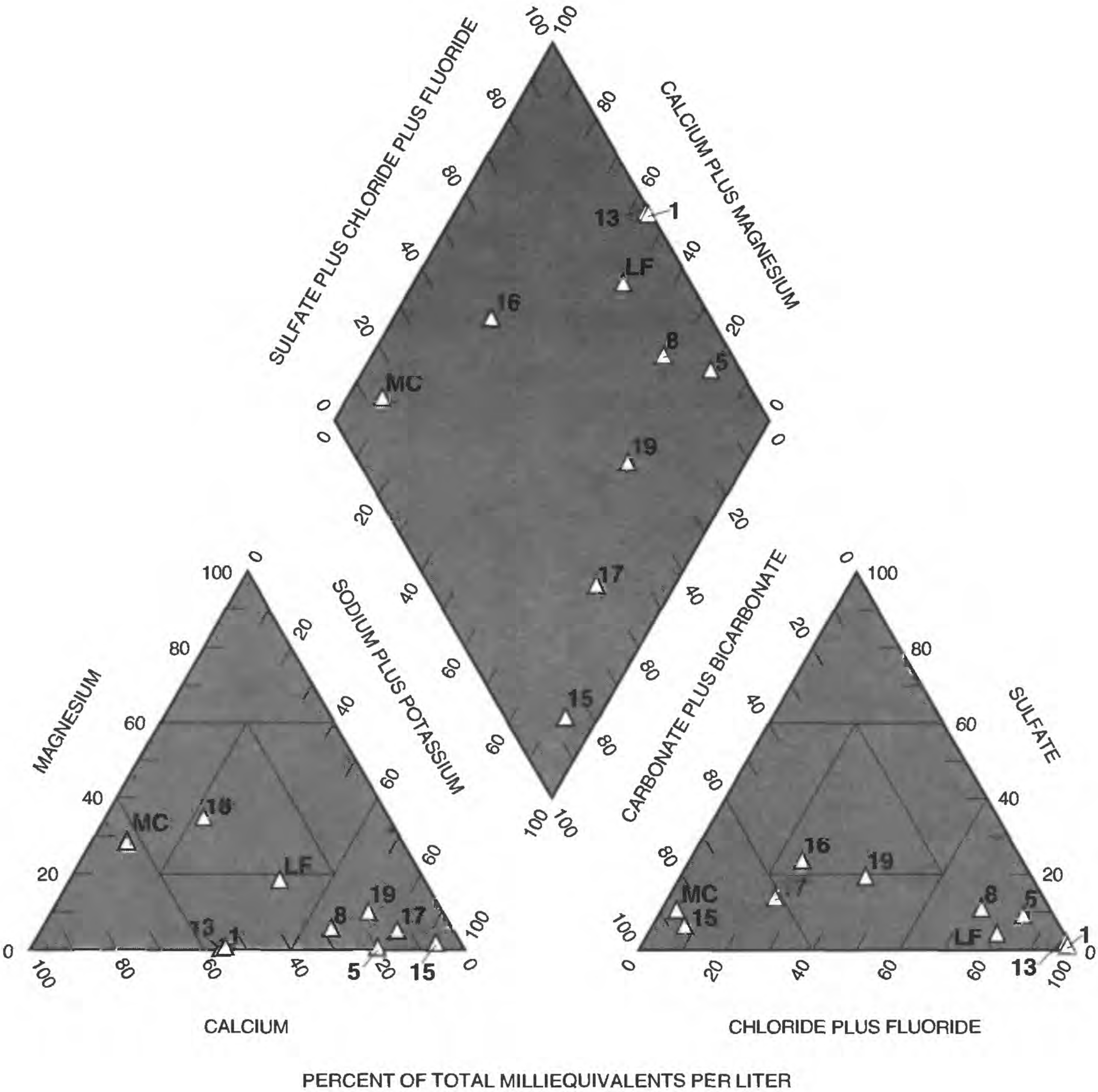
Well index letters or number	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Carbon, organic, dissolved (mg/L as C)	Dichloro-bromo-methane, total (µg/L)	Carbontetra-chloride, total (µg/L)	1,2-Dichloro-ethane, total (µg/L)	Bromoform, total (µg/L)
1	<100	20	<0.1	<1	<1	260	--	--	--	--	--
5	<100	<1	<.1	<1	<1	14	--	--	--	--	--
8	<100	16	<.1	<1	<1	52	--	--	--	--	--
13	<100	20	<.1	<1	<1	20	--	--	--	--	--
15	<100	<1	<.1	<1	<1	3	--	--	--	--	--
16	<100	59	<.1	<1	<1	23	--	--	--	--	--
17	<100	11	<.1	<1	<1	<3	--	--	--	--	--
19	<100	12	<.1	<1	<1	<3	--	--	--	--	--
MC	<100	19	<.1	<1	<1	13	--	--	--	--	--
LF	<100	31	<.1	<1	<1	<3	.60	<.2	<.2	<.2	<.2

Table 3.--Water-quality data from wells in the Grand Portage Indian Reservation, Minnesota, 1992--Continued

Well index letters or number	Chloro-dibromo-methane, total (µg/L)	Chloroform, total (µg/L)	Toluene, total (µg/L)	Chloro-benzene, total (µg/L)	Benzene, total (µg/L)	Ethyl-benzene, total (µg/L)	Methylene-chloride, total (µg/L)	Tetrachloro-ethylene, total (µg/L)	Trichloro-fluoro-methane, total (µg/L)	1,1-Dichloro-ethane, total (µg/L)	1,1-Dichloro-ethylene, total (µg/L)
1	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--	--	--
19	--	--	--	--	--	--	--	--	--	--	--
MC	--	--	--	--	--	--	--	--	--	--	--
LF	<.2	<.2	.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Well index letters or number	1,1,1-Trichloro-ethane, total (µg/L)	Dichloro-benzene, total (µg/L)	1,2-Transdi-chloro-ethene, total (µg/L)	1,2-Dichloro-propane, total (µg/L)	1,3-Dichloro-benzene, total (µg/L)	1,4-Dichloro-benzene, total (µg/L)	Dichlorode-fluoro-methane, total (µg/L)	Vinyl chloride, total (µg/L)	Trichloro-ethylene, total (µg/L)	Cis-1,2-di-chloro-ethene water, total (µg/L)	Styrene, total (µg/L)	Trichloro-trifluoro-ethane, total (µg/L)	Xylene, total recoverable (µg/L)
1	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--	--	--	--	--
19	--	--	--	--	--	--	--	--	--	--	--	--	--
MC	--	--	--	--	--	--	--	--	--	--	--	--	--
LF	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.5	<.2

[1] Bicarbonate estimated from field alkalinity.



EXPLANATION

△ Individual water samples identified by well index number or letters listed in table 1

Figure 12. Percentage distribution of major ion concentrations determined for water from nine wells completed in bedrock and from one well completed in gravel, Grand Portage Indian Reservation, Minnesota.

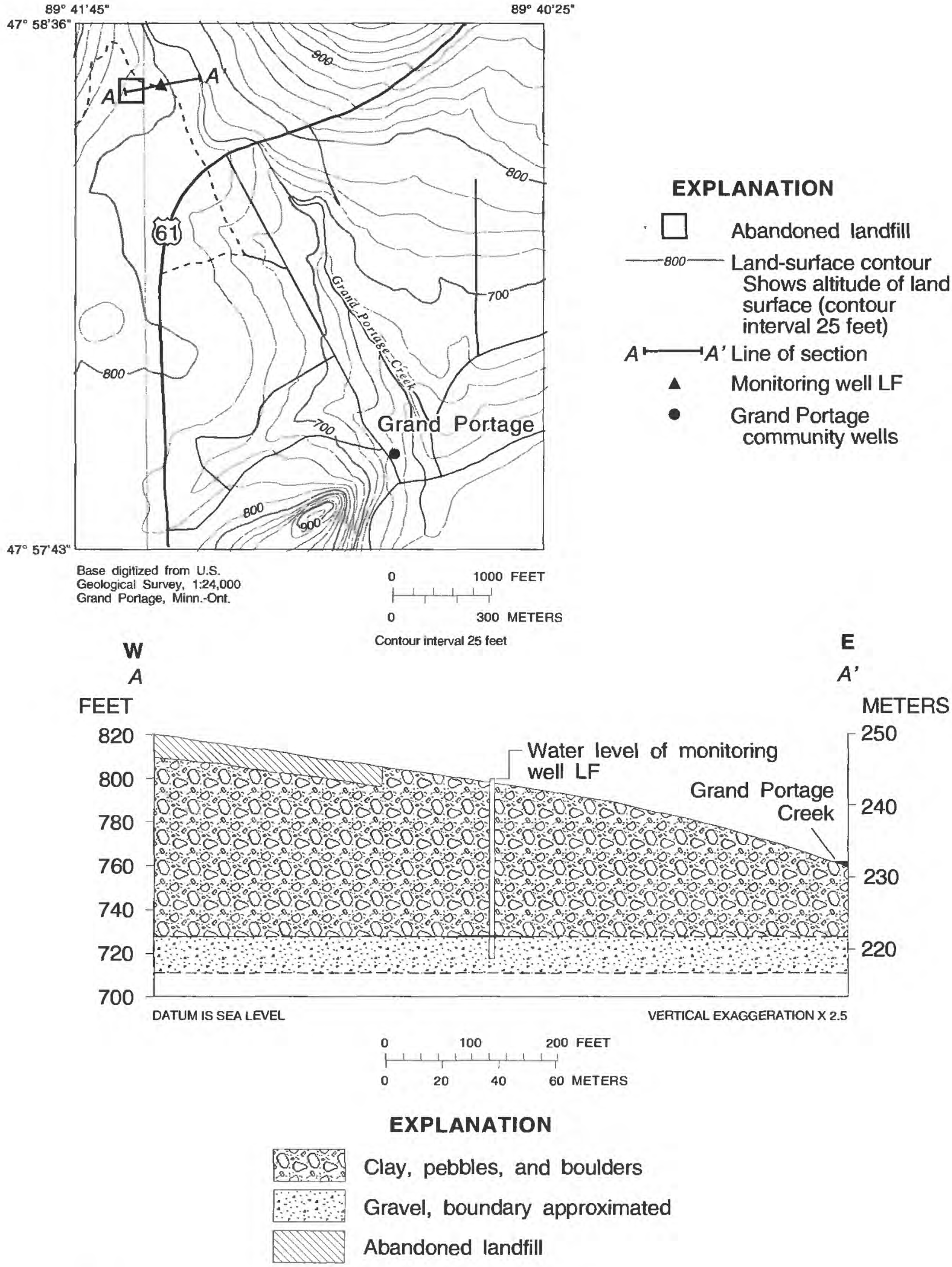


Figure 13. Locations of monitoring well LF near an abandoned landfill, Grand Portage community wells, and hydrogeologic section of the landfill site, Grand Portage Indian Reservation, Minnesota.

land surface to the top of the gravel aquifer is 75 ft. The gravel aquifer is overlain by clay, pebbles, and boulders. The static water level in monitoring well LF was about 4 ft above land surface. Migration of leachates from the abandoned landfill may be a potential hazard to the quality of the ground water. The gravel aquifer is the nearest one to the abandoned landfill site.

A trace amount of toluene was detected in water from well LF at a concentration of 0.2 μg/L (table 3). The MCL for toluene is 1,000 μg/L (U.S. Environmental Protection Agency, 1986). The presence of toluene suggests that ground water in the gravel aquifer underlying the landfill site may be contaminated. No domestic or municipal wells are completed in the gravel aquifer near the landfill site. Community wells that serve Grand Portage, Minnesota (one was well 16 that was sampled for this study) are located about three-fourths of a mile southeast of the abandoned landfill. The community wells are completed in bedrock at depths that range from 155 to 176 ft below land surface.

Nitrate concentration in water from LF was less than 0.05 mg/L as nitrate nitrogen, which was much less than the 10 mg/L MCL (U.S. Environmental Protection Agency, 1986). The dissolved chloride concentration was 240 mg/L, which was slightly less than the 250 mg/L SMCL (U.S. Environmental Protection Agency, 1986). The concentrations of dissolved arsenic, barium, chromium, copper, iron, manganese, mercury, selenium, silver, and zinc were less than their respective MCLs and SMCLs (U.S. Environmental Protection Agency, 1986).

Summary

The Grand Portage Indian Reservation is located in extreme northeastern Minnesota in an area of about 56,000 acres between the north shore of Lake Superior and the Canadian border. Most homes of the 350 people, commercial development, and tourist attractions are in the community of Grand Portage, along Highway 61, and along Highway 17 east of Mineral Center.

Pleistocene glacial drift and scattered post-glacial deposits overlie Proterozoic bedrock. The total thickness of this unconsolidated material generally is less than 50 ft. The bedrock consists of the following formations: (1) Rove Formation argillite, slate, and graywacke of the Animikie Group, (2) Puckwunge Formation sandstone of the Keweenawan Supergroup, (3) North Shore Volcanic Group basalt of the Keweenawan Supergroup, (4) Logan intrusion diabase of the Keweenawan Supergroup, and (5) Keweenawan Volcanic and intrusive rocks (referred to as Keweenawan intrusives) of the Keweenawan Supergroup, which are gabbro and diabase.

Average annual precipitation is about 29 in. During normal years about one-half of the precipitation contributes to runoff and the remainder returns to the atmosphere by evapotranspiration. A small amount of ground water discharges into Lake Superior as underflow.

The Pigeon and Reservation Rivers flow along the northern and western boundaries of the Reservation. These two streams and several smaller ones drain into Lake Superior. Estimated 100-year recurrence-interval peak streamflows for the Grand Portage and Reservation Rivers are 1,520 and 3,470 ft^3/s, respectively.

Ground water is used for municipal, commercial, and residential water supplies. The principal sources of ground water are Proterozoic bedrock aquifers. The bedrock aquifers are the (1) North Shore Volcanic Group, (2) Keweenawan Volcanic and intrusive rocks, and (3) the Rove Formation. Sand and gravel aquifers are a small source of ground water. Of 19 domestic and municipal wells analyzed in this study, 10 are completed in the North Shore Volcanic Group, 4 are completed in the Keweenawan intrusives, 4 are completed in the Rove Formation, and 1 is completed in sand and gravel.

The estimated storage coefficient of the bedrock aquifers was 1×10^{-4}, which is a small value typical for confined, fractured rock aquifers. Streamflow recession analysis of the Reservation River indicated that the hydraulic diffusivity of the basin is 9.0×10^5 ft^2/d. The high estimate of the hydraulic diffusivity means that the storage coefficient is very small relative to the transmissivity in bedrock aquifers of the Reservation River Basin. The high estimated hydraulic diffusivity also indicates that the effects of hydrologic stresses such as ground-water withdrawals are rapidly propagated throughout these bedrock aquifers.

Transmissivity estimated from data for 17 wells completed in bedrock had a median of 20 ft^2/d and a range of 3 to 500 ft^2/d. The estimates of transmissivity showed no trend of variation with depth of bedrock penetrated by the well borehole. Well yield reported for

19 wells completed in bedrock had a median of 7 gal/min and a range of 1 to 100 gal/min. The median well yield reported for 11 wells completed in the North Shore Volcanic Group was 16 gal/min; the median well yield for 8 wells completed in the Keweenawan intrusives and in the Rove Formation was 4 gal/min.

Caliper logs and televiewer images of two wells completed in bedrock indicated the boreholes intersected many fractures. The two wells were hydrofractured by injection of pressurized water into the well boreholes to increase their yield. The yield estimated for 50 ft of drawdown from the two wells was 0.05 and 0.25 gal/min before hydrofracturing, and was 1.5 and 1.2 gal/min, respectively, after hydrofracturing. Although the estimated yield from the two wells was 30 and nearly 5 times higher after hydrofracturing than before hydrofracturing, the yield after hydrofracturing was still small.

The water types determined from analyses of water from nine wells completed in bedrock were sodium-chloride, calcium-chloride, sodium-bicarbonate, and calcium-bicarbonate. The dissolved solids concentration and dissolved chloride concentration in water from three wells ranged from 800 to 3,110 mg/L and from 410 to 1,600 mg/L, respectively, and exceeded their respective USEPA SMCLs of 500 and 250 mg/L.

Concentrations of dissolved arsenic, barium, chromium, copper, silver, zinc, and selenium in water from nine wells completed in bedrock were less than their respective USEPA MCLs and SMCLs. The concentration of cadmium in water from two wells was 10 µg/L, which exceeded the USEPA MCL of 5 µg/L. The concentration of dissolved lead in water from the nine wells was less than the detection limit of 100 µg/L. The concentration of dissolved iron in water from two wells was 1,600 and 1,300 µg/L, which exceeded the USEPA SMCL of 300 µg/L. The concentration of dissolved manganese in water from one well was 59 µg/L, which exceeded the USEPA SMCL of 50 µg/L. Water from a well completed in gravel and screened from 79 to 84 ft below land surface, located near an abandoned landfill, contained a trace amount of toluene (0.2 µg/L). The presence of toluene suggests contamination. The concentrations of dissolved nitrate-nitrogen, chloride, arsenic, barium, chromium, copper, iron, manganese, mercury, selenium, silver, and zinc in water from this well were less than their respective USEPA MCLs and SMCLs.

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